International Competitiveness in Electronics

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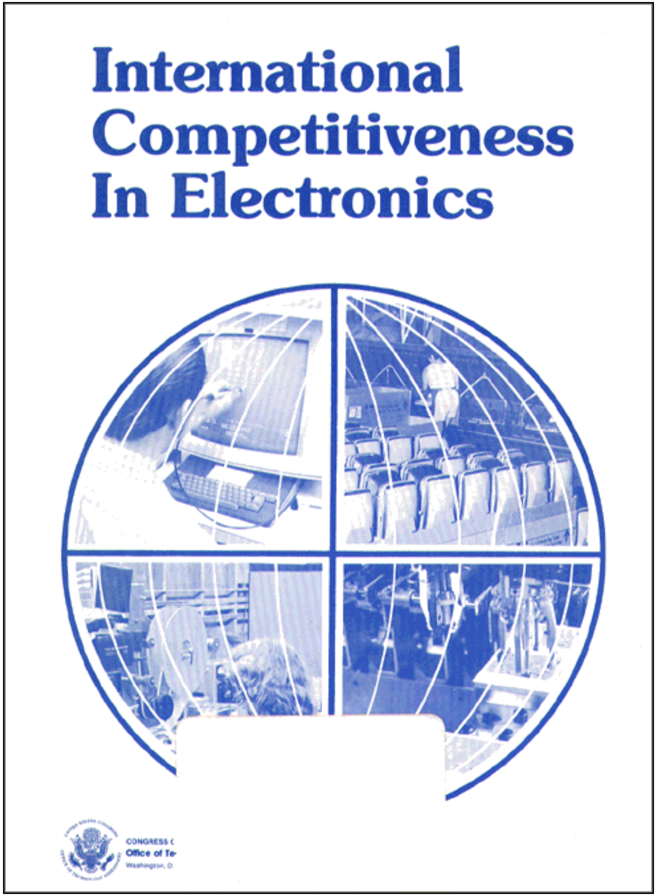

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Foreword

This assessment, requested by the Senate Committee on Commerce, Science, and Transportation, the House Committee on Ways and Means, and the Joint Economic Committee, completes a series of three reports on the competitiveness of U.S. industries. The series began with *Technology and Steel Industry Competitiveness* and continued with *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles.*

Today, the subject of international competitiveness has more visibility among the general public than ever before. It has emerged as one of the primary economic issues facing Congress. Debates over "reindustrialization" and "industrial policy" beginning several years ago have been renewed. This assessment continues OTA's exploration of the meaning of industrial policy in the U.S. context, while also examining the industrial policies of several of our economic rivals.

Electronics virtually defines "high technology" in the 1980's. This assessment sets the characteristics of the technology itself—a technology already of such ubiquity that microprocessors and computers outnumber people in the United States—alongside other forces that exert major influences over international competitiveness. These factors range from human resources and costs of capital to the priorities that corporate managers place on manufacturing technologies and the quality of their products. The report concludes by outlining five options for a U.S. industrial policy, drawing on electronics for examples of past and prospective impacts, as well as on OTA's previous studies of the steel and automobile industries.

OTA is grateful for the assistance of the advisory panel for this assessment, as well as for the help provided by many individuals in other parts of the Federal Government. OTA assumes full responsibility for the report.

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Contents

CHAPTER 1

Part A: Summary

Contents

Table

List of Figures

CHAPTER 1

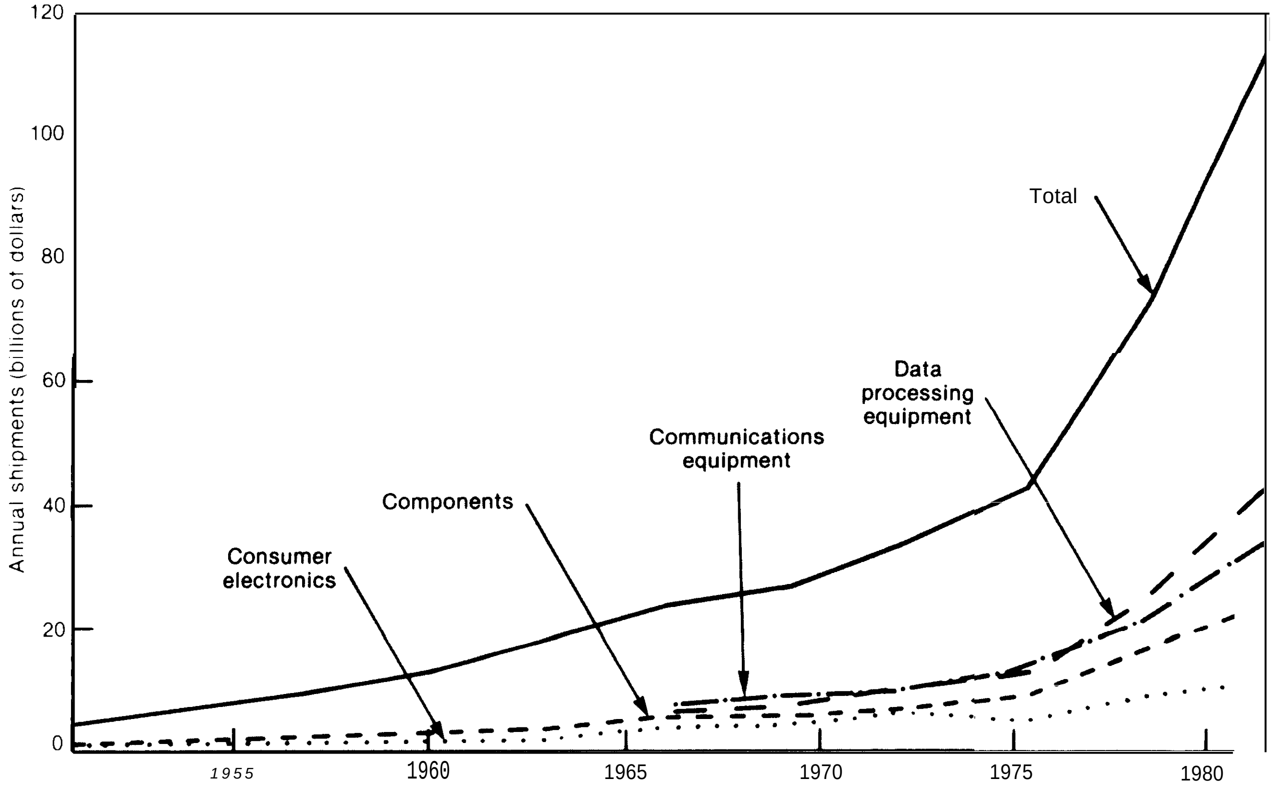
Part A: Summary

Is the United States in danger of losing, to the Japanese or others, in the race to develop new high-technology electronics products—fifth-generation computers, high-density integrated circuits, pocket televisions? Does the decline of the American consumer electronics industry prefigure that of semiconductors or computers? Is U.S. standing in world markets deteriorating because of poor management, slipshod Government policymaking, overregulation of business? Will work in automobile production or heavy industry be permanently replaced by high-technology jobs fewer in number and paying wages at half the level of the $15 to $20 per hour earned by auto or steelworkers? To what extent can electronics stand for other technology-based U.S. industries? Which policies of the Federal Government are most crucial to the international competitiveness of industries like electronics? Does the United States need a more coherent industrial policy?

These questions and others like them are addressed in this report, which covers three portions of the industry: consumer products (primarily color television); semiconductor devices such as integrated circuits; and computers. The focus of the report is the United States, but considerable attention goes to the electronics industries of Western Europe and Japan, as well as several of the newly industrializing countries.

Electronics in total employs more than a million and a half Americans; 1982 sales exceeded $125 billion—roughly one-fifth of total U.S. durable goods output—and have been

Sales Trends in the U.S. Electronics Market



SOURCE *Electronics Market* Data *Book* 1982 (Washington, D C Electronic Industries Association, 1982), p 4 growing at nearly 15 percent per year; the sector is an export leader, with a surplus of about $3 billion on a total trade volume of nearly $50 billion. The industry's products feed many other portions of the U.S. economy. Not only does the Nation's defense depend heavily on electronic technologies, but both manufacturing and service industries—ranging from the production of numerically controlled machine tools to banking and insurance—use electronic products both directly and indirectly.

The competitiveness of firms and industries refers to the ability of firms in one country to design, develop, manufacture, and market their products in competition with firms and industries in other countries. At several points below, shares of the U.S. market or of world markets are used as examples of trends in international competitiveness; in fact, however, competitiveness is a more subtle concept. While market share is one possible indicator, it is only indirectly related to competitiveness,

How an industry will fare in international competition depends on factors ranging from technology itself, to industrial policies pursued by national governments, to the human resources—technicians to upper-level managers—available in a given country. In some cases, competitiveness is primarily a function of prices, hence manufacturing costs—themselves determined by wage rates, labor productivities, the design of both products and manufacturing processes. This is the case in consumer electronics. In higher technology portions of the industry, one firm may be able to offer products that are beyond the technical capabilities of its rivals—e.g., high-density integrated circuits, advanced computer software. Where this is true, costs are less important.

From the Federal perspective, shifts in the international competitiveness of American industries have ramifications far beyond matters of trade balances and foreign economic policy, even military security. The competitive standing of a nation's industries will determine quite directly its gross domestic product, and therefore the standard of living of its citizens.

The linkage between competitiveness and employment—in the aggregate, in particular sectors, or in particular occupational categories—is much looser. Industries can rise in competitiveness while declining in employment—the case in the U.S. textile industry in recent years. In other cases, competitiveness may remain high, output may expand, but domestic employment may grow relatively slowly compared to output; this has been the case in both the U.S. semiconductor and computer industries. Similarly, domestic employment is only loosely related to trends in foreign investment or to government policies directed at controlling flows of imported goods; trade protection has helped the employment picture in the U.S. consumer electronics industry no more than it has in the steel industry or the automobile industry.

While the competitiveness of a given sector of the U.S. economy depends on both domestic and international economic forces, the domestic context—e.g., people and institutions here, not overseas—generally carries the most weight in determining which industries will grow in competitiveness, which decline. As a result, *public policies with domestic objectives exert the most influence over trends in international competitiveness.* These are matters of industrial policy. OTA uses this term in a neutral sense to refer to the body of regulations, laws, and other policy instruments that affect the activities of industry and the resources, including human capital, that the Nation's economy depends on. The United States has not in the past had a self-conscious industrial policy, in part because it had no need for one. The lesson of the U.S. electronics industry, along with industries like steel and automobiles that OTA has examined previously, is that future international competitiveness may well depend on a more coherent and consistent approach by the Federal Government to matters of industrial policy,

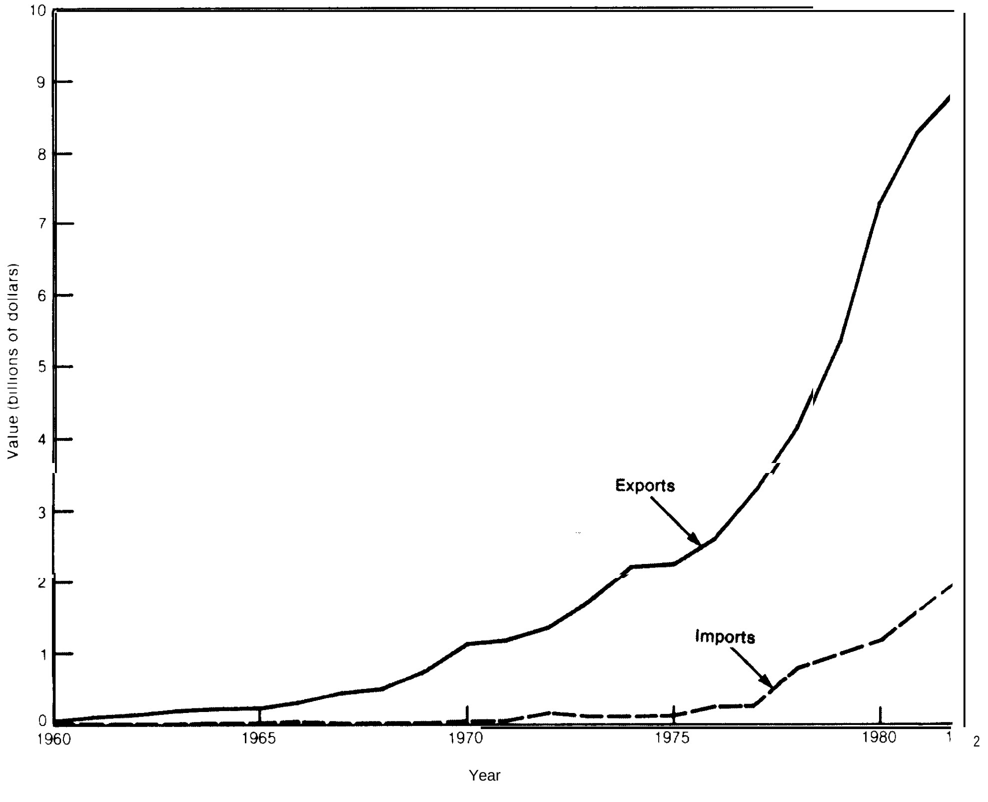
Principal Findings

U.S. Competitiveness in Electronics

1. *Electronics remains a leader among American industries.* High-technology firms—including those making microelectronic devices like integrated circuits and complex electronic systems such as computers—continue to be leading exporters, second to none in technology as well as most measures of commercial success. Although the Nation's imports of semiconductor products exceeded its exports for the first time in 1982 (by $160 million out of $3.8 billion in imports) more than three-quarters of these imports were shipments by American-owned firms; computer exports ($9 billion in 1982) far exceed imports.

This is not to say that there is little cause for concern, or that the waves of publicity given the progress made by Japan's electronics manufacturers over the past few years have in all cases been overdramatized. If the U.S. electronics industry is still strong when compared to other domestic industries, its margins with respect to electronics industries in other nations have shrunk, in some cases vanished. Moreover, the Japanese electronics industry is one of the most productive in that nation's economy; this high standing relative to other domestic sectors is a major reason for the export strength of Japan's electronics manufacturers. In almost all categories of electronics products—office copiers and typewriters, mi-

U.S. Exports and Imports of Computers and Equipment



SOURCES 1960-86-Gaps *in Technology Electronic Computers* (Paris Organization for Economic Cooperation and Development, 1969), p 50.
1967-81 — 1972, 1977, 1980, 1982 editions, U.S. Industrial Outlook, Department of Commerce
1982-U.S. Department of Commerce, Bureau of Industrial Economics

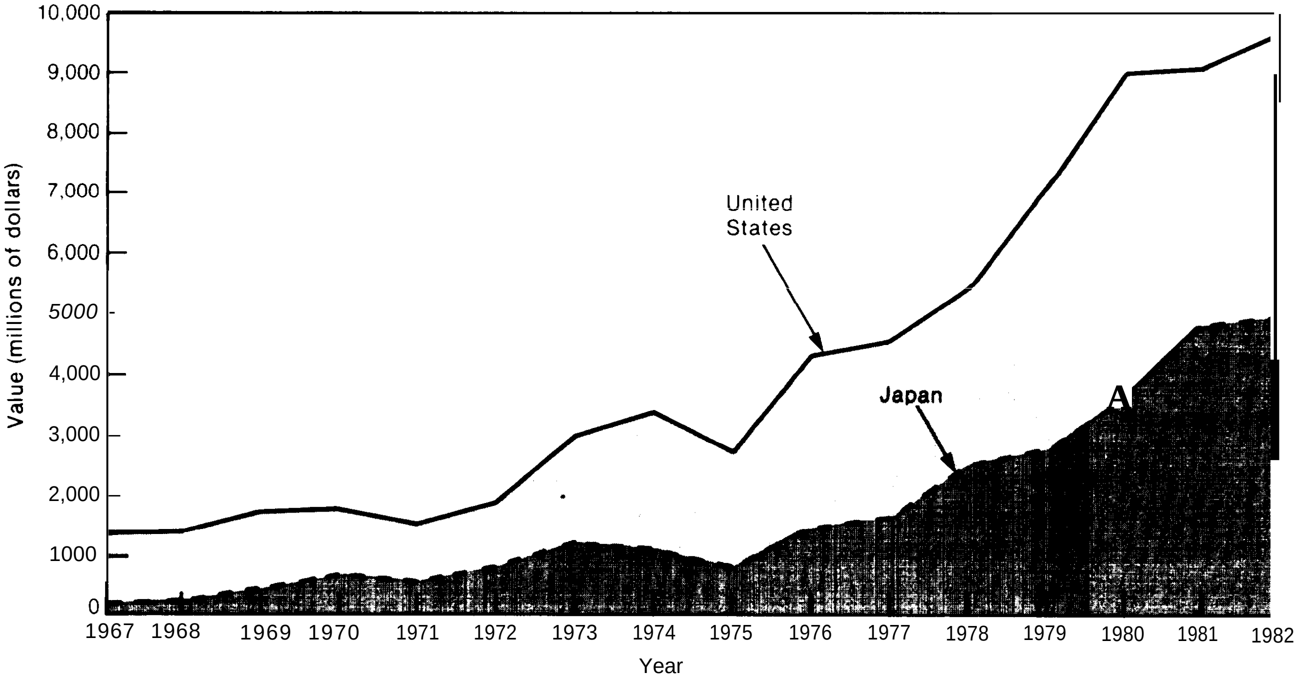
croelectronics, communications equipment and consumer goods—the U.S.-Japan trade balance is strongly negative (see ch. 4).

2. Just as the competitive positions of a nation's industries will differ, with some rising and others declining, so competitive positions within an industry like electronics will vary. Likewise, within one portion of the industry, such as color television manufacturing, some firms will at any given time be more competitive than others.

Within the U.S. electronics industry, compet*itiveness in consumer products has declined precipitously since the* **1960's.** The Nation now imports many of its consumer electronic products, while more than 10 foreign-owned firms assemble and market television sets within the United States. In contrast, *there are few signs of slackening competitiveness in the manufacture of computers,* although the U.S. lead in technology is certainly less than even half a dozen years ago. *American-owned firms making and selling semiconductor devices have faced increasingly intense competition from Japanese manufacturers,* again primarily over the last half-dozen years; although they have lost market share both at home and abroad in some key products—e.g., computer memory *chips—their overall position remains strong.*

3. It is not realistic to expect that American semiconductor and computer firms will, in the near future and in the absence of cataclysmic changes in other parts of the world, return to the preeminent positions they held at the beginning of the 1970's. Nor can the United States expect to achieve the technological and commercial leads of earlier years in other high-technology industries. The capabilities of other countries have improved; foreign electronics industries have risen within their own econo-

Semiconductor Production in the United States and Japan



SOURCES: ***United States—1967-76—A Report on the*** U.S. ***Semiconductor Industry*** (Washington, D. C.: Department of Commerce, September 1979), p. 39.
1977-80—Summary of *Trade and* ***Tariff Information: Semiconductors*** (Washington, D. C,: US International Trade Commission Publication 841, Control No. 8-5-22, July 1982), p. 28.
1981, 1982—19S3 U.S. ***Industrial Outlook*** (Washington, **D**.**C**.: Department of Commerce, January 1983), p. 29-7.
Japan—1967.80-Japan Fact Book '80 (Tokyo: **Dempa Publications,** Inc.,1980), p. 188; ***Japan Electronics Almanac 1982*** (Tokyo: **Dempa** Publications, Inc., 1982), pp. 149, 178.
1981, 1982—In-Stat Electronics Reports Feb. 21, 1983, p. 5.

mies; international economic conditions have changed.

4. *The United States can continue to be highly competitive in electronics and other technologically driven industries,* with U.S. firms remaining leaders in innovation, in international trade, and in sales and profits at home and abroad. *Not only is this possible, it is necessary* if the United States is to maintain its standard of living, its military security, and if the U.S. economy is to provide well-paying and satisfying jobs for the Nation's labor force. Electronics is indispensable to a broad range of manufacturing and service functions, from computer-aided design of the structures of office buildings to the switching of the telephones within those buildings,

5. *Congress could take the initiative in devising programs that would actively support the electronics industry,* and others of comparable importance. The first requisite is broad national agreement on the role of high-technology sectors like electronics as a driving force for future economic growth, a greater degree of consensus on where the U.S. economy is now heading and where it *should* head. The second is better understanding of how particular pieces of legislation affect the competitiveness of American industry, which in turn requires developing the capability of the Federal Government for analyzing the sources of competitive strength.

The Role of Technology

1. One way to establish a competitive advantage in an industry like electronics is through superior technology. *Better process technology —e.g., automation—can help reduce costs.* For similar products, lower manufacturing costs permit lower selling prices, hence a more competitive product. Alternatively, higher profits may be possible, which can help finance further improvements. Production technologies are particularly important in consumer electronics and semiconductors, less so for large computers.

2. Superior product technologies may command premium prices in the marketplace, making manufacturing costs less significant. Product features—ranging from appearance to quantifiable characteristics such as the performance of a computer system in running "benchmark" programs—can contribute to competitive advantage; in high-technology fields as in low, product differentiation and astute marketing can be important.

Understanding customer wants and needs is vital to designing successful products; integrated circuits that are functionally similar, perhaps even interchangeable, may be differentiated through subtle variations in performance; advertising strategies can be built around claims of high quality or rapid delivery; a broad array of alternate source suppliers may reassure prospective purchasers. Manufacturers of computers and peripherals devote considerable effort to industrial design and human factors engineering; ease of use is vital in selling computer systems to first-time customers,

Rapid technical change creates much more scope for product technology as a competitive weapon in microelectronics and computers than in consumer electronics. For many years, American semiconductor and computer manufacturers prospered by offering products that firms elsewhere in the world could not design or build.

Industrial Policy

1. OTA takes industrial policy to be a neutral term referring to the group of Federal policies that affect competitiveness, productivity, and economic efficiency—sometimes directly, sometimes through influences on business decisions or on individuals. Industries rise and fall in international competition for many reasons. Seldom can single causes be found—more seldom yet simple, straightforward policy remedies. Plainly, *industrial policy offers no quick fixes for the dilemmas of the U.S. consumer electronics industry, nor any sure prescriptions that can guarantee the future com-*

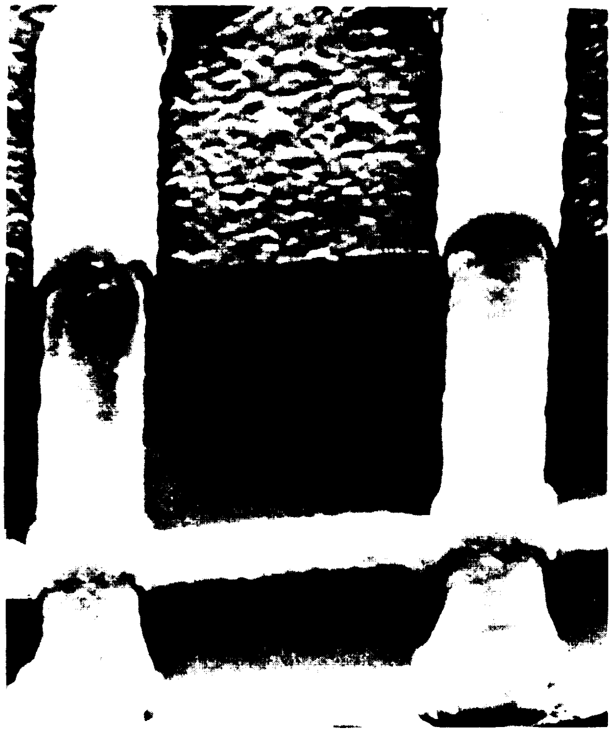


Photo credit: Mostek Corp.

Portion of a read-only integrated circuit memory

petitiveness of our microelectronics or computer sectors. Just as plainly, competitiveness in electronics—and in other U.S. high-technology industries—will depend on factors including:

- capable people, hence on Federal policies dealing with education and training;
- capital for new business startups and for expansion, hence on macroeconomic and tax policies;
- open markets for American products, hence on foreign economic policy; and
- the research base that supports domestic firms, hence on Federal technology and science policy.

The job of industrial policy is to evaluate, link, and coordinate the many Federal efforts that deal with such concerns.

2. *While international competitiveness is firmly rooted in the efforts of private companies, public policies set many of the rules of the game.* In the United States and in other parts of the world, business enterprises compete in an environment shaped to considerable extent by government industrial policies (including elements of fiscal, monetary, tax, manpower, trade, and regulatory policies).

Foreign governments are experimenting with industrial policies intended to aid and support their own electronics industries; virtually all industrialized and industrializing nations single out electronics for special treatment. American firms seeking to export or to manufacture overseas must contend with economic and social policies of host governments that are more complex and sophisticated than in the past. Rather than outright protectionism or other forms of overt discrimination against foreign firms, host governments now adopt indirect subsidies for their own industries—tax incentives, capital allocations, funding for commercially oriented research and development (R&D). At the same time, governments bargain with foreign multinationals using carrots and sticks such as investment incentives and performance requirements while seeking to acquire jobs and technology, or to improve their balance of payments.

3. Although a well-designed and supportive industrial policy is not, by itself, sufficient to build competitiveness in a given sector of a nation's economy, government policies can, under some circumstances, tip the balance. *The United States can expect no more than very limited success in negotiations with other nations aimed at minimizing the impacts of those countries industrial policies.*

For this and other reasons, a "business-as-usual" approach is unlikely to prove sufficient to the task of maintaining U.S. competitiveness in electronics, *Better prospects for strengthening the U.S. position would come with the adoption of more effective industrial policies of our own.* The American electronics industry faces only a few *major* problems, mostly in the trade arena, that are directly susceptible to Government remedy. On the other hand, Federal agencies could support the industry—directly and indirectly–in many ways. Few of these would have much visibility. By the same token, they would not necessarily cost much. Consistent and careful attention to the many smaller matters that affect competitiveness—diffusion of technology within the United States, tax treatment of equipment contributions to universities, the antitrust environment for joint R&D, long-term basic research—are the necessary ingredients in a more coherent and productive industrial policy. A supercomputer project, to take a current example, may be glamorous as well as desirable in itself, but is no substitute.

4. The choice of policy tools, and the design of individual measures, depend on overall objectives; an industrial policy is the sum of many parts that can be put together in different ways, Should Congress wish to pursue a more focused industrial policy for the United States, it could choose from among five broad alternatives:

- A protective strategy aimed at *preserving the domestic market base for U.S. industries,* along with preservation of existing jobs and job opportunities.
- *Protection and/or support for a limited number of industries judged critical* for the U.S. economy or, more narrowly, for national security,
- *Support for the technological base and institutional infrastructure* that underly American industries, with particular attention to structural adjustment (e.g., labor force retraining and mobility).
- *Promotion of the global competitiveness of U.S. firms and industries* by encouraging exports and open competition in domestic as well as international markets.
- *Deferral where possible to the private sector* when choices concerning industrial development are to be made.

While these five approaches to industrial policy, discussed in chapter 12, are certainly not mutually exclusive, they represent distinctly different thrusts, implying different mixes of policy instruments as well as different goals.

What would be the implications of a decision to pursue a more coherent industrial policy in the United States? First and foremost, that to automatically equate “industrial policy” with a greater degree of Government involvement in the economy is to view the matter from an arbitrarily narrow perspective. *Industrial policy does not have to run counter to efforts to “get Government off the backs of business. ” Rather, it should be construed as an effort to make the inevitable—indeed oftentimes desirable and necessary—Federal involvement a more consistently productive one.* It implies an effort to develop, both politically and institutionally, Government policies toward industry that:

- explicitly consider impacts on competitiveness and economic efficiency;
- seek to treat the problems and opportunities of particular industries in the context of the economy as a whole, rather than in isolation; and,
- do a better job of relating policy tools to policy objectives.

Policy Concerns in Electronics

Among the elements of industrial policy, the following are vital for the continuing competitiveness of the U.S. electronics industry. They might have rather different places, and be addressed in different ways, under each of the alternatives listed above,

1. High-quality *education and training* (including retraining) for engineers, technicians, and other skilled workers,

More than anything else, the competitive position of the United States in high technology has been built on the human resources available here. A renewed Federal commitment to education and training seems called for (see chs. 8 and 9). Engineering enrollments running at record levels have swamped the resources available in colleges and universities; even so, the United States graduated but 63,000 engineers in 1981 compared to 75,000 in Japan, U.S. electronics firms have faced serious problems in finding adequate numbers of engineers, as well as technicians and service personnel with needed skills and aptitudes. Inadequate resources in U.S. engineering schools are harming the quality of education as well as constraining the numbers of new graduates. Training and retraining for technicians and paraprofessionals varies widely in quality and appropriateness to emerging needs. Many people in the United States emerge from high school quite unprepared to work in technology-based industries.

Despite fluctuations in supply and demand over the years, engineers in principle comprise one of the most employable occupational groups in the labor force; it is hard to imagine an "oversupply" of engineers or of people with good technical training of any of a wide variety of types in an economy like that of the United States, provided that people are willing and able to shift jobs according to demand within the economy and organizations are willing to help them do so.

2. A strong technological base—stemming from basic research and applied R&D with long-term objectives, including the diffusion of results, in fields such as solid-state electronics, optical devices, communications technologies, computer-aided design of circuits and systems, and computer software.

The Federal Government could not only continue to fund basic research, it could establish new mechanisms for diffusing the results of R&D to the private sector, experiment with the support of commercially oriented (rather than military) research, and strengthen tax incentives and other encouragements for successful innovators.

3. *Economic adjustment* policies that smooth flows of capital and labor within the economy, aiding growing firms in their efforts to compete while providing well-paying jobs for the domestic labor force.

Structural change is a fact of life in American industries, driven by the currents of an increasingly open international economy (see chs. 4 and 5), as well as by technological change (ch. 3). Corporations, cities and regions, and people must adjust to changes, many of which are outside their control. Federal attention to maximizing the positive effective of change—e.g., stimulating growth industries—while ameliorating the negative impacts, could be one of the central elements in a more coherent industrial policy for the United States. Policy initiatives aimed at personnel mobility—whether geographic, inter-industry, or within organizations—are one example.

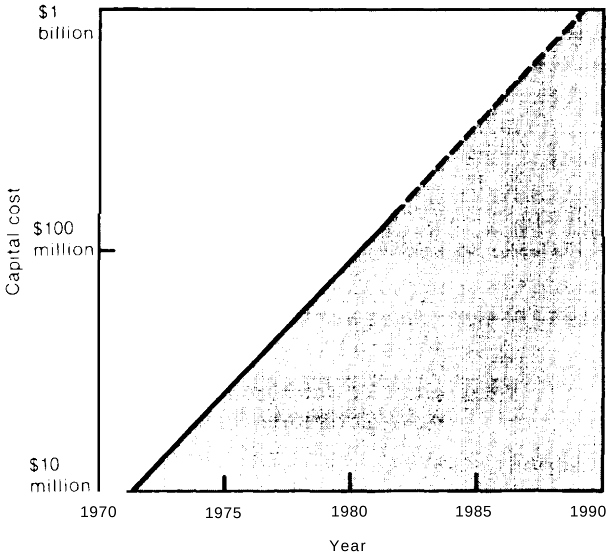
4. Adequate supplies of *investment capital* for new startups as well as rapidly expanding established firms.

As discussed in chapter 7, venture capital markets in the United States function well, although cyclic downturns are likely to recur and risk capital is often hard to find at early stages of technology development.

Rapidly growing companies, particularly in the semiconductor industry, do face severe financial pressures. These stem from increasing capital intensity, due both to higher R&D expenses and to production equipment that has gone up in cost by an order of magnitude over the past decade, coupled with the preference of American managers to finance expansion from internally generated funds. Tax policies have a major influence over sources of financing and risk absorption.

While the advantages are not as great as sometimes implied, large diversified electronics companies in Japan, and perhaps in some Western European countries, do benefit from real (i.e., inflation-adjusted) costs of capital that are somewhat lower than for merchant semiconductor firms in the United States. By themselves, these differences—matters of a few percentage points—are not enough to weigh heavily in the competitive balance. Constraints on *rates* of capital spending—due in part to the preference of American firms for internal financing—are more likely to be a drag on the competitive abilities of U.S. manufacturers. These and other factors, primarily expectations concerning inflation, tilt the investment decisions of American managers toward the shorter term.

Increase in Capital Costs for High-Volume Integrated Circuit Production Line



SOURCE R W Broderson, "Signal Processing Using MOS-VLSI Technology, " *VLSI Electronics.Microstructure Science,* VOl 2, N. G. Einspruch (cd.) (New York Academic Press, 1981), p 206

5. An *international trading environment* that places U.S. firms on a more-or-less equal footing with their competitors in other countries, including those that have well-developed industrial policies intended to protect or promote domestic manufacturers.

As discussed in chapter 11, the framework for international trade that emerged in the postwar era is being overrun by events. The thrust of industrial policies in many nations is toward indirect supports with effects on prices and on competitiveness that cannot be quantitatively assessed (see ch. 10). Japanese industrial policy, for instance, works in part by breaking bottlenecks; the VLSI project of the 1970's helped train Japanese engineers, transferred design and processing know-how to industry, rallied public support behind the structural shifts that were leading Japan toward an "information economy" (or at least helped diffuse counterpressures by those disadvantaged by such shifts). The goals of the heavily publicized fifth-generation computer project are similar, When many of the impacts of industrial policies are intangible, how do we countervail them? Over at least the rest of the decade, U.S. trade negotiators can expect to grapple with such issues, The prerequisite is an analytical capability by the Federal Government adequate for understanding the ways in which public policies—here and elsewhere—affect international competitiveness.

American electronics firms, particularly manufacturers of semiconductors and computers, may also need the continuing support of the U.S. Government, via both bilateral and multilateral negotiations, in securing access on reasonable terms to foreign markets—for exports and for direct investment—if they are to maintain their competitive position. Only by competing aggressively all over the world, taking advantage of scale economies and new opportunities, can American firms expect to share fully in the growth and expansion that will characterize this industry into the next century. As an example, semiconductor sales in Japan already exceed those in all of Western Europe by more than half; U.S. *firms need access to Japan market comparable to that enjoyed by Japanese suppliers here.*

Regardless of the overall approach and direction of U.S. industrial policy, Congress could act in support of objectives such as those outlined above.

The Competitive Position of the U.S. Electronics Industry

Consumer Electronics

1. American firms making radios, TVs, and audio products such as stereo receivers and tape recorders have been under severe competitive pressures for years; many have failed or left the market. Few radios or black-and-white TVs are made in the United States. No video cassette recorders are manufactured here. Color television production has become largely an assembly operation, heavily dependent on imported components—whether the parent firm

U.S. Sales and Imports of Selected Consumer Electronic Products, 1982

	U.S. sales (millions of dollars)	Imports (millions of dollars)	Import penetration (percent)[a]
Color television	$4,253	$546	12.8%
Black-and-white TV	507	344	67.9
Video cassette recorders. . .	1,303	1,032	100.0[a]
Home and auto radios[b]	1,579	1,207	76.4
Stereo systems[c]	1.754	1,342	76.5
	$9,396	$4,471	47.60/o

[a] Because many items imported in a given year are not sold until the following Year, dividing imports during a given calendar year by sales In that same year may give only a rough indication of import penetration; for instance, *all* video cassette recorders sold in the United States are Imported even though 1962 sales figures exceed 1962 import figures.

[b] Including auto tape players,

[c] Including audio tape units and other component equipment.

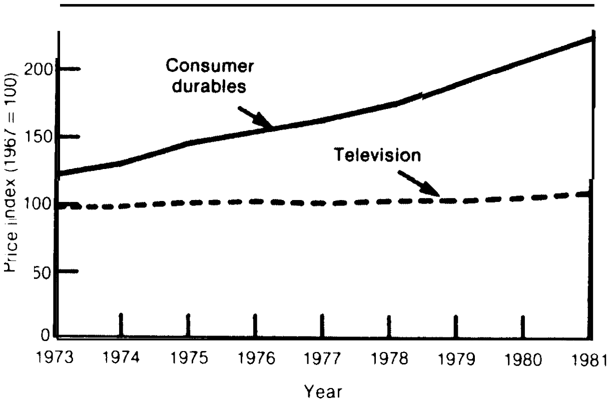
SOURCE *Electronic Market Data Book 1983* (Washington, D.C : Electronic Industries Association, 1963), pp. 6, 19, 31,

is American-owned (RCA, Zenith, GE) or foreign-owned (Sony, Quasar, Magnavox). In television manufacture *especially, the policies of the Federal Government have contributed to the plight of the industry.* Dumping complaints against importers going back to 1968 have never been fully resolved. An industry legally entitled to trade protection has not received it,

2. Nonetheless, trade practices illegal under U.S. law have been only one factor in the declining competitiveness of the American consumer electronics industry. More fundamentally, competitive advantages have shifted to other parts of the world—first Japan, now newly industrializing countries like Taiwan and South Korea. These countries have mastered the technological requirements for mass-producing consumer products such as TV sets, They have lower labor costs than the United States, an adequate corps of skilled workers and engineers, supportive government industrial policies, and astute corporate managements.

American firms have been reduced to a reactive posture; they have lost the lead in product design and development while moving manufacturing operations to foreign countries in order to keep their costs competitive, American *products* in consumer electronics—e.g., color television receivers—continue to be competitive in performance, quality, and reliability, but they are no better than imports. *The consumer electronics market is highly price-competitive; without advantages in technology or product features, American manufacturers will be hard-pressed to keep up with their foreign-based competitors.* While U.S. firms may continue to innovate and to be leaders in consumer products aimed at specialized market niches—computer games have been a recent example—broadly speaking, product leadership has been lost, At least in the short term, prospects for taking the lead in new generations of high valued-added mass market products seem slim.

Price Index for Televisions Compared to All Consumer Durables



SOURCES: ***Consumer Durables****—Economic Report of the President 1982* (Washington, D.C.: U.S. Government Printing Office, February 1962), p. 294,
Televisions*—Electronic* Market *Data Book* (Washington, D, C,: Electronic Industries Association, 19S2), p, 29,

3. The rise of foreign firms together with protracted trade disputes have contributed to a major shift in the structure of the U.S. consumer electronics industry. The number of firms has not changed greatly since the 1960's; but while once there were 16 or 17 American-owned

manufacturers of TVs, today only 4 of 15 with plants in the United States have headquarters here. Still, the *market shares of the traditional U.S. leaders—zenith and RCA—have not changed much;* together these two companies continue to hold about **40** percent of the U.S. color TV market. It is the weaker American manufacturers that have succumbed.

4. At the same time foreign enterprises were investing in assembly plants in the United States, American-owned firms were transferring labor-intensive manufacturing operations to low-wage offshore locations. In general, final assembly for the U.S. market remains here, with subassembly} in Mexico and the Far East. These moves were driven by foreign competition. U.S. color TV manufacturers felt they had little option but to move production abroad if they were to cut costs and meet their competitor's prices.

Offshore production substitutes quite directly for jobs in the United States. Nonetheless, if American firms had not moved offshore, it is quite possible that they would have lost even more ground to foreign-based competition, with yet more jobs lost over the longer term. In most cases, *transfers of production overseas have net impacts on U.S. employment and on the U.S. economy that appear relatively small; improvements in labor productivity, for example-also driven by foreign competition—have been at least as important as a cause of employment declines in television manufacturing.* Needless to say, the impacts on individuals and communities where job losses concentrate are often severe and long-lasting; in 10 years the production work force in consumer electronics has been cut by more than 40 percent, from **85,000 to 50,000.**

5. Beginning near the end of the **1970's,** Orderly Marketing Agreements (OMAs) limited imports of color TVs while encouraging foreign firms to produce here, The result was to equalize the terms of competition and to moderate employment declines in the United States. Otherwise, the OMAs did little to help the U.S. industry rebuild its competitive strength.

In this regard, U.S. experience with OMAs restricting color TV imports has paralleled other cases of import quotas, for instance in the steel industry. Although the ostensible purpose may be to give domestic firms time to restructure and adjust to changing competitive circumstances, in most cases *protected industries continue to react to pressures from abroad rather than taking strong positive steps of their own;* the notion that a respite from import competition will, by itself, help corporations restore their competitiveness gets little support from events in color television.

Semiconductors

1, U.S. manufacturers of semiconductor products such as integrated circuits remain highly competitive in markets all over the world. American-owned merchant firms--those that produce for the open market-are leaders in circuit design and process technology. While their share of world sales has changed little over the past few years, with U.S. firms and their subsidiaries still accounting for about **70** percent of worldwide output of integrated circuits, Japanese manufacturers have been catching up in technology, Nonetheless, U.S. companies have the capability to maintain their competitiveness in most world markets. The inroads made by Japanese suppliers of commodity-like chips, notably random access memories (RAMs), portend stronger competition in other types of microelectronic devices but do not translate automatically into advantages for products such as logic chips or microprocessor families. There is no reason to expect a loss of competitiveness in advanced microelectronic products paralleling that in consumer electronics.

Although foreign manufacturers may sometimes have advantages—e.g., supportive government industrial policies, as in Japan or Western Europe—the U.S. merchant firms have their own strengths, Among these are the ability to rapidly develop and commercialize new technologies, to anticipate and design for shifting customer needs, and to adapt to changing realities of international competition by entering into joint venture and technology transfer agreements with both domestic and foreign firms when this is advantageous.

2. The *structure* of the merchant portion of the U.S. semiconductor industry is changing. A number of well-established semiconductor firms founded during the 1960's or early 1970's have been acquired by larger, diversified enterprises, either American- or foreign-owned. In part, these structural shifts are associated with a trend toward captive production by end-product manufacturers.

Companies that design and build systems ranging from computers and communications networks to automobiles increasingly see needs for internal capability in the design, development, and manufacture of state-of-the-art microelectronic devices. The *acquisition of merchant semiconductor firms by larger corporations is a predictable trend in the evolution of the industry.*

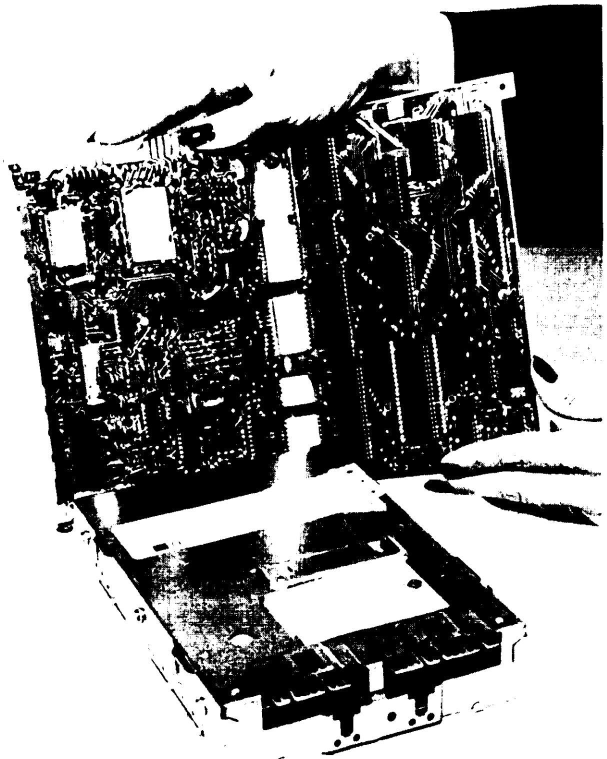


Photo credit: General Motors

Microcomputer for controlling an automobile engine

3. At the same time that relatively mature companies like Intersil—purchased during 1981 by General Electric—are being acquired, *new entrants continue to repopulate the merchant semiconductor industry.* While the downturn in venture capital markets during the middle and late 1970's virtually halted start-ups, new firms are again being established. Since 1980, several dozen small firms producing custom integrated circuits, gate arrays, specialized memory chips, and other niche products have entered the industry. Aiming at portions of the market where the knowledge and expertise of their founders can be brought to bear, some of these start-ups will be successful and expand, some will remain small, others will be acquired by larger enterprises.

4. *Captive manufacturers of semiconductor devices make vital contributions to U.S. competitiveness.* Such companies include IBM, the largest producer of semiconductors in the world, and Western Electric, which moved into the merchant market in 1983—an action made possible by the settlement of the Government's antitrust suit against AT&T—as well as a number of aerospace and defense contractors. Companies that produce for internal use not only provide a major part of the technological foundations for microelectronics, they spawn start-ups and give training and experience to people who later move to other companies.

5. *Just as important for continuing international competitiveness are firms that design, develop, and build production equipment* for applications ranging from annealing silicon wafers to automated testing and assembly.

While the United States maintains the lead among open-market suppliers of many types of processing equipment, notably in lithography, other countries are catching up. Government-sponsored R&D in Japan has focused on production equipment.

6. R&D—particularly that with relatively long-term payoffs—will remain a critical force in support of U.S. semiconductor firms. In the

past, much of the technology base has come from larger firms such as IBM and AT&T. Government support for research has not been significant in recent years, although the Very High-Speed Integrated Circuit program of the Defense Department will have commercial spinoffs.

The U.S. semiconductor industry can no longer rely on past approaches to R&D and technology development. The industry recognizes the changing situation, and is developing new mechanisms for strengthening its technical foundations; these include closer interactions with universities, along with joint ventures and cooperative research efforts. *Congress and the Federal Government could actively support and encourage both basic and applied research with longer run payoffs.* This is one of the surest ways of supporting continued U.S. competitiveness in microelectronics.

Computers

1. American manufacturers of digital computers have dominated world markets for many years. Much as U.S. semiconductor firms have demonstrated the ability to rapidly capitalize on new technological and market opportunities, so have American computer firms pioneered most of the design concepts that have driven information processing: networking and distributed computing, small business machines and minicomputers, time-sharing among multiple work stations, cheap mass storage, desktop microcomputers.

There are few concrete signs that this dominance by U.S.-based firms is threatened. Nevertheless, relative positions within the world computer industry will continue to shift, stimulated in many cases by new applications of computing power, As the industry continues to evolve, the technological leads of American firms are likely to shrink, and competitive positions may become more difficult to maintain. Nevertheless, the U.S. lead in worldwide marketing of data processing systems is so large that prospective challengers such as Japan cannot hope for more than modest success over the rest of the century.

2. American firms have done a much better job than their foreign competitors of balancing what the available technology can do against what customers for data processing systems have wanted to accomplish. This has been an important element in patterns of competitive success, which have depended as heavily on software that could be easily used by neophyte purchasers and was reliable—i.e., free of “bugs’’ -as on raw hardware performance.

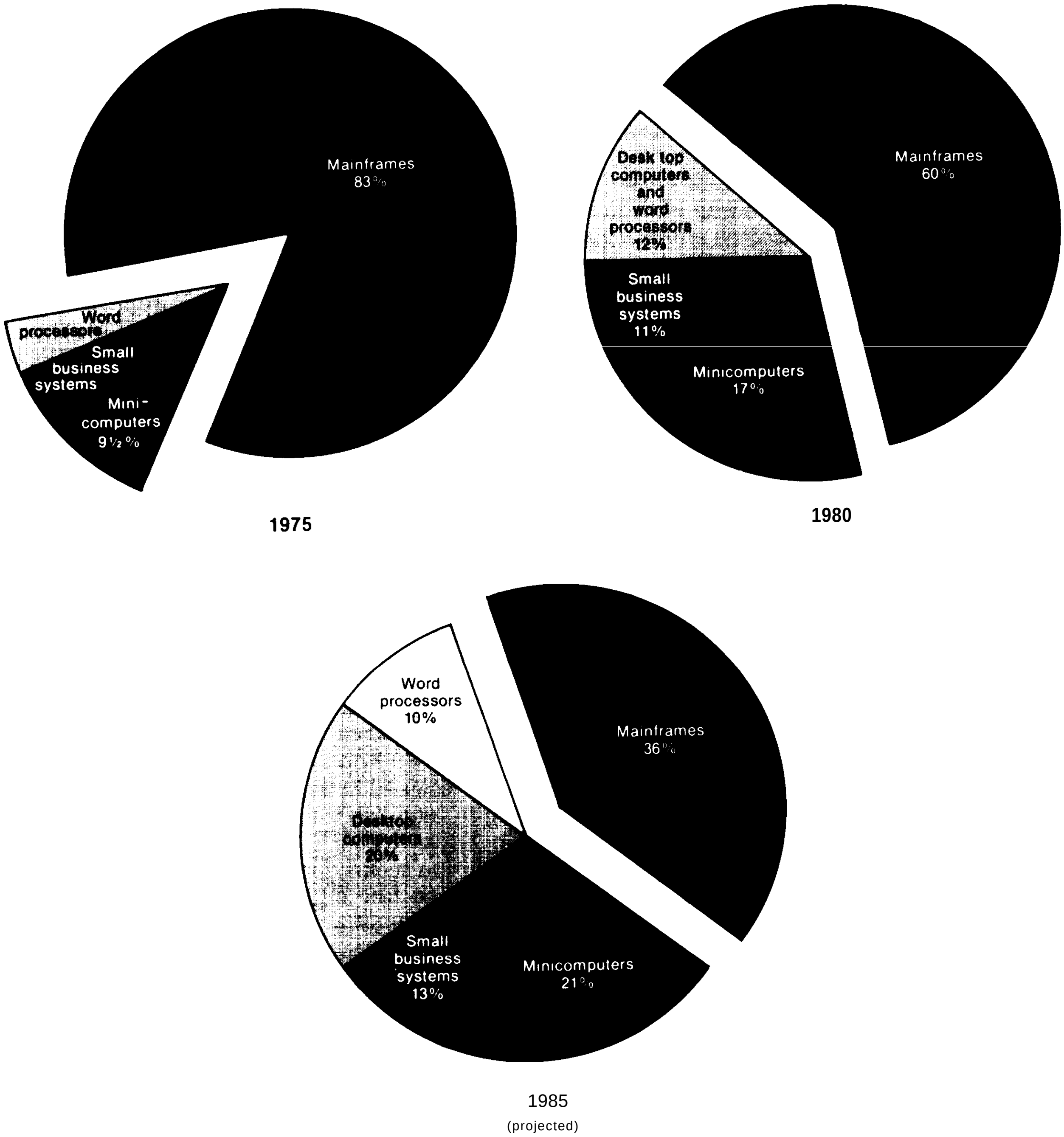
In fact, *foreign computer firms have sometimes been able to match the United States in terms of hardware;* by and large, Japan’s computer manufacturers can at present. But their *systems* are still behind, mostly because the software—at all levels—is not as good, Moreover, foreign firms—whether European or Japanese—have not been as adept as Americans at finding new ways to apply their hardware. For example, U.S. firms remain well ahead in office automation, point-of-sale terminals for retail merchandisers, and many other applications of distributed intelligence.

3. The ongoing structural alterations in the data processing industry will be deeper and farther-reaching than those in microelectronics or consumer electronics.

Most of the recent technological innovations in consumer electronics have come from large, well-established firms; new products from small companies have seldom reached mass markets. In microelectronics, while start-ups have resumed in the United States—many striving to establish themselves with the aid of innovative products—the path of technological evolution seems, for the moment, well charted; there are few signs of sudden change that would seriously unsettle the industry. Computer technology—which depends on microelectronics, but also on other feeders, primarily software—is potentially more volatile. *As new applications of computing power open windows of opportunity for firms in many parts of the world, American manufacturers will face more intense competitive pressures.* Distributed intelligence will transform a broad range of other industries as well.

While the era of the mainframe computer is hardly over, the increasing importance of smaller machines—minicomputers, small business systems, personal computers, and "smart" devices that do not even look like computers—will continue to provide the greatest oppor-

Market Segmentation of U.S. Computer Sales by Value



1975

1980

1985
(projected)

SOURCE: "Moving Away From Main Frames: The Large Computer Makers' Strategy for Survival," *Business Week,* Feb. 15, 1981, p. 78

tunities for growth and expansion. The multitude of prospective applications of computing power will offer new openings for overseas firms as well as American companies. In some portions of the data processing equipment industry—especially those still in relative infancy, such as desktop machines and standardized office automation products—foreign firms may eventually achieve a greater presence than they have managed in mainframe systems or general-purpose minicomputers. To the extent that computers become mass-market products, manufacturers in other parts of the world are likely to emerge as more formidable competitors.

4. In the computer industry, as in microelectronics, U.S. employment is rising much less rapidly than output. *Although new jobs are being created making, operating, and maintaining "smart machines," other jobs are being destroyed; the net effects on U.S. employment might be positive or might be negative,* While there is little meaningful evidence on either side of the job creation/job destruction question, there is no question that skill requirements are changing rapidly. In some cases, automation—aided by electronics—lowers the skill requirements associated with the remaining jobs; in other cases, "upskilling" rather than "deskilling" results. A readily predictable conse-

Photo credit Unimation

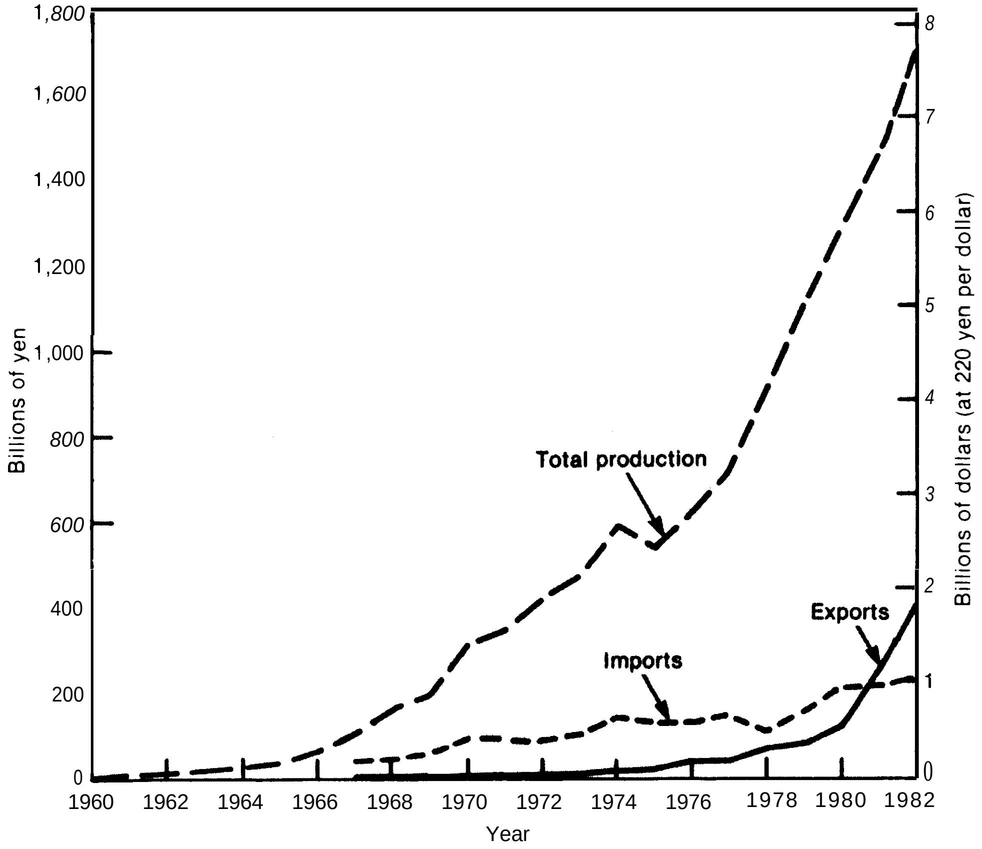
Industrial robot at work

quence has been serious labor market dislocations; these seem bound to intensify. Even if labor market shifts cannot be predicted very well, the need for adjustment is clear. To the extent that labor market shifts—geographical, in terms of skills, in terms of wage levels—are unexpected (and some will always be), the impacts will be more severe. An obvious implication is that policy responses must emphasize flexibility.

5. Japan's computer manufacturers will not be content with narrow or specialized markets. Following strategies similar to those that have succeeded in consumer electronics and semiconductors, Japanese computer firms will attempt to establish themselves in selected data processing markets and expand from there. Backed by government efforts such as the fifth-generation computer project, Japan's industry is bent on achieving technological and commercial parity (or superiority) in machines ranging from desktop processors to supercomputers. Still, Japan's rising export strength in computers differs in a major way from the patterns visible in consumer electronics or semiconductors: the leading Japanese exporter of computers, by a large margin, is IBM-Japan—despite the fact that it has been barred from many of the government programs that have aided other computer manufacturers.

While IBM has abundant resources and technology to compete effectively against Japanese computer firms, other American manufacturers may face increasing difficulty in the future. Although the U.S. industry is not immediate-

Japanese Production, imports, and Exports of Computers and Equipment, including Production and Exports of U.S.-Owned Subsidiaries



SOURCES: ***1967-78—Japan Fact Book '80*** (Tokyo: Dempa Publications, Inc., 1980), pp. 173, 174.
1978-80—Japan Electronics Almanac 1982 *(Tokyo:* Dampa Publications, Inc., 1962), pp. 58, 59,
1981, 1982—Department of Commerce, Bureau of Industrial Economics.

ly imperiled, the Federal Government could help ensure future competitiveness through a better developed, more consistent industrial policy, particularly one supporting technology development and technical education,

6. As computers and their applications continue to spread through the U.S. economy, the Federal Government might act to strengthen the competitiveness of the industry both directly and indirectly:

- "Computer literacy"—the ability to effectively utilize smart machines and systems—will be a critical skill for the labor force. Education and training in fields ranging from traditional modes of quantitative thinking (arithmetic, algebra) to software engineering deserve renewed support. Congress could provide leadership as well as direct and tangible aid.
- Federal support aimed at critical bottlenecks in data processing, mostly in software, could be a vital long-term stimulus for the American industry. Productivity in software development has gone up only slowly over the years. Financing for education and training in software engineering, as well as R&D directed at computer architectures, new programing languages, and artificial intelligence appears appropriate.
- Smaller firms striving to establish themselves in the data processing equipment industry–particularly those developing software, peripherals, and innovative applications of computing power—have the same needs as do U.S. microelectronics firms: not only people with highly developed technical skills, but adequate supplies of capital for investment in R&D and production capacity and access to foreign markets.

If effectively implemented, industrial policies in support of such needs could pay vast dividends throughout the U.S. economy because of the multitude of ways in which applications of computing power can enhance the competitiveness of firms in industries of all types,

Conclusion

A nation can never be competitive in all industries at once. Not only will some rank higher than others, but places will change over time. Economies need to adjust; adjustment brings pain and distress to firms that encounter trouble, people who lose their jobs, the communities affected. Even within an industry like electronics—in the United States, highly competitive as a whole—some parts, such as consumer electronics, face a far more problematic future than others. That such events are inevitable does not mean that at least some of the problems cannot be anticipated, and some of the distress ameliorated by Government action, Moreover, the Federal Government can take positive actions to support the development and diffusion of technology, human resources, the infrastructure that companies depend on when pursuing their individual competitive strategies. Government policies can aid growing sectors, help people and institutions adapt to change. The dynamic of international competitiveness is continuous, and calls for a continuing series of policy responses.

People can and will argue endlessly about the successes and failures of industrial policies in other countries, but the primary lesson to be drawn from foreign experience is simply this: *industrial policymaking is a continuing activity of governments everywhere.* In the United States, industrial policy has been left mostly to the random play of events. Improvement is clearly possible; policymaking can be a purposeful activity characterized by learning from past experience within a framework of empirically based analysis. Developing a more effective industrial policy for the United States must begin in this spirit, while recognizing that the process is inherently political. There is no one thing that the Federal Government can do that will make a big difference for the future competitiveness of the U.S. electronics industry, but there are many specific policy concerns that deserve attention. Only by linking and coordinating these more effectively can the United States expect to develop a coherent and forward-looking approach to industrial policy. Until the Nation begins this task, American firms will continue to find themselves at a disadvantage when facing rivals based in countries that have turned to industrial policies as a means of enhancing their own competitiveness.

CHAPTER 1

Part B: Extended Summary

Contents

List of Tables

List of Figures

CHAPTER 1

Part B: Extended Summary

Part B of chapter 1 expands upon, without repeating, the findings in the Summary. In particular, the sections below highlight the role of technology as a force on competitiveness in consumer electronics, semiconductors, and computers, along with factors such as capital for investment in research and expanded production capacity, human resources and their development, and industrial and trade policies both here and abroad.

The several meanings that can be assigned to the rather amorphous concept "international competitiveness' are discussed in detail in chapter 5. The viewpoint adopted below is first that of the manufacturer, Private companies design, develop, produce, and market goods which may have more or less success in the marketplace, more or less positive impact on a nation's competitive position. Later the view switches to that of governments and their policies, which act on competitiveness directly and indirectly—by influencing business activities, supporting education, subsidizing exports, through the climate for capital formation and economic growth.

Technology

Chapter 3 covers electronics technology in some detail (also see the Glossary, app. A, for explanations of technical terms). Here the interactions between technical capabilities and market success are explored,

Consumer Electronics

In consumer electronic products such as color TVs, both product and process technologies are well-understood and widely diffused. Product differentiation strategies are more important than technical differences; component television, stereo sound, and digital chassis designs illustrate the frontiers of this now largely routine field. Japan's consumer electronics manufacturers have benefited from the economies of higher production volumes and perhaps from more extensive automation, but both product and process technologies in consumer electronics tend to be standardized, technical change to be incremental. Companies anywhere in the industrialized world have access to much the same pool of knowledge—the exceptions being newer product families like video cassette recorders (VCRs). Color TVs with similar product features are made not only in Western Europe, the United States, and Japan, but in developing countries like Taiwan and South Korea, Manufacturing technologies are similar wherever TVs are built, with labor-intensive operations carried out in low-wage developing countries by European and Japanese firms, as well as American. The *result is a competitive environment in which American firms have few unique advantages,*

Differences in both product and process technologies for televisions were greater during the late 1960's and early 1970's when Japanese firms were beginning to invade the U.S. market, Then, firms in Japan moved more quickly than their American counterparts toward solid-state chassis designs. By using transistors and integrated circuits (ICs), they were able to improve the reliability of their products, and more easily automate portions of the production process. Automation helped compensate for component costs that at the time were higher for transistorized designs than for those relying on vacuum tubes. Reliability was particularly important to Japanese firms because they did not have service organizations or dealer networks within the United States. To increase their market shares, they needed to sell through retail outlets such as discount chains. To

Color TV Imports Into the United States

	Number of color TVs imported by origin (thousands)				Imports from all sources as a percentage of U.S. consumption
Year	Japan	Taiwan	Korea	Total[a]	
1967	315	—	—	318	6.70/o
1969	879	22	—	912	15.7
1971	1,191	85	–	1,281	18.9
1973	1,059	325	2	1,399	15.8
1975	1,044	143	22	1,215	17.9
1977	1,975	318	92	2,476	27.0
1979	513	368	314	1,369	13.6
1981	727	514	393	1,946	15.6

[a] Includes imports from countries not listed individually

SOURCES 1987, ***1969**—Television Receivers and Certain Parts Thereof* (Washington, D C U S Tariff Commission Publication 438, November 1971), p. A-62.

***1971,1973**—Television Receivers, Co/or and Monochrome, Assembled or Not Assembled, Finished or #of Fin/shed, and Subassemblies* Thereof (Washington, D C. U S International Trade Commission Publication 808, March 1977), pp. A-90, A-99

1975-79—Co/or Television Receivers and Subassemblies Thereof (Washington. D C U S International Trade Commission Publication 1088, May 1980), p D-6.

***1980**—Television Receiving Sets From Japan* (Washington, D.C U S International Trade Commission Publication 1153, June 1981), p H-21

198f-information from Department of Commerce

achieve credibility, they had to supply TVs that did not need frequent service. Japan's consumer electronics manufacturers succeeded in this far from riskless strategy.

If technology is now a secondary factor for TVs, in more recently introduced product families—not only VCRs, but video disk players, home computers, and related applications of electronic technologies to consumer goods—designs are evolving at a faster pace. Japanese entrants spent many years and a great deal of money on engineering development of VCRs—Matsushita even reached production in 1973 with a design that was shortly thereafter judged not to be good enough—before achieving commercially viable products. But otherwise, competition in consumer electronics is largely a matter of prices and marketing, brand loyalties and customer perceptions. While Japanese exporters have established themselves firmly in American markets for TVs and audio products, individual companies have suffered frequent reverses in consumer goods ranging from stereo receivers to CB radios and pocket calculators, where markets have been unpredictable and competition always stiff.

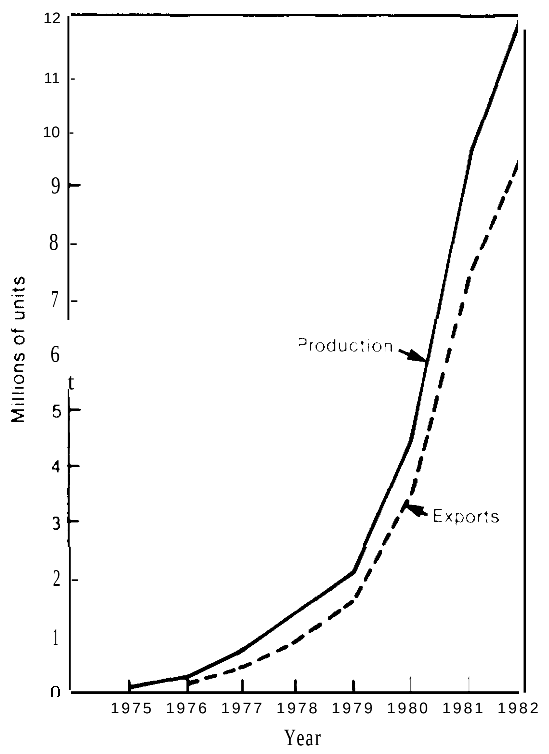
Semiconductors

Microelectronic devices, in contrast, are intermediate products sold in accordance with detailed technical specifications to sophisticated customers who design them into final products ranging from TVs and electronic games to missile guidance systems and powerful computers. To be successful, semiconductor firms must not only meet the current requirements of such customers but do a good job of anticipating their future needs.

Technological Factors in Competition

As explained in chapter 3, the interdependence of product and process technologies in leading-edge microelectronic devices—very large-scale ICs–is unusual even for a high-technology industry. Circuit designers must understand the nature and capabilities of the fabrication process—including proprietary details—to optimize the performance of a chip. Product and process technologies advance together, with process capability a restriction on devices that can be fabricated with acceptable yields (the fraction of circuits that function). The in-

Japan’s Production and Exports of Video Cassette Recorders (VCRs)



SOURCE ‘‘VTR Product Ion Demand,” Japan Report, Joint Publications Research Service JPRS L/1 1100, Jan 28, 1983, p 35

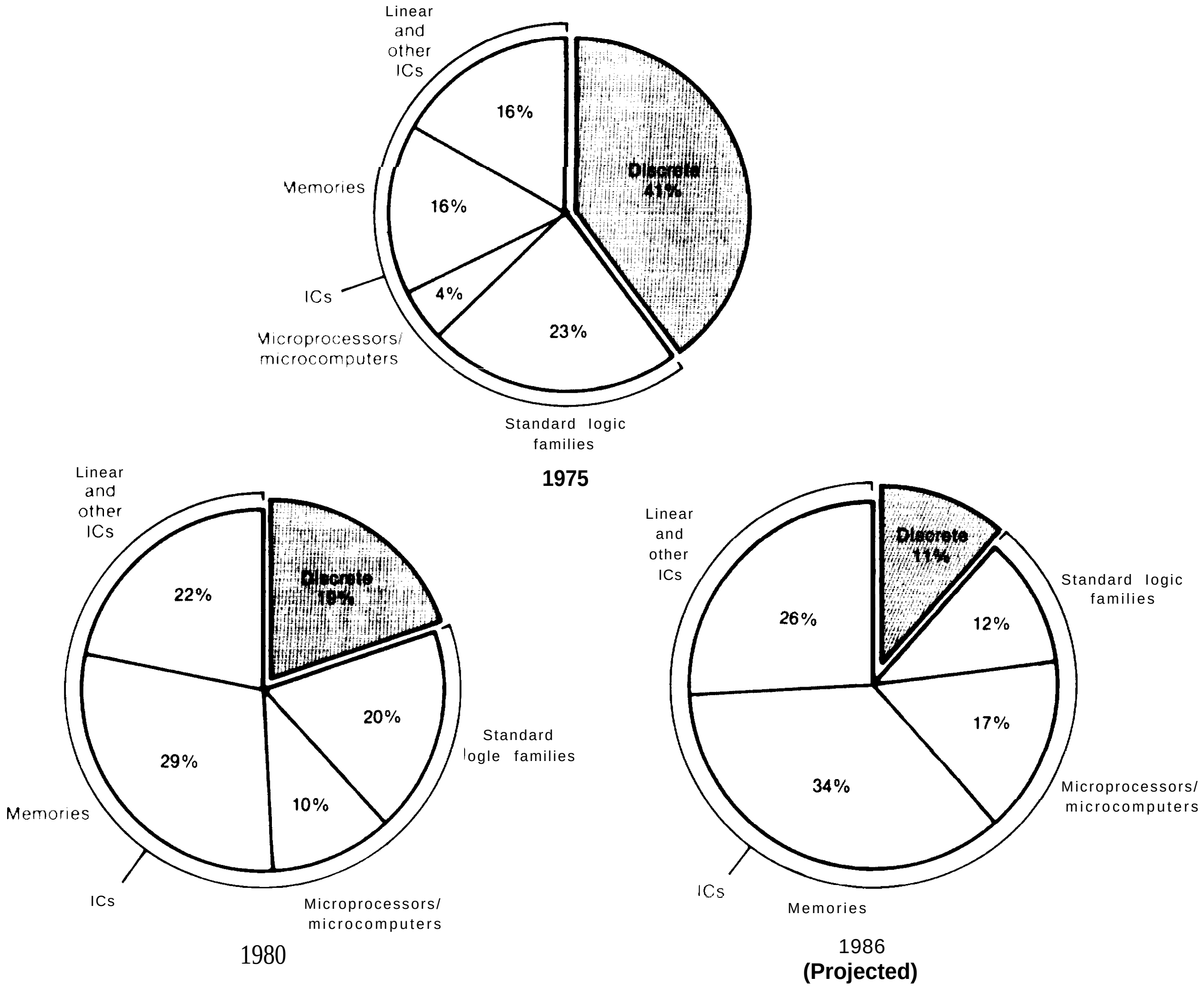
tractions go in both directions. Clever circuit design can compensate for some kinds of process limitations. Among the examples are simply doing more with fewer transistors or other circuit elements and incorporating on-chip testing and redundancy. Some American firms added redundant circuit elements to their 64K RAM (random access memory) designs, a step which may pay dividends in the future as they move to still higher levels of integration,

Competition in standardized products like RAMs depends on both price and technology–chapter 5. When 64K RAMs were first introduced, they sold in sample quantities for about $100 each. From this level in early 1980, prices fell to $10 to $15 by the end of that year. After another year, 64K RAMs could be purchased for $5 or less. These rapid price declines, typical of the semiconductor industry, are driven by intense competition to improve process yields, reduce manufacturing costs, and cut prices to build market share. As the prices of 64K RAMs dropped, prices also fell for the previous-generation 16K devices, which by 1982 sold for about $1 each. Similar patterns will be followed as 256K RAMs, in pilot production in both Japan and the United States during 1983, take over from 64K chips.

Despite the intense price competition in these commodity-like circuits, product technology continues to play a role. Not only is a good circuit design essential for high yields and low costs, but a high-performance RAM can command a greater price. While the most common varieties of 64K RAMs have access times (the average time to retrieve the contents of a memory cell) in the range of 200 nanoseconds [200 x 10–’ seconds), otherwise comparable circuits with lower access times sell for more; during 1982, 64K RAMs with access times of 150 nanoseconds brought prices a dollar or so above those for 200 nanosecond circuits. Nonetheless, RAMs—and most other memory chips—are in essence standardized items. As for consumer products like TVs, progress is incremental and predictable, at least at present—although the pace is much swifter.

If process technology is vital for RAMs, product technology—i.e., circuit design—carries greater weight in competition involving other varieties of ICs. Foreign firms have been less successful in microprocessor families and the arrays of support chips designed to be used with the processors themselves, as well as some types of linear circuits, logic families, semicustom chips, interface circuits, and the many other varieties of specialized microelectronic products, In contrast to memory chips—in essence “brute force” devices—circuits that implement logic depend more heavily on creative engineering design, on anticipating user needs, and on recognizing new opportunities made possible by developments in either process *or* device technology, A well-designed microprocessor—one with an architecture that takes maximal advantage of the circuit elements it employs, with an instruction set that pro-

U.S. Semiconductor Sales by Type



SOURCE *1975—Electronics,* Jan 8, 1976, pp. 92, 93
1980 —*Electronics,* Jan 13, 1982, pp. 124, 125.
1966 —*Electronics,* Jan 13, 1983, pp. 128, 129; Mar. 10, 1983, p. 8

gramers find easy to use, a convenient bus structure and input/output ports—could be a commercial success even if developed by a company with only mediocre process technology. Were this the case, however, alternate source manufacturers might end up with more of the market and/or higher profits.

International Positions in Microelectronics Technology

While Japanese manufacturers now make and sell many types of microprocessors and logic circuitry, and have always had excellent technology for linear ICs, they have not been able to match American semiconductor firms in design-intensive products. For instance, the microprocessors that Japanese semiconductor firms sell in large volume on the world market are U.S. designs. Such patterns will probably continue to hold, although here as elsewhere the magnitude of the U.S. lead is likely to shrink as the Japanese get better at circuit design, and as Japanese semiconductor manufacturers hire engineers from other countries,

In semiconductor processing, Japanese firms are often on a par with the United States and may be better in some cases. One reason has been the VLSI research project and its several follow-ens, orchestrated and partially funded by Japan's Government. By 1983, Japanese manufacturers were, as a group, further along in production plans for process-intensive 256K RAMs than their American competitors. Process control also exerts a major influence over quality; nevertheless, if a few years ago the quality of some types of Japanese ICs—specifically, RAM chips—was higher than supplied by American firms, today any differences are much smaller (see ch. 6).

Semiconductor manufacturers in Japan have made great strides as well with complementary MOS (metal oxide semiconductor) circuitry, one reason being its attractions for certain of the consumer applications in which Japanese semiconductor firms for many years specialized. In contrast, companies in Western Europe are generally behind both the United States and Japan in all varieties of MOS. European nations are making determined efforts to catch up, in several cases with strong government support, Despite underlying technological abilities that in many cases are excellent, European manufacturers have not been as successful as American suppliers at converting their technology into successful commercial products. In circuit design, neither the Japanese nor the Europeans seem able to match wits with Americans. This is an advantage—a source of "technology gap''—that the United States should be able to maintain. To do so, U.S. firms must continue to vigorously pursue new markets and American engineering schools must retain their preeminent position in fields related to microelectronics.

Research and Development

Despite the continued prowess of American circuit designers, the comfortable lead once enjoyed by the United States in the underlying technology of semiconductor devices is now spotty at best. American merchant semiconductor firms devote most of their R&D efforts to product and process developments with immediate application to end-products; relatively small companies with limited resources, they have had little choice but to place the greatest priorities on R&D that will help them in next year's marketplace battles.

In the United States, more basic research—ranging from studies of the physics of electron devices to the development of process tools such as ion-beam lithography—has been funded and performed elsewhere. Some of the work has been supported by the Department of Defense—e.g., research on high-speed gallium arsenide devices, In other cases, large organizations such as IBM or AT&T's Bell Laboratories have carried much of the burden; Bell Labs, in particular, has been responsible for many of the seminal developments in solid-state electronics. In the past, Bell diffused these widely to both U.S. and foreign enterprises, Now, with AT&T entering new markets,

World Integrated Circuit Output by Headquarters Location of Producing Firms

	1978		1982[a]	
	Product ion (millions of dollars)	Share of world output	Product ion (millions of dollars)	Share of world output
United States	$4,582	68.3%	$9,700	69.5%
Merchant	3,238		6,450	
Captive	1,344		3,250	
Captive percentage	29.30/o		33.5 ”/0	
Western Europe	453	6.7	620	4,4
Japan	1,195	17.8	3,440	247
Rest of the world[b]	482	7.2	190	14
	$6,712		$13,950	

[a] Estimated
[b] Includes the Soviet Union and Eastern Europe for 1978 but not 1982

SOURCES **1978**—*Status 80 A Report on the /n tegrated Circuit Industry* (Scottsdale Ariz Integrated Circuit Engineering Corp 1980), p 4
1982—*Status* 1982 *A Report on the /n tegrated Circuit Industry* (Scottsdale, Ariz Integrated Circuit Engineering Corp 1982), p 5

including merchant semiconductor sales, and competing under new conditions, the company may no longer feel that it has the luxury of supporting basic research so heavily; at the least, it will guard its technology much more closely (as IBM always has). Other forces at work include growing software demands on microelectronics firms—an area constrained by personnel shortages, low productivity, and weak theoretical foundations. Furthermore, the highly competitive merchant firms have perhaps been taking advantage of new technological opportunities faster than the stockpile has been replenished. The need for new sources and mechanisms of technology development and diffusion is plain.

Along with continued Federal support and incentives for R&D, particularly more basic work, *institutional innovations that would help to build the technological base for continuing U.S. competitiveness in microelectronics—as well as in computer systems—appear worthy of congressional attention.* U.S. competitiveness in electronics has depended heavily on the technical strengths of American firms, So long as the United States held a substantial overall lead in electronics technology, smaller companies could successfully design and develop their products and processes without doing much research on their own. The foundation provided by large companies, military spending, and the universities sufficed. Today, not only is this base eroding, but the overall technical edge of the Nation has diminished, In particular, research capabilities in American universities have deteriorated because of obsolete equipment and shortages of graduate students and faculty. A redefined Federal role in R&D could address the need for better mechanisms of technology diffusion within the United States, as well as encouraging inflows of technology from overseas,

A number of promising models exist, beginning with domestic ventures such as the Semiconductor Research Cooperative and Microelectronics & Computer Technology Corp. and including a number of experiments in other countries. Some of these are aimed at enhancing the diffusion of technology as well as at encouraging basic and applied research with potential commercial, rather than exclusively military, applications, The Fraunhofer Gesellschaft in West Germany, as well as Japan's joint R&D programs, both discussed in chapter 10, come to mind. The U.S. electronics industry, including but not restricted to microelectronics, could benefit from institutional mechanisms more closely linking R&D efforts in Government laboratories, industry, and universities. A relatively large but decentralized system of centers-of-excellence, directed toward commercial developments—with ample scope for local funding and entrepreneurial participation—would fit American traditions. Given some fraction of funding, perhaps 30 or 40 percent, from the Federal Government on a continuing basis, the time horizons could be longer than those for R&D programs funded entirely by industry.

Computers

If manufacturing technology is critical for cost control in consumer electronics, and both process and product technologies are vital in semiconductors, the computer industry exemplifies reliance on product technologies, Particularly for larger systems, manufacturing is less significant for competitiveness because production volumes are modest compared to TVs or semiconductor devices. For small computers sold in large numbers—and particularly the desktop machines offered by companies like Apple—or for peripherals such as printers and terminals, manufacturing technologies are of greater and growing importance.

Technological Competition

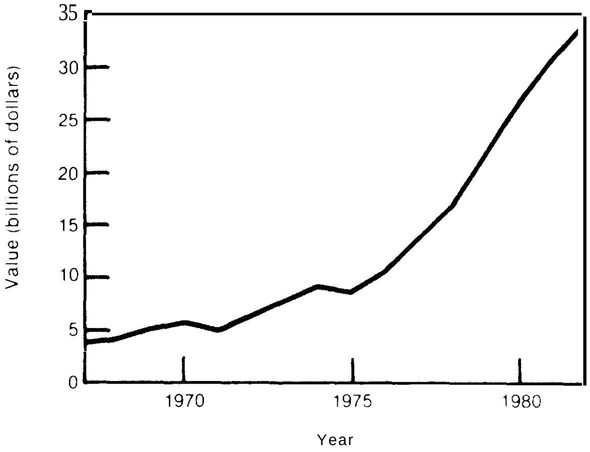
What *are* the major factors in marketing computers? First and foremost, performance/cost ratio: the computing power per dollar that a manufacturer can supply. This depends heavily on system design—both hardware and software—i.e., in doing more with less rather than cutting production costs. For most computer systems, assembly is labor-intensive, costs increasing with overall complexity, The company that can design a system offering higher performance at a given cost has the advantage. IBM, as in so many other instances in the computer industry, provides something of an exception because its higher sales volumes mean more pronounced scale economies. A further exception has developed at the lower end of the market, where personal machines, small business systems, and micro or minicomputers sold to original equipment manufacturers are built in much greater numbers. In both cases, greater production volumes increase the significance of manufacturing technologies but in no way diminish the role of system design.

Because of these characteristics, the computer industry is just as design- and R&D-intensive as microelectronics, but computer engineers are seldom as constrained by manufacturing processes as chip designers. They are, however, constrained by the performance characteristics of available components, principally ICs. Microelectronic devices are the building blocks for processors as well as essential elements in many other parts of computing systems, from controllers for disk drives to semiconductor memories themselves. Because system performance depends so heavily on ICs, many computer firms have established captive microelectronics R&D and production facilities. While component technologies ultimately limit what can be done, computer designers have considerable latitude in configuring systems; the many alternatives from which they can choose are affected in different ways by the characteristics of both hardware and software,

Systems Aspects

Although firms located in other countries are nibbling at U.S. market share, our dominance in computer manufacture still continues, built largely on the abilities of American producers at system design and integration. Conceiving and developing new applications of computing power depends on engineering design and on understanding user needs—including field service and software support. American manufacturers opened the personal computer market, not through technical advances, but because they perceived a potential market where others did not. Substantial penetration by Japanese imports may eventually follow, but based more on low prices–stemming from the well-established capability of Japanese electronics firms to manufacture in high volume at low cost—than unique product features. Nevertheless, so long as technical evolution is rapid, and software one of the keys to sales, American entrants with creative product designs should have little to fear from overseas competitors. At least at first, the more successful Japanese personal computers will be based on U.S.-designed microprocessor or microcomputer chips, as well as software developed in the United States—e.g., the popular CP/M or Unix® operating systems and the many applications programs that run on them.

U.S. Production of Computer Equipment



SOURCE: 1972, 1975, 1977, 1980, 1983 editions, *U S Industrial Outlook*, Department of Commerce 1981 and 1982 shipments estimated

This is only one example where American computer manufacturers have been at the forefront in spotting new applications of computing technology. Among the other examples are:

- Small machines suited to the needs of businesses with a few dozen to a few hundred employees.
- Fault-tolerant systems that can be used where reliability is critical.
- Specialized data processing installations for banks, insurance companies, and Government agencies.
- Dedicated processors to be integrated into

industrial controllers, scientific instruments, aircraft flight-control systems.

- Networked systems, time-sharing, satellite terminals and other mechanisms for providing users with computing power when and where needed.
- Both large and small machines for specialized scientific and technical computing, ranging from supercomputers for complex numerical calculations in computational fluid dynamics or the development of nuclear weapons to array processors to be used in conjunction with dedicated minicomputers in modeling chemical reactions.

Sometimes market demand has driven the technology, with the design efforts of computer manufacturers shaped by perceptions of these needs; occasionally, more raw computing power has been available than has found immediate application.

System integration remains the forte of American firms, and—just as for U.S. semiconductor manufacturers—so long as American companies and American engineers continue to push aggressively into new software and hardware applications, they should be able to maintain a technological edge sufficient to hold a large fraction of the world computer market.

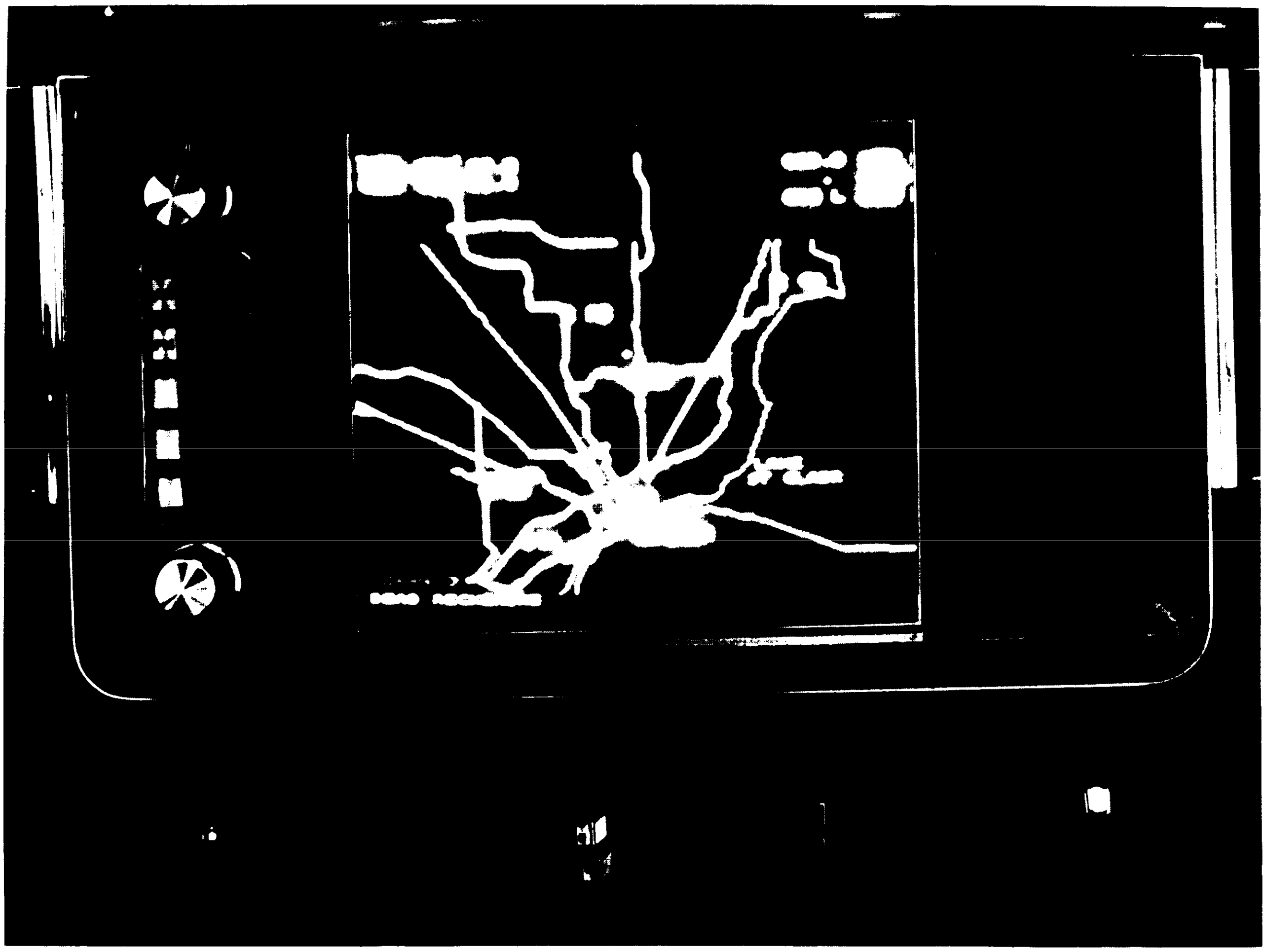


Photo credit General Motors

Experimental electronic map display for automobile dashboard

Nonetheless, this share may not be the 70 percent of 10 years ago. If so, the causes will be multiple, as discussed in chapter 5. Rapidly expanding and fragmenting markets mean that no one manufacturer can cover all the bases; windows of opportunity will open for foreign as well as U.S. suppliers, Manufacturers in other countries may benefit from supportive industrial policies, as well as drawing on growing pools of capable computer scientists, systems engineers, and managers. The result is likely to be a narrowing of the technology gaps that have favored American firms. Improvements in the standing of computer industries in countries like Japan relative to other sectors of these country's economies may lead to greater international competitiveness in computer manufacturing. Most of these forces are outside U.S. control. Given the circumstances, ***it*** *becomes particularly important that the Nation avoid unnecessary sacrifices in competitiveness through missed opportunities by American firms or defective policy choices by* ***the Federal Government.***

Finance

Well-developed capital markets have been a major source of strength for entrepreneurial high-technology firms in the United States. Under most circumstances, both new start-ups and young, rapidly expanding companies have been able to find the money needed to grow with their markets. Still, this has not been universally true; in recent years, some electronics companies--preferring, in common with most of American industry, to fund expansion with internally generated cash flows--have found themselves lacking the financing needed to keep pace with market opportunities. Perhaps of greatest significance, volatile interest rates in the United States reinforce other factors that bias decisionmaking by corporate managers toward short-term undertakings,

Venture Capital

Over the past quarter century, venture capital in its various forms has spawned many of the new entrants in the U. S. electronics industry: companies supplying software, instrumentation, semiconductor devices, computers and peripherals. Some of these—Digital Equipment Corp., Intel--have become mainstays of U.S. competitiveness. Other nations-West Germany, the United Kingdom, even Japan—have sought to build some of the characteristics of U.S. venture capital markets into their industrial policies. These attempts to generate the vitality and dynamism that venture start-ups have brought to American growth industries have seldom met with success.

Bottlenecks in U.S. capital markets are more probable and more significant when it comes to financing rapid expansion in sectors like microelectronics, where capital intensity is escalating along with sales, than in funding new ventures. Nevertheless, venture funding has not always been available, part capital for developing new ideas well before production is in sight. When venture funds dried up in the middle 1970's, new start-ups in electronics manufacture virtually halted. Around the turn of the decade, after the reduction in capital gains taxes that took effect in 1978—one of many forces affecting venture capital supplies—the market received. Most of those supplying venture funds look for capital appreciation over a 3- to 5-year period, with typical target returns being 35 to 50 percent per year. Plainly, capital gains tax rates are important both to individual and institutional suppliers of risk financing. However, for reasons that are poorly understood, venture capital funding is notoriously cyclical; factors other than tax changes also contributed to the revival of the market. By mid-1980, a veritable boom in venture funding was underway, with much of the money going to electronics. Prospective entrepreneurs, many in the Silicon Valley region of California, saw opportunities in microcomputers and other applications of microprocessors, in software and computer peripherals, in semiconductor chips themselves. Capitalists saw the technological windows in much the same light. More than 20 new microelectronics firms alone were established during the first two years of the venture capital resurgence.

Financing Growth

As chapter 7 points out, finding capital for continued expansion has been a greater concern for many U.S. electronics companies, particularly given the high growth rates in much of the industry. While there are few if any signs of overall shortages of capital for investment in the United States, financing growth is a common problem for young companies anywhere in the economy, Electronics firms, especially those producing ICs, face unusually steep hurdles. The first is simply the need to keep up with markets that in some years have grown at 25 percent or more. Firms trying to *increase* their shares of such markets have to add production capacity at rates that can severely strain financial resources; needless to say, the investments must precede the added revenues they bring in. At times, U.S. semiconductor manufacturers may have been unable to secure the funds needed to keep up with market growth—or, more likely, have judged the conditions imposed by prospective suppliers of capital unacceptable.

Rising capital intensity for semiconductor processing creates a second hurdle. Denser ICs require more expensive fabrication equipment. A state-of-the-art manufacturing facility, which cost perhaps $5 million a decade ago, now might run $50 million. High levels of R&D spending, mandatory for companies that hope to compete in markets for advanced devices, contribute a third hurdle, Thus capital demand is mounting even more rapidly than the market has been growing, compounding the already difficult financing problems of U.S. semiconductor firms.

In common with most of American industry, U.S. electronics firms have been reluctant to rely heavily on external funds—either debt (loans, bonds) or equity–for financing growth. At times over the past decade, it would have been difficult to issue either bonds or stock. Nonetheless, the U.S. electronics industry exhibits a pattern of consistently low debt/equity ratios contrasting sharply with foreign manufacturers. Aversion to borrowing may have constrained the growth of some American electronics companies over the past decade.

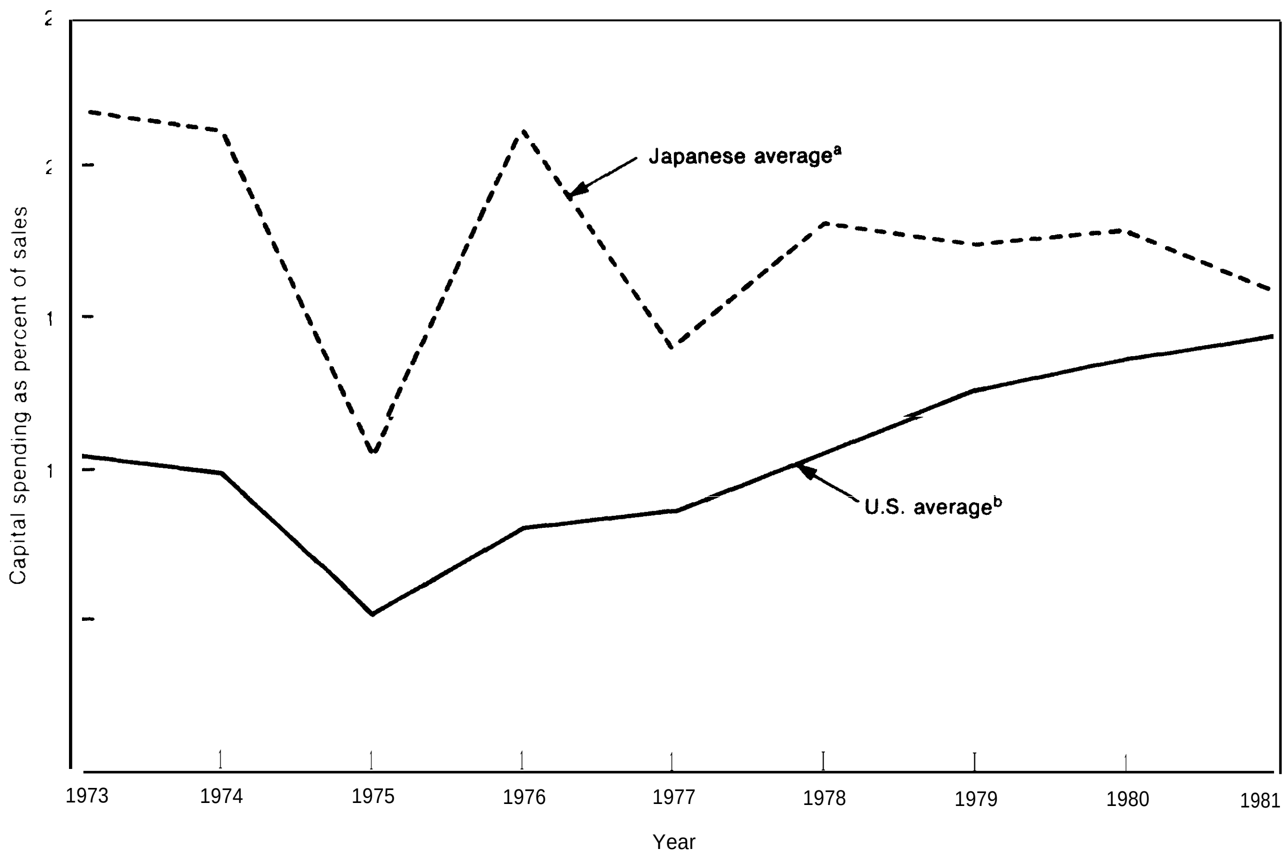
The changes in U.S. tax law implemented by the Economic Recovery Tax Act of 1981 have increased cash flows for electronics firms along with other businesses in the economy. High-technology electronics manufacturers benefit particularly from the R&D tax credit. Accelerated depreciation is a different matter: although more rapid capital cost writeoffs are now available to virtually all U.S. corporations, the benefits are much greater for numerous other sectors. Because electronics firms, particularly in the high-technology portions of the industry, have always been able to depreciate at fairly rapid rates, they have not been helped as much as sectors like primary metals. In earlier years, many such industries faced lengthy capital cost recovery periods. The *relative* position of electronics has suffered under the 1981 Tax Act to the extent that companies in other lines of business have an easier time securing external funds.

International Differences

Why do American companies limit their use of external funds? Most managers would answer by citing high costs of capital, whether debt or equity, as reflected in high U.S. interest rates over the past few years. American businessmen have claimed that they face costs of capital perhaps twice those of their competitors in Japan. In fact, although costs of funds in the United States *are* higher than in Japan, the differences—when adjusted for inflationary expectations—appear relatively small, certainly less than 5 percentage points, While not insignificant, the resulting advantages for Japanese electronics manufacturers are hardly overwhelming, even when the tax benefits of the higher debt/equity ratios characteristic of Japanese corporations are taken into account. Lower costs of capital in Japan make no more than minor contributions to differences in manufacturing costs. *A much more potent source of advantage for large, diversified Japanese electronics firms, particularly in periods when markets are expanding rapidly, stems from their ability to allocate funds internally, using moneys generated in other lines of business to finance high rates of spending on R&D and new production capacity.* U.S. semiconductor firms, especially those that remain independent and have a limited range of products, will always be hard-pressed to keep up with diversified companies, Japanese or American. A major difference between diversified Japanese and American electronics firms is the evident *willingness* of Japanese semiconductor manufacturers to compete in the mass market for merchant products, and to aggressively add new production capacity. It remains to be seen how American firms like Mostek or Intersil, which are now parts of large conglomerates, will behave over the longer run—and how Western Electric will fare, now that it is entering the merchant market.

While the contrasts between financing practices of American and Japanese electronics corporations are many—as are those with European enterprises—the net advantages that Japan's companies receive from government guidance applied to investment funds are small. Japanese industrial policies continue to influence capital allocations and costs of funds, but the high leverage characteristic of Japanese

Rates of Capital Spending by U.S. and Japanese Semiconductor Firms



[a] Integrated circuits only, 1973-1979, weighted average of 12 manufacturers 1973-1979 11 manufacturers 1980, 1981

[b] 1 9731980 Weighted averages for 11 U S merchant semiconductor manufacturers, 1981 estimated

SOURCE ***United States***— 1973-1977, Bureau of Census, 197&1981, Department of Commerce and Semiconductor Industry Association ***Japan—1973-1979,*** *Japan* fact *Book '80* (Tokyo" Dempa Publications, 1980), p 203; *1980,1981, Japan Economic Journal* corporations, as measured by the ratio of debt to equity or debt to total capital, helps primarily in terms of taxation. In Japan as in the United States, interest can be written off as an expense (while dividends paid to shareholders cannot); therefore higher proportions of debt reduce corporate tax bills. That banks in Japan lend willingly to highly leveraged firms places these banks in a position more like that of equity-holders in the United States: Japanese banks absorb higher risks than American banks, but the impacts of this, by itself, on the competitiveness of Japanese companies are small. Furthermore, leverage ratios of Japanese firms have been slowly declining over the years—one example among many of the gradual movement of the Japanese economic system toward convergence with other advanced nations. Likewise, the unusually high rate of personal savings in Japan has impacts at the aggregate level which are only loosely coupled with costs of capital for individual firms. These costs vary widely across the Japanese electronics industry, just as in the United States. Indeed, *cost and availability of capital differ more from firm to firm within the U.S. electronics industry than, on the average, between the electronics industries of the United States and Japan.*

The apparently high costs of capital in the United States—as reflected in high interest rates, stemming in the past from expectations of continued price inflation-do have a serious consequence. *High and uncertain interest rates in the United States tend to skew investment decisions toward short-term undertakings.* Although no one knows how to measure or aggregate the time horizons of business executives in any meaningful way—much less compare those of American executives with their counterparts in West Germany or Japan—all else the same, interest levels that fluctuate unpredictably will act to shorten time horizons. Investments with longer payback periods—for example in basic research or in advanced production equipment—will appear less attractive. To the extent that capital markets in the United States continue to mirror expectations of high and uncertain interest rates, the future competitiveness of American industries like electronics may suffer,

Human Resources

Business enterprises depend on capable people for tasks ranging from assembly line work to service and repair of their products, design and development, and general management. From the standpoint of international competitiveness, the larger the pool of qualified people a firm or an industry can draw from, the better. An ample supply of engineers and technicians means that companies will have the luxury of picking and choosing, while from the employee viewpoint, salaries may be depressed. A small pool means potential shortages, most likely of specialists, perhaps driving organizations to move people laterally to meet their needs. Soaring demand for computer professionals, for example, has drawn in many people without formal training in the discipline; about two-thirds of those employed in programing and related jobs have degrees in other fields.

Quantity and Quality

For several years, during which engineering graduates in all disciplines were in short supply, the U.S. electronics industry experienced a scarcity of entry-level electrical engineers and computer scientists. In the short term, demand has dropped—largely because of recession—while the supply continues to rise, fed by swollen undergraduate engineering enrollments, The longer term picture—including prospects of continuing shortages of software engineers, integrated circuit designers, and others with specialized skills—has not changed. Moreover, the supply of grey-collar workers for the electronics industry—technicians, drafters, and designers, field service repairmen, laboratory aides—may also be short, although quantitative data on supply and demand for such jobs are scarce. There is, needless to say, no shortage of unskilled assembly workers; *the heart of the problem in this, as in a number of other American industries, is an excess of unskilled workers coupled with sporadic shortages of those with higher levels of education and training.*

The scarcity of recent U.S. graduates in engineering has been real, extending to virtually all specialties. Its origins lie in low enrollments during the early and middle 1970's (see ch. 8). Since then, engineering enrollments have rebounded to record levels. Educational resources have not kept pace, with the result that a substantial number of engineering schools have had to limit the numbers of students admitted. Not only is supply constricted, but *the quality of engineering education is suffering.*

Shortages of teaching faculty have constrained engineering education more than any other factor. Despite undergraduate enrollments that have nearly doubled over the past decade, trends in graduate engineering study have been nearly flat, In particular, students have been reluctant to enter doctoral programs. Fewer Ph.D.'s in engineering were graduated in 1982 than in 1972. Nearly half those now receiving Ph.D.'s from American engineering schools are foreign nationals. Recent Ph.D.'s have been avoiding teaching careers, for which the doctoral degree is today virtually mandatory. Not only are salaries low relative to industry, but new teachers can anticipate heavy course loads as a result of high undergraduate enrollments and the faculty shortages that already exist. Coupled with uncertain prospects for research support and a lack of prospective graduate students of their own, university teaching is no longer an attractive prospect to many who in earlier years would have been prime candidates. The result is 1,400 to 2,000 unfilled vacancies on the faculties of U.S. engineering schools.

Deteriorating laboratory facilities create a second bottleneck. Engineering education is expensive; curricula include numerous laboratory courses, as well as heavy use of computing facilities. Keeping laboratories relatively current, so that students get some experience with up-to-date equipment—instrumentation, small computers, applications of microprocessors—is a long-standing problem that has grown worse in recent years.

If the trends outlined above continue, serious harm to the competitive prospects of *many* American industries could result.

Continuing Education and Training

In contrast to constraints on supplies of new engineering graduates, the United States has hundreds of thousands of midcareer engineers already in the labor market. If the half-life of a college education in engineering is, say, 10 years, upgrading these peoples' skills offers vast opportunities both for individuals and for U.S. industry. In some cases periodic short courses or self-study may be enough to boost people along chosen career paths; in others, they may wish to move laterally—e.g., from analog to digital circuit design, from hardware design to software. As pointed out in chapter 8, little data exists on the frequency with which engineers take advantage of opportunities for continuing education and training; it appears that most who do are recent graduates, and that those with the greatest need—i.e., people 10 years or more out of school—rarely pursue continuing education beyond the occasional (and seldom very challenging) short course. Several implications follow: 1) the rewards of pursuing continuing education and training in engineering could be low—e.g., employers may not support such activities extensively, preferring to hire new graduates with the skills they need at lower salaries; 2) the programs available may not be attractive—i.e., working engineers may perceive them as academic and unrelated to their jobs; 3) the quality of programs may vary quite widely, so that those who have or hear about bad experiences are reluctant to try again.

The paucity of information on this subject is in itself disconcerting, but it appears that all of these factors are at work, and others as well. Certainly, existing incentives seem high enough to motivate only those with unusual ability or perseverance. While some companies have devised effective programs for encouraging employees to maintain and improve their skills, others do little or nothing. The picture is likewise mixed among educational institutions; some engineering schools have developed aggressive outreach programs aimed at providing high-quality coursework for technical professionals, those who are seeking advanced degrees and those who are not. Continuing education programs offered by professional societies as well as profitmaking organizations vary considerably in quality. The *quickest, surest way of providing the numbers of qualified engineers needed to maintain the competitiveness of American industries like electronics is to make high-quality continuing engineering education more widely available and attractive to midcareer professionals.*

Despite recent difficulties, engineering education in American universities remains the best in the world. In part because schools and universities in some countries do relatively poorly at preparing their graduates for careers in industry, foreign companies resort more frequently than U.S. firms to internal and on-the-job training, Extensive company-run training programs are prominent in the Japanese electronics industry, where continuing education is widespread among blue-collar and grey-collar employees as well as white-collar professionals. One way for the United States to increase its pool of skilled grey-collar workers would again be to develop a more effective approach to continuing education and training. Such programs will be more effective where closely coupled with prospects for upward mobility within organizations. At present, the probability that an unskilled worker in an electronics firm will be able to move up to a higher paid position is small.

More broadly, *programs of all types aimed at vocational education in technical fields appear to need reexamination and modification if the quantity and quality of graduates is to grow.* In the United States, as many as 8,000 public and private schools offer vocational-technical education and training (compared with roughly 300 engineering colleges). The quality of the courses and programs offered by these institutions varies widely, Activities are fragmented, with little detailed information available even to form a baseline for analysis, One point is clear: the fraction of the labor force in U.S. manufacturing industries with formal training in technical fields (through apprenticeship programs or schooling) and/or credentials (e. g., certification granted after examinations) is far lower than in a number of other industrialized nations, including West Germany and Japan. While correlations with on-the-job ability may be imperfect, the prevalence of such programs in other countries is good evidence of a commitment by individuals, governments, and business enterprises to building a labor force that will help maintain the competitive ability of technologically based industries into the future. So far this commitment has been lacking in the United States.

Congressional leadership could have a major impact. As the pace of technical advance in industries like electronics continues or accelerates, workers at all levels will face new demands on their capabilities. *Given the increasing disjunction between the skills of the U.S. labor force—what people are capable of doing—and the skills that industry needs, the American economy seems bound to face increasing problems in meeting its manpower needs, as well as controlling unemployment, unless progress can be made in training and retraining.* A company might, for example, lend an employee the money to cover vocational schooling, retraining, or an advanced degree program, with repayment forgiven if the employee remains with the firm for an agreed period. Tax policies and other instruments of Government support could increase the incentives for both corporations and individuals.

Public policies might be designed to lessen the risks that companies sponsoring education and training for their employees would lose their investments when people switch jobs. The Federal Government could provide incentive grants to the States, to be matched with corporate support.

Preparation for Work in Technology= Based Industries

At the root of many of the present and prospective difficulties outlined above lies poor preparation in science and mathematics provided by the public schools. Leaving aside the large number of functional illiterates among U.S. high school graduates—an illiteracy rate that some estimates place as high as 20 percent—and the one-quarter of this age group that does not even complete high school, many good students get little education in science or mathematics once they reach the upper grades. The number of students electing courses that are prerequisites for careers in technical fields is low and still falling; even those who choose science often shy away from physics and chemistry in favor of biology or geology. Technology, as opposed to science, is invisible within the public schools. *As the U.S. economy continues to shift from manufacturing toward services, and toward more knowledge-intensive industries, the American labor force will need to be prepared for technology-based jobs or risk doing without.* Even those performing unskilled work will be in a position to make greater contributions to productivity and competitiveness, while enhancing their own job security and job mobility, if they are comfortable with numbers and quantitative reasoning, and have a basic understanding of the physical world.

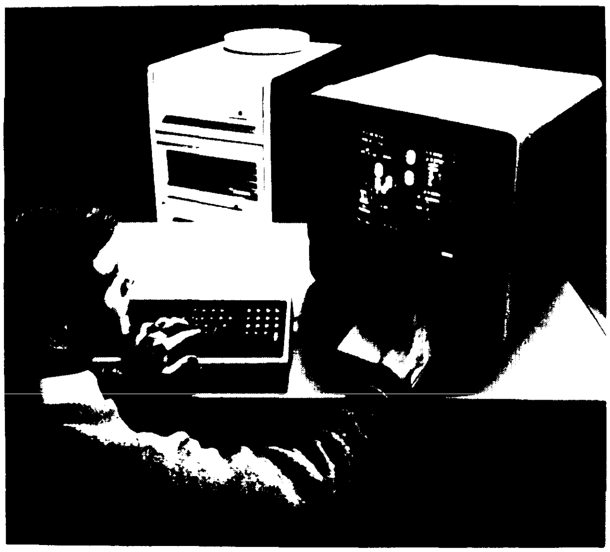


Photo credit: *Digital Equipment* Corp

Computer-aided engineering design

Part of the problem is again a shortage of teachers; secondary schools are being stripped of their science and mathematics instructors by the attractions of higher paying jobs in industry. But the fundamental point is this: a student who opts out of science—and particularly mathematics—at an early age has made a virtually irreversible decision, foreclosing a wide range of options in college and in his or her career. If American students continue to turn away from mathematics and science at secondary and high school levels, the United States will find itself with an even greater fraction of technological illiterates in the adult population. Already, the Nation finds itself with few leaders in industry or Government who grasp the workings of technology.

Management and Organization

Patterns of organization and management in business enterprises mediate between the skills and abilities that employees bring with them to the workplace and outcomes in terms of competitive firms and industries. How well companies utilize the talents of the people they hire is quite as important as how good these people are to begin with. Thus management style and philosophy becomes a second critical element in human resources for the U.S. electronics industry. While American management includes a "human relations" or participative management tradition, employee involvement tends to be honored in theory more than in practice. Techniques flowing from scientific management, the other main tradition, remain dominant in U.S. industry. The recent vogue for Japanese management practices represents a swing of the pendulum toward the human relations pole, offering paths to improved competitiveness for some U.S. firms, though no sure cures.

Within a given country—whether the United States, Japan, or one of the European nations—electronics firms show a good deal of diversity in management style. Nonetheless, successful electronics companies in the United States and Japan exhibit more similarities than differences, Despite the current fascination with the "secrets" of Japanese management, uniquely Japanese traits are rare even in the cruder stereotypes. If the differences between firms within each country are often greater than the differences between countries, and clear-cut distinctions between management styles in the United States and Japan less common than often assumed, two features of Japanese management do stand out: first, reward structures in Japanese companies create incentives for talented people to build careers in manufacturing; second, Japanese organizations tend to stress human relations more consistently and more effectively.

Generally speaking, *manufacturing and production engineering get more attention and more status in Japanese companies than American.* This is one reason consumer electronics and semiconductor firms in Japan could move swiftly to create perceptions that their products offered better quality and reliability, Often, as discussed in chapter 6, those perceptions were firmly grounded in reality; although American firms have largely caught up, the strong institutional commitments in Japanese corporations to production engineering mean continuing pressure in this area. Furthermore, that manufacturing managers in Japan carry more weight in corporate councils means in at least some cases faster shifts into automated production, The importance Japanese companies place on manufacturing in their internal decisionmaking also translates into a greater share of resources for developments such as the complex and demanding tasks of integrating robotics and other forms of programmable automation into the factory environment; companies that learn to utilize programmable automation most effectively will reap substantial competitive dividends in the future.

Stress on human relations is certainly not unique to Japanese organizations, but is more consistently visible—notably among large companies characterized by low labor mobility and "lifetime" employment (ch. 8). That workers at all levels tend to spend much if not all of their careers within a single organization creates strong incentives for internal training, job rotation, and other steps aimed at improving people's skills and preventing stultification. A number of successful American electronics firms also go to considerable lengths to retain their employees, even in periods of business downturn. Rather than treating the labor force as a variable cost, such firms, in both countries, regard their workers as a resource to be retained and nurtured although economic conditions might seem to point toward layoffs, Accomplishing this implies more than keeping people at work and providing education and training. It also implies opportunities within the corporate structure to fully utilize present and potential skills without sliding into paternalism or coercion, A number of the highly publicized techniques associated with Japanese management could, in fact, be as fairly termed manipulative as participative,

A renewed commitment to the development and utilization of the human resources available to American firms could make a major contribution to the future competitiveness of the U.S. electronics industry, indeed may be critical for the future prospects of this as well as other high-technology sectors of the American economy. *Management practices in successful organizations, whether American or Japanese, tend to be associated with attention to human relations and employee participation.*

Employment

Continuing inadequacies in U.S. education in science and mathematics will aggravate structural unemployment caused by technological development and shifting competitiveness among American industries. In the past, technical change has generally created more jobs in the aggregate than have been destroyed. Unfortunately, there *are no guarantees that continued technological change—especially that resulting from applications of microelectronics and computers—will in the future lead to aggregate increases in job opportunities*. In Europe, the term "jobless growth" has come to describe the widespread phenomenon of high unemployment despite expanding output, This may or may not have been happening in the United States—the evidence either way is scanty—but structural unemployment *is* a reality here.

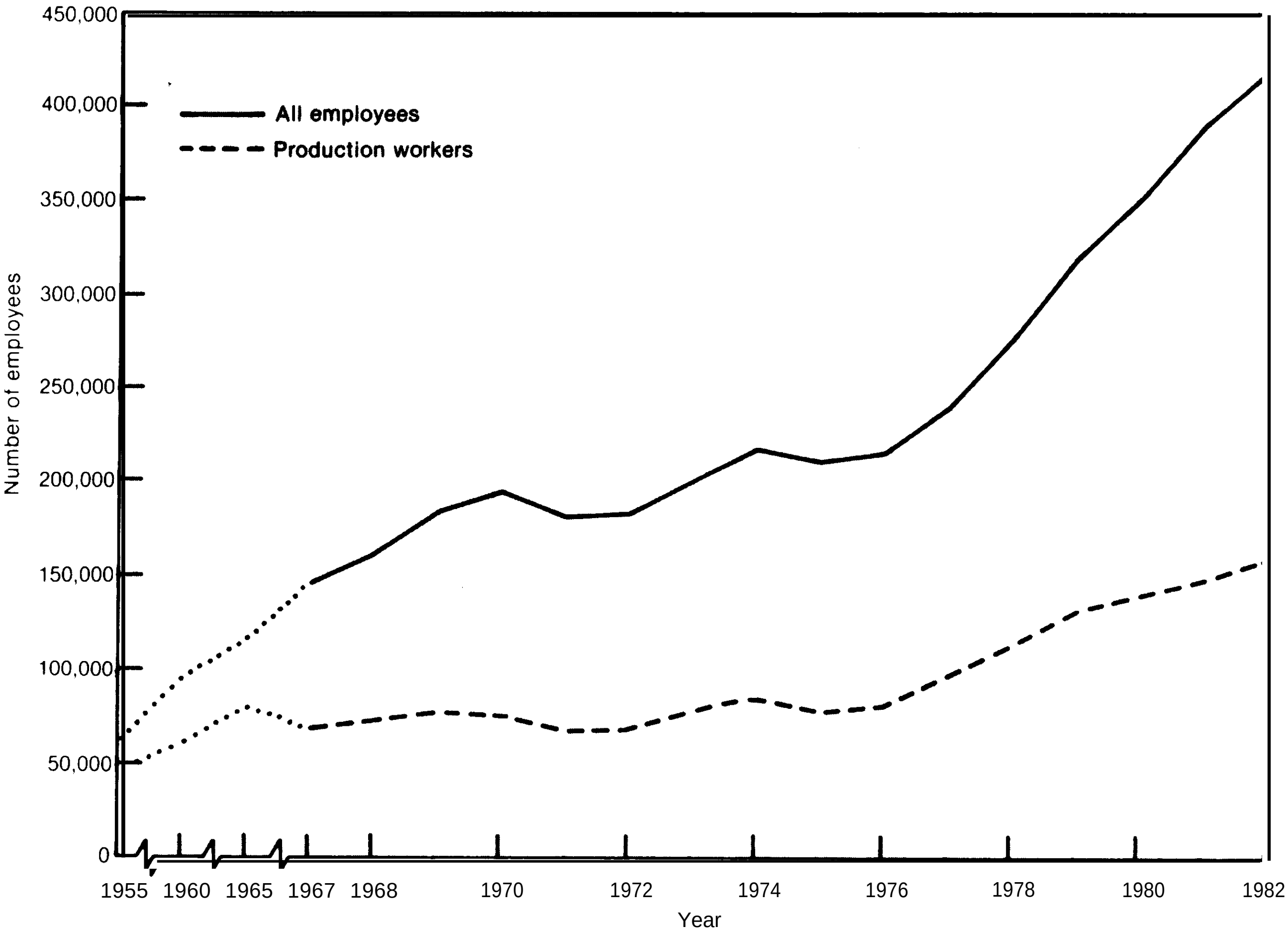
Shifts in the composition of the work force in electronics illustrate one of the consequences of technological and structural change. In the United States, it is fair to say that jobs in electronics are becoming more skill-intensive. Only in the manufacture of consumer products like TVs, a portion of the industry that has been relatively stagnant, has the ratio of blue-collar to white-collar employees remained high. In both computers and semiconductors, the fraction of white-collar workers is much greater and increasing.

But a division into skilled and unskilled—or white-collar, grey-collar, and blue-collar, not at all the same thing given the high levels of know-how associated with some but not all jobs in each of these categories—is too simple. It masks the increasing stratification and specialization characterizing technologically based industries, not only electronics but the sectors it feeds. The journeyman machinist may go the way of the tinker as computer-controlled machines replace engine lathes. The skilled mechanic who could rebuild such a lathe can probably no more fix the electronics of a

U.S. Employment in Consumer Electronics

SOURCES: 1960-1965—1977 Census of Manufactures. 1972-82—Bureau of Labor Statistics.

U.S. Employment in Computer (and Peripheral Equipment) Manufacturing



SOURCES: 1955-65-1977 *Census of Manufactures.* 1966—82-Bureau of Labor Statistics.

numerically controlled machine than program the computer that controls it. Specialists not only design the parts to be made and program the computer, but pick the feeds and speeds, specify tool materials and cutting fluids. Gaging and inspection may be automated, rather than the responsibility of practiced hands with dial gage and surface plate. As skilled jobs change—and at least some skilled work disappears along with unskilled—people who have no skills to start with will face still more trouble in finding satisfying, well-paying employment. Those who cannot learn new skills may find themselves outside the labor pool. Upward mobility in the United States may decline.

Many unskilled jobs are migrating overseas—in electronics, mostly to low-wage countries in Asia. Moves offshore by American corporations have attracted widespread attention, and opposition on the grounds of “exporting jobs. ” Offshore assembly has been much more prevalent in semiconductors and consumer electronics than in computers; even so, in both sectors, other factors have often made greater contributions to declining blue-collar job opportunities (see ch. 9 as well as app. B). Among these factors, improvements in labor productivity, many stemming from investments in automated manufacturing equipment, have generally had the greatest impacts. Moreover, transfers of production offshore tend to be driven by competitive pressures, domestic as well as foreign in origin, which are largely outside the control of individual firms. For instance, once a few U.S. semiconductor manufacturers began assembling chips in low-wage countries to cut costs, other suppliers had little choice but to follow suit. When the pressures are international, moves offshore may in some cases save domestic employment opportunities over the longer term by helping maintain U.S. competitiveness, though sacrificing jobs in the shorter term.

Manufacturing by American-owned as well as foreign-owned companies has become widely dispersed internationally. But this is only one cause of unemployment in the United States. Ongoing structural and demographic shifts are causing serious and persistent adjustment difficulties, People with few skills or with obsolete skills will find diminishing job opportunities in many of the older U.S. industries. Ten million and more Americans have been out of work at a time when American industry has been short of as many as a million employees with specific skills and abilities. In the aggregate, and even considering multiplier effects, a million new jobs only dents the unemployment problem facing the United States. Yet from the standpoint of the individual, each job counts. policy makers may find themselves unable to predict the causes and consequences of structural unemployment with any precision. This does not mean the problems cannot be attacked. It means that adjustment measures should aim to enhance job mobility—intra-firm as well as inter-firm—without depending on detailed predictions of supply and demand by occupational category and industrial sector.

Predicted Growth Rates by Occupational Category in the United States Over the 1980's

Occupation[a]	Predicted increase in employment (1980-90)
Paralegal	*1090/0*
Data processing machine mechanic	93
Computer operator	72
Computer systems analyst	68
Business machine service technician	60
Computer programer.	49
Employment interviewer.	*47*
Computer peripheral operator	44
Psychiatric aide	*40*

[a] Noninclusive; fastest growing Occupations in electronics are listed together with selected occupations outside of electronics (in italics) for comparison

SOURCE: "Testimony Before the Senate Subcommittee on Employment and Productivity, March 26, 1982, by Ronald E Kutscher, Assistant Commissioner, Office of Economic Growth and Employment Projections, Bureau of Labor Statistics," *Productivity in the* American Economy, 1982, hearings, Subcommittee on Employment and Productivity, Committee on Labor and Human Resources, U S. Senate, Mar 19 and 26, Apr 2 and 16, 1982, p 327

The total number of jobs created over the next decade in electronics and other high-technology industries will not be large. After all, the entire U.S. electronics industry employs only about 1½ million people today, and employment has not expanded as rapidly as output. Still, many of the fastest growing occupational categories in the economy will be found in this sector. The people who fill the new jobs will benefit; at the same time, U.S. electronics companies need good people to remain competitive. Nonetheless, there has as yet been little concrete discussion of what is needed to prepare people for future job opportunities; the organizations and institutions that deal with such concerns tend to be dispersed and to operate independently of one another. Although the past few years have seen considerable criticism of training programs said to be preparing people for jobs that have already disappeared, little usable information on such subjects in fact exists. Local control of secondary and vocational education is the traditional pattern in the United States. Educators and schools of education seldom interact extensively with industry or organized labor. Vocational education and training has little visibility at the Federal level. Over the past two decades, schools have turned away from providing marketable skills. Company-run training programs are limited in number and tend to be emergency responses to hiring shortfalls rather than everyday features of corporate organization. *A thorough re-thinking of the American approach to education and training, particularly for blue- and grey-collar workers, seems called for.* Congress could decide to take the lead in reinvigorating the traditional American commitment to education and training.

Trade

Trade policies pursued by the Federal Government have affected the several portions of the U.S. electronics industry in radically different ways. Consumer electronics has suffered from uncertain enforcement–some would say nonenforcement—of antidumping statutes, although other parts of U.S. trade law have been called on to protect domestic firms from import competition. American manufacturers of semiconductors and computers have benefited from U.S. leadership over the postwar period in creating an open environment for international trade and investment. One of the strengths of American semiconductor and computer firms has been their global approach to markets, a strategy aided by reductions in barriers to trade and investment over the past three decades. Even though semiconductor imports from Japan have increased rapidly during the last few years, more than three-quarters of U.S. semiconductor imports continue to consist of interdivisional shipments of American companies. In Japan, the largest exporter by far among local computer manufacturers is IBM-Japan,

Antidumping Enforcement

Dumping complaints leveled at importers of Japanese TVs as early as 1968 have never been fully resolved. Dumping–selling imported TVs at prices below those charged in Japan—was proven under U.S. law, but legal challenges and interagency disputes have delayed final collection of duties for years.

During the 1960's and 1970's, Japanese TV manufacturers, followed by those in South Korea and Taiwan, relied heavily on price cutting to force their way into U.S. markets. Nonetheless, dumping was neither the sole cause nor even a primary cause of competitive shifts in consumer electronics. The worldwide success of Japanese consumer electronics firms amply demonstrates their ability, not only to manufacture at low cost, but to produce reliable TVs with good performance and product features that American consumers want. At the same time, uncertainty created by lengthy and inconclusive legal proceedings meant that domestic firms could not know whether they might eventually be able to raise prices as a result of antidumping duties levied on imports. These added duties might have totaled well over $100 million; higher prices generating higher profits could, in principle, have aided embattled American firms in revitalizing their businesses.

Eventually, U.S. color TV manufacturers and their suppliers did receive trade protection, in the form of negotiated quotas on imports from Japan, Korea, and Taiwan. Under the name Orderly Marketing Agreements (OMAs), the quotas followed escape clause proceedings filed in the wake of sharp rises in color TV imports during the 1970's. Unfair trade practices were not at issue. The OMAs speeded structural shifts already underway in the U.S. consumer electronics industry. By limiting imports, they created incentives for foreign firms to invest in assembly plants within U.S. borders. OMAs did little to revive the American consumer electronics industry; they did accelerate foreign investments, many of which would eventually have been made in any case. In effect, weaker American TV manufacturers driven from the market by imports have been replaced by subsidiaries of foreign firms. While these subsidiaries help to maintain domestic employment, half or more of the value added typically remains overseas.

The Environment for World Trade

A number of American computer firms that began as makers of office equipment, including IBM, maintained foreign operations before the war. During the postwar period, overseas investments by American computer manufacturers expanded; subsidiaries of U.S. firms became the backbone of computer industries in most parts of the industrialized world. Today, along with the older companies whose product lines still center on general-purpose mainframes, the major American manufacturers of minicomputers also operate all over the globe. Likewise, U.S. semiconductor firms began to invest overseas at an early stage; these investments, beginning around 1960, were made for two reasons: 1) to supply foreign markets via local production in industrialized nations; and 2) to cut costs by moving labor-intensive manufacturing operations to low-wage countries.

Direct and Indirect Barriers

Foreign investments by U.S. computer and semiconductor manufacturers, along with their continuing high levels of exports, have been facilitated by a relatively open environment for international trade and investment—chapter 11. Created largely under the auspices of the General Agreement on Tariffs and Trade (GATT), in which the United States has played a major role, this opening of opportunities for multinational firms via relaxation of direct barriers to trade and investment—tariffs, import quotas, restrictions on flows of capital outward as well as inward—has, on the whole, been of great benefit to the U.S. electronics industry. At the same time, relaxation of direct barriers to trade has been accompanied by a simultaneous increase in less direct obstacles and controls.

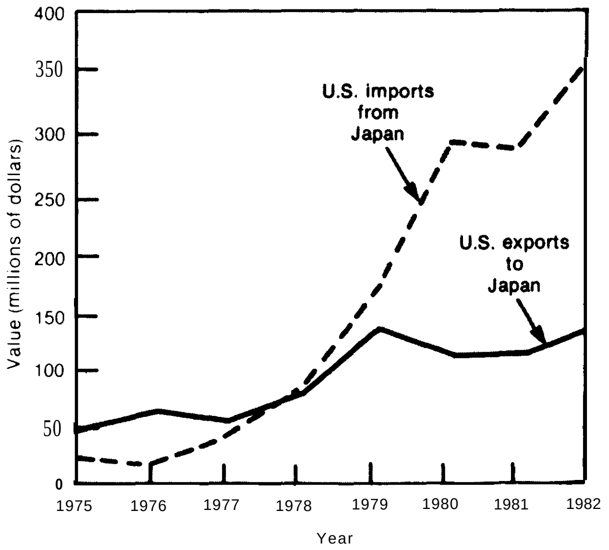
As the industrial and trade policies of foreign governments have evolved, they have swung toward more subtle combinations of indirect import barriers, performance requirements, investment incentives, and subsidies. In some cases, these measures—described in chapter 10—are intended to influence investment and exporting, In others, the objectives are primarily matters of domestic policy: national security, employment, regional development, Governments intent on pursuing industrial policies that will support local industries while attracting U.S. dollars and / or technology can choose from a well-stocked arsenal: trade barriers range from paperwork obstacles to "buy national" rules; performance requirements may entail transferring technology, purchasing supplies and materials locally, or exporting a prescribed fraction of production as a condition for investment; common forms of subsidies include R&D funding, capital preferences, and guaranteed procurements, European nations, in particular, have sometimes used investment incentives to attract American electronics firms in the name of jobs and technology,

Over the past half-dozen years, spokesmen for the U.S. semiconductor industry have frequently complained that the trade practices of some foreign enterprises have been unfair, while also voicing concern over government industrial policies in countries such as France and especially Japan. (U.S. computer firms have seldom been as vocal over trade practices or internal subsidies benefiting their foreign rivals.) Among the restrictive practices that still exist in many parts of the world, the relatively high tariffs levied by the European Community (EC) on semiconductors—17 percent—are perhaps the most visible. One consequence has been to encourage investments within the EC by American firms, but the European market is in any case large enough that these investment patterns could have been anticipated. In neither semiconductors nor computers have European suppliers been very successful in approaching the EC market as a whole. With only a few exceptions, local firms have exhibited relatively fragmented patterns of production and sales, In contrast, American-owned enterprises have often done a better job of treating Europe as a unified regional market, But whereas the trade practices of Western European nations may have ended by harming the ability of local firms to compete with the Americans more than they have helped, the situation has been vastly different in Japan.

Japan

For many years the Japanese Government effectively protected the country's electronics industry, including manufacturers of consumer products such as TVs, through controls over foreign investment as well as restrictions on imports. With only a few exceptions—e.g., IBM-Japan—American-owned computer and semiconductor firms have had no more than modest success in selling their products through either exports or local production. A complex of factors ranging from chauvinism

U.S.-Japan Trade in Integrated Circuits



SOURCE: *1983 U.S Industrial Outlook* (Washington, D C : Department of Commerce, January 1983, p. 29-5. 1982 figures estimated.

to explicit government policies has impeded both exports and investments in Japan by American electronics suppliers. The negative impacts on U.S. competitiveness have been far greater than those visible anywhere else in the world.

American companies have been able to sell products that the Japanese could not make for themselves—advanced integrated circuits, state-of-the-art semiconductor fabrication equipment, some types of computers. But products available from Japanese suppliers tend to be purchased locally, in part because of deeply ingrained "buy Japanese" attitudes. Structural differences also play a role, particularly in microelectronics: the half-dozen large companies that produce most of Japan's semiconductors also consume perhaps two-thirds of these same semiconductors; such a market is difficult to attack from the outside. While foreign investment is in theory much less restricted today than in the past, only a few American semiconductor and computer firms have as yet established wholly owned operations of any size within Japan.

Given the rapidly improving technological abilities and competitive postures of Japanese electronics manufacturers, investment in Japan by American firms appears vital for maintaining U.S. competitiveness; while many in Japanese Government and industry will no doubt continue to oppose such investments, Japan's Government has officially endorsed liberalization many times, and should be held to these statements in practice as well as in principle. The Japanese market for electronics products is now second only to that of the United States; for many types of products, sales within Japan exceed those for all of Western Europe. Not only will local manufacturing help expand markets for American firms, enabling them to compete more effectively with Japanese companies in third countries as well as inside Japan, it will accelerate flows of technology *from* Japan *to* the United States. As in industries such as steel or automobiles, American electronics companies can now learn from their Japanese counterparts—and not only in consumer products. U.S.-owned R&D laboratories in Japan could help compensate for personnel shortages here, as well as improving access to the results of subsidized research programs such as the fifth-generation computer effort. *Full participation in the dynamic Japanese electronics market is critical to the continuing competitiveness of American computer* and

Semiconductor Sales in the United States, Western Europe, and Japan

	Sales (billions of dollars)	
	1974	1982
United States		
Discrete semiconductors . . .	$0.88	$1.3
Integrated circuits.	1.2	6.3
	$2.1	$7.6
Western Europe		
Discrete semiconductors . . .	$0.77	$0.77
Integrated circuits.	0.52	1.5
	$1.3	$2.3
Japan		
Discrete semiconductors . . .	$0.55	$1.2
Integrated circuits.	0.59	2.4
	$1.1	$3.6

SOURCES: *1974—Electronics,* Jan. 8, 1976, pp. 92, 93, 105.
1982—Electronics, Jan. 13, 1983, pp. 128, 142, 150; Mar. 10, 1963, p. 8.

semiconductor manufacturers; Congress could help ensure that the Federal Government actively supports such endeavors by American firms, which are fully consistent with this country's historic commitment to open trade and investment. Competition in Japan on terms perceived to be fair will yield dividends within the United States by creating conditions under which American companies can better maintain their competitiveness.

Recent Developments

Broadly speaking, the Tokyo Round multilateral trade negotiations, completed in 1979 and implemented shortly thereafter, in the United States by the Trade Agreements Act of 1979, are having generally positive though small impacts on the American electronics industry. Continuing tariff reductions will help U.S. exports; accelerated duty reductions on semiconductor products and computers by Japan are especially significant, though perhaps as symbol more than substance.

Nonetheless, tariffs are no longer the principal barrier to international trade in electronics. They are being replaced by indirect and nontariff barriers, including a wide range of implicit and explicit subsidies. In particular, American electronics firms continue to complain over government-funded R&D programs in Europe, Japan, and a number of developing countries. Although the Tokyo Round yielded a new subsidies code intended to deal with this and related issues, the prospects for substantial progress seem slim.

Taken one at a time, individual programs in foreign countries—including such prominent examples as Japan's VLSI R&D effort, and, prospectively, the fifth-generation and supercomputer projects now underway—have often had no more than modest impacts on international competitiveness. At the same time, their goals often include intangibles such as technology diffusion or improvements in the skills of the labor force; these make outcomes difficult to evaluate. Subsidies directed at commercial technologies and typically rationalized as domestic support measures rather than export promotion policies have few counterparts in the United States. It is the justification in terms of domestic objectives rather than strengthened export competitiveness that makes such policies a problematic subject for international negotiations. Public funds for R&D, the use of government procurement to favor domestic industries, and the many related instruments of industrial policy detailed in chapter 10 have become part of the conventional approach by foreign governments. Countries in many parts of the world pursue such measures in hopes of building their competitiveness in high-technology sectors like electronics.

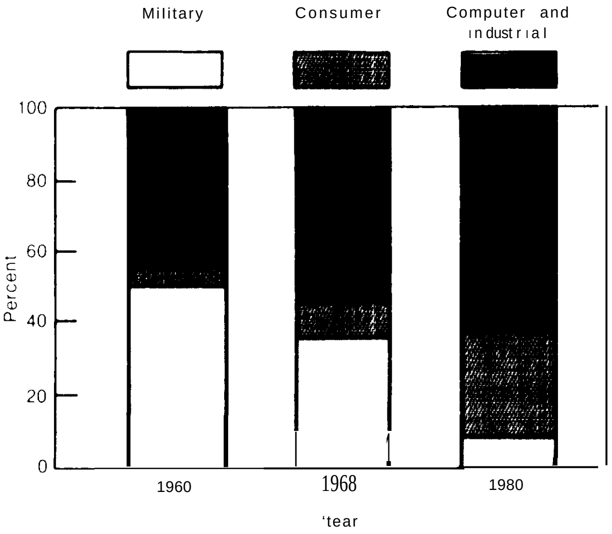
Given the growing prevalence of planned programs of industrial development, virtually all of which give electronics a prominent place, it seems unlikely that continued U.S. attacks on such policies as "export subsidies" will have much effect in arresting the trend. This is particularly true given the indirect and intangible impacts of programs directed at infrastructural support, precompetitive technology development, or human resources. Many of Japan's industrial policy initiatives have been directed at overcoming structural obstacles such as limited labor mobility and a less than stimulating working environment for technical professionals. Totaling the monetary value of such subsidies, even where possible, is an exercise that holds little meaning. And, in the end, most foreign governments will regard such efforts as too important to give up; certainly they do not welcome them as legitimate topics of international negotiations, bilateral, or multilateral. While it *is clearly in the interests of the United States to press for clarification and agreement on the "rules of the game," it may not be very productive to devote a great deal of effort to combating on a case-by-case basis what have become standard tools of industrial policy in other countries.*

U.S. Industrial Policies

As many observers have noted, industrial policy in the United States has been a largely ad hoc construct of unrelated measures aimed at diverse objectives; not infrequently, policy measures have worked at cross purposes or led to unanticipated outcomes. Seldom have they represented conscious attempts to stimulate the competitiveness of American industries. Trade policy, treated separately above, is only a partial exception.

In recent years, U.S. industrial policies have seldom had major impacts on the electronics industry; however, early developments in both computers and semiconductors benefited from Government procurement and from R&D funded by Federal agencies concerned with defense and space. Since the 1960's, overlaps between military/space applications and civilian needs have diminished. Today, military electronic systems are seldom as advanced as civilian; *it has been many years since Federal spending has had much influence over electronics technology or competitiveness.*

Distribution of U.S. Semiconductor Sales by End Market



SOURCES: ***1960,1968:*** "Innovation, Competition, and Governmental Policy In the Semiconductor Industry," Charles River Associates, Inc., final report for Experimental Technology Incentives Program, Department of Commerce, March, 1980, p. 2.13.
1980: *Status '80: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz. Integrated Circuit Engineering Corp., 1980), p 34

Faced with increasing competition in many industrial sectors, slower economic growth, and a multitude of adjustment problems, the question for the United States has become: Can the country continue with a de facto industrial policy or is a new approach needed? The surprising variety of programs intended to nurture technologically based industries in Japan, Western Europe, and several newly industrializing countries reveal an attentiveness to economic development simply lacking here. One response has been to argue that the United States needs to find ways of negating or countering foreign industrial policies, Alternatively, rather than a reactive posture, the United States could itself move toward policies intended to stimulate and support industrial development.

Foreign industrial policies have had their failures—and successes too. The important point is that countries which have adopted relatively systematic industrial policies continue to experiment with policy tools, to develop new programs—in short, to accumulate experience and improve effectiveness. The U.S. system has strengths and weaknesses different from any and all of the nations—Japan, France, South Korea—that have pursued industrial policies aimed at economic growth and development, What sort of industrial policy could help the United States to maximize its own strengths, minimize its weaknesses? To help frame this question, OTA suggests five possible orientations that Congress may wish to consider for a more coherent U.S. industrial policy:

1. A policy approach aimed at *ensuring a strong domestic market base for U.S. industries,* along with preservation of existing jobs and job opportunities.
2. Policies designed to *protect and/or support a limited number of industries judged critical to national security,* defined narrowly or broadly.
3. Measures that will *support the technological base and institutional infrastructure for American industries,* particularly those undergoing structural change.

4. Policies intended to *promote the global competitiveness of American industries.*
5. An orientation that would *defer wherever possible to the private sector* when choices concerning the development of industry are to be made.

These policy directions, examined in detail in chapter 12, are by no means mutually exclusive; they might draw, for example, on similar policy tools in areas such as international trade or technology development. Nonetheless, they represent distinctly different thrusts: the goals differ even where the instruments are alike.

The five alternatives, outlined below in the context of the electronics industry, carry implications for the entire economy, as well as the political environment where any policy would have to be implemented. These broader dimensions are emphasized below because focusing too strongly on specific policy tools—e.g., those addressing problems visible at the moment in electronics-would simply repeat the ad hoc approach to U.S. industrial policies now current.

Each of the five approaches has positive and negative aspects, They can be usefully contrasted in terms of differential effects on sectors of the economy as well as susceptibility to the political forces that corporations and their employees bring to bear on the policymaking process. The intrinsically political character of this process, now or in the foreseeable future, has often been couched in terms of Government's ability to pick and choose among "winners" and "losers. " Early debates over industrial policy in the United States tended to focus on such questions—rather pointless given that many Federal policies have always had this effect. The Economic Recovery Tax Act of 1981 treats some industries much more favorably than others; trade protection has in recent years been extended to manufacturers of color TVs, automobiles, and clothespins; political pressures routinely affect decisions on public works and defense projects.

When industrial policy decisions are made on an ad hoc basis—without linking one sector of the economy to others, without setting the problems of a domestic industry into the context of the world economy—political considerations can more easily predominate. To begin coordinating such decisions more closely carries two quite different implications: 1) greater reliance by the Federal Government on empirically grounded analysis of industrial competitiveness, productivity, and economic efficiency; and 2) risks that—beyond influencing policy decisions on a case-by-case basis, as happens already—political pressures will skew the policy approach as a whole. The first is one of the potential advantages of a more coherent industrial policy, the second, one of the pitfalls—a pitfall because companies and industries in trouble, and their employees, have a more obvious stake in policy decisions, hence bring more pressure to bear, than sectors of the economy on the upswing.

The first two of the policy orientations listed above carry the greater risks of political deflection. Ensuring the domestic market base for U.S. industries could easily amount to nothing more than a protectionist response to trade pressures and the rise of competitive enterprises in other countries. Basically an inward looking, defensive strategy, it equates import penetration with damage to U.S. interests. An industrial policy centered on safeguarding American markets and American jobs would be largely congruent with the political forces that will always advocate protectionist measures—firms and industries in competitive decline, their employees, the communities and regions in which they are located.

Decline may be temporary and reversible, or it may be the consequence of deeply rooted shifts in the international economy that, over the longer term, are likely to force contraction regardless of public policy responses. A market protection strategy implies, first of all, determining whether protection is needed because of short-term problems—which might range from macroeconomic dilemmas to misjudgments by corporate managements. For such reasons, temporary protection is sanctioned by international trade law under circumstances as described in chapter 11. Indeed, temporary trade restrictions might find a place in any industrial policy alternative. Longer term decline brings a different set of issues to the policymaking process; the options may range from managing decline (via adjustment measures intended to ameliorate the most immediate problems) to wholesale protection and subsidization (as several European nations have occasionally attempted).

A critical industries strategy—whether "critical" refers narrowly to military strength or carries some broader economic connotation—would also lead to a great deal of political jockeying among firms and industries bent on demonstrating their criticality. Such an outcome is virtually inevitable because few objective criteria exist that would allow essential or critical industries to be identified beyond the broadest and most general level. Under virtually any criteria imaginable, electronics would be judged vital to "economic security" as well as military security. Even so, when the industry is disaggregated, judgments at finer levels immediately become difficult.

Electronics would probably not suffer under either a protectionist or a critical industries approach; although backlashes by other countries are always a possibility, nations that import high-technology electronics products usually need them badly enough that they would pick other alternate targets for retaliation. Even so, a number of other Us. industries would be likely to benefit more. For at least some companies, the lobbying involved would be business-as-usual. Large and powerful corporations experienced in dealing with the Federal Government, defense contractors, and firms in heavily unionized industries would tend to have an edge over smaller, technology-based concerns. The more aggressive and outward looking high-technology portions of electronics could not expect as much positive support as they might get under other policy decisions.

Under any of the five alternatives, political forces would bear heavily on policy outcomes. Firms and industries will always have strong incentives to press for direct and indirect subsidies flowing from Federal decisions, This is quite understandable, and built into the American political system, but has consequences that are largely undesirable if a basic objective of industrial policy is to improve U.S. competitiveness. Industrial policies are most likely to be productive and effective when they complement ongoing changes in the world economy—e.g., by aiding structural adjustment. When industrial policies oppose long-term shifts in comparative advantage, they are generally doomed to high costs, inefficiencies, and marginality if not ultimate failure.

This could well be true, for instance, in the case of Federal actions that would steer capital to selected industries. Such policies have frequently been advocated by those favoring "reindustrialization, " as well as a critical industries orientation. However, targeting of investment in a conscious way—a key element in many foreign industrial policies—seems an unlikely prospect for the United States, if only because capital markets here work much better than in most other economies. Moreover, the Federal Government's experience with investment, leaving aside sectors such as housing, has been restricted mostly to aggregate measures and to a few well-known bailouts of troubled corporations. Finally, the records of foreign countries that have tried to channel investment into industries intended as mainstays of economic growth and competitiveness are decidedly mixed.

Everyone knows what the future growth industries will be. The current list includes computer-aided manufacturing and robotics, biotechnology, new nonmetallic materials, microelectronics, computers and communications. U.S. capital markets have been "picking" these winners quite effectively. An industrial policy intended to support future U.S. growth industries—under a critical industries rubric or some other policy approach—would have to do more. Specifically, it would have to search out cases where markets were not performing consistently well. These do exist. The time horizons of markets maybe shorter than desirable from a public standpoint (there are many examples in R&D, most notably in basic research but also in the development of generic technologies that could benefit a wide range of firms while being difficult to protect or monopolize). Bottlenecks are always possible (the unambiguous successes of foreign industrial policies often involve breaking bottlenecks). Response times can be excessively long (as in the case of the educational system, heavily dominated by government bodies which create inertia and slow responses, while also suffering from cloudy perceptions of future needs and opportunities). Such examples point to approaches that would not be explicitly sectoral.

The third of the policy orientations considered by OTA—policies that would provide generalized support for technology and infrastructural development, cutting across sectors of the economy—would reduce the leverage that special interests could exert by avoiding, where possible, policies with strong sector-specific thrusts, Instead, the tools of first choice would have more aggregate objectives—not only R&D and its diffusion, but education and training, open competition, structural adjustment. At the same time, sectoral policies would not be totally ruled out.

A variety of instruments are available:

- manpower training and retraining;
- new institutional mechanisms for technology development (emphasizing, for example, cooperative efforts among Government, business, and universities);
- incentives as well as direct funding for research and development;
- the infrastructure for diffusing available technologies as well as new R&D results through the U.S. economy (including technologies from overseas); and
- policies aimed at stimulating capital formation and investments in new and productive technologies.

By supporting the technological and human resources underlying competitive industries, interest groups angling for special favors would have fewer obvious and attractive targets, at least in terms of immediate financial rewards, Primarily future-oriented, this policy orientation is based on the assumption that the Federal Government can help build competitiveness by promoting evolutionary shifts in the economy, as well as by easing the negative impacts of adjustment on particular groups and regions.

In terms of R&D, the chief difference between private sector and Federal Government decisions lies not in the ability to evaluate opportunities but in the longer time horizons that Government can bring to such questions. Motivated by social rather than private returns to investment, unconcerned with capturing immediate rewards, public policy initiatives can be formulated with a longer term view than private corporations take. This is as true for mature industries like steel or automobiles as for "sunrise" or growth sectors. One of the tasks of an industrial policy oriented toward adjustment and infrastructural support would be to find such opportunities and develop appropriate responses, To develop an industrial policy capable of attacking problems of this sort, the Federal Government would need to understand industries and their workings on a concrete, practical level—the level of the shopfloor and the R&D laboratory as well as the boardroom, The Government does not now have this capability, a capability it would need in order to

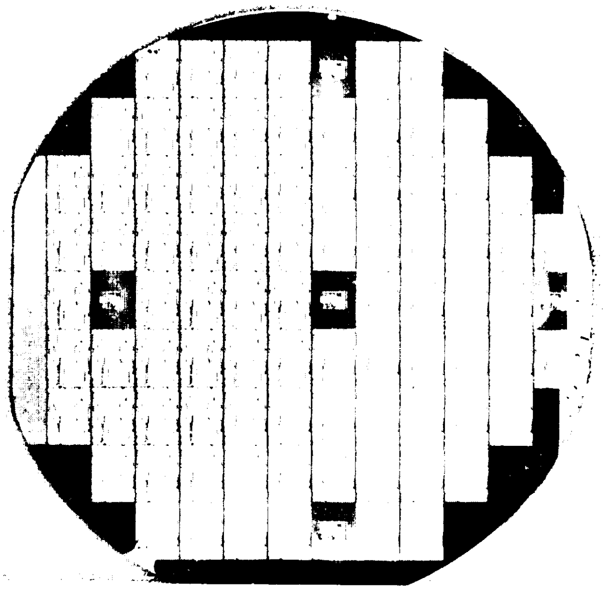


Photo credit Intel Corp

Silicon wafer after chip fabrication

implement with reasonable effectiveness *any* consistent and explicit industrial policy.

As pointed out above, competitive industries depend on the human resources available, while training and retraining are essential to economic adjustment. But what, specifically, should people be trained to do? What kinds of skills will be needed 20 years from now? What are the best ways of reaching people already in the labor force? Are institutional changes needed? Should the United States continue to leave training and retraining largely to local initiative, or is a continuing but redefined Federal role needed? These are among the questions with which this third approach to industrial policy would have to come to grips. They illustrate the need for a well-developed analytical capability within the Federal Government.

Like the first of these five policy alternatives, preservation of domestic markets, the fourth—promoting the global competitiveness of U.S. industries—centers on trade issues. However, *promoting* competitiveness implies an outward looking, export-oriented stance, an emphasis on openness in international trade coupled with stimuli for emerging, competitive sectors of the economy. Taking as its starting point the dynamics of international competitiveness—the rise and decline of industries over time—the global trade alternative would seek out, even accelerate, processes of change, attempting to keep American industries technologically and commercially ahead of their foreign rivals. To the extent that such policies hastened the decline of other portions of the economy, adjustment measures aimed at speeding resource flows out of these sectors, as well as cushioning the impacts of decline, might also be called for.

The global approach to industrial policy builds naturally on the traditional U.S. attitude that international trade benefits all parties and should be encouraged. It is the option furthest removed from the common notion of industrial policy as necessarily working *against* openness in trade. The Federal Government might not only continue to press for access for U.S. exports and investments in other countries, but reciprocally keep the domestic market open, while vigorously pursuing antitrust enforcement in the name of competition. Rather than resorting to bilateral trade negotiations, the United States could continue to work toward multilateral agreements aimed at reducing barriers to trade—in the current climate, primarily nontariff and indirect barriers, Tax incentives could be used to reward competitive, export-oriented firms, While more direct forms of export promotion might also find a place, direct measures always carry the danger of becoming subsidies—which, in the name of competition, this policy orientation would seek to avoid. Instead of protectionist measures for aiding troubled industries, the Government might attempt to manage decline and encourage restructuring,

If interest groups in the United States see the Nation opening its own markets to foreign goods and foreign investment—an intrinsic part of the global approach—without corresponding openings in other parts of the world, this option could invite a strong backlash, Even if the United States persuaded its trading partners to join in a thoroughly open and competitive world market system, the accelerated processes of domestic change might generate strong sentiments in favor of protection as well as adjustment assistance. Open world trade has many attractions as one element in a more cohesive U.S. industrial policy, but by itself might not offer advantages great enough or visible enough to attract the political support needed for implementation.

The last alternative is built around giving industry a free hand, where possible, in decisions that affect productivity y and international competitiveness. This alternative fits the recent mood in the United States: that Government involvement in economic affairs is counterproductive, that business activities should be deregulated, that markets work best and industries compete best when the Federal presence is minimized. Like the global trade alternative, it could mean more rapid rises and declines within the U.S. economy, Unlike that alternative, it implies less attention by Government to structural adjustment and less support for the efforts of American firms to export and/or invest overseas. Nor would protection against import competition be looked on with favor.

Such a policy approach would have to confront and resolve the following dilemma. American businessmen direct many of their complaints at foreign industrial policies that intervene in markets by, for example, encouraging mergers or allocating capital. Spokesmen for U.S. industry often hold, on the one hand, that industrial policies in other countries are not only unfair, but serve to tilt the competitive balance by strengthening or even creating comparative advantage. On the other hand, these same spokesmen frequently argue that Government policies could not do so here. Some of these statements may simply express a desire for unfettered (competition among all comers; in other cases, they appear to imply that government actions are counterproductive in the United States but not overseas, In any event, the fundamental question is: Given that foreign governments are not likely to abandon their industrial policies so long as they consider them useful, can the United States counter them simply by avoiding policy interventions?

More positively, then, this fifth policy approach might include tax incentives for capital format ion and investment, deregulation, and free competition. Control of inflation and macroeconomic stability would certainly remain a Federal responsibility. Closer examination of recent changes in tax policy points to one of the central issues raised by this alternative: Can Government really be a neutral arbiter of economic competition? Past experience gives little evidence in favor of the proposition.

The 1981 Tax Act seems on balance to have been a move away from neutrality in treatment of the various sectors of the economy. Noting that accelerated depreciation has varying consequences for manufacturers of consumer electronics and semiconductors—and that these two parts of the electronics industry are treated quite differently than producers of heavy electrical machinery, much less nonelectrical machinery—indicates some of the potential problems. Differential effects on various parts of the economy are an unavoidable con sequence of any industrial policy, and it may be better to confront such issues directly than try to avoid them, as this last alternative would in general do. While true neutrality can never be achieved, an industrial policy ostensibly intended to "get Government off the backs of business" would more likely end up rewarding those who could bring the most political pressure to bear. These interests would probably be able to perturb the policymaking process--tax policy being only one example--to their own benefit, aided by the illusion that the Federal presence was diminishing. Industries with less political strength or sophistication would, in a relative sense, fare less well.

Indeed, it seems wishful thinking to argue against Government involvement in economic affairs, although not against counterproductive or excessive involvement. The fact is, of course, that governments here and elsewhere do intervene; it is part of their job. Moreover, as economies grow more complex and more heavily dependent on advanced technologies, the forces that governments seek to modify or control may become more powerful, the need for government action greater. When, t~'here, why, how—the circumstances in which governments intervene, the effects of the involvement—are the crucial questions.

What does this mean for industrial policy in the United States? First, more effective policies toward industry in the United States will require relatively broad agreement on objectives. Second, the Federal Government would need to develop an analytical capability adequate to the task of reaching these objectives. Both are efforts to which Congress could turn its attention. The first is largely a political task, the basis of the argument that our standard of liv ing depends on the international competitiveness of industries like electronics. The second demands that Government go beyond the largely static and abstract economic perspective that in many agencies is now called on to justify policies adopted for other reasons.

The political environment in the United States makes movement toward a more consciously developed industrial policy—following any of the five alternatives outlined above—not only slow and painful, but an endeavor that risks being turned to ends far removed from economic efficiency. (This is not to imply that economic efficiency is the only goal of industrial policy, but that one of the purposes of a more coherent approach would be to bring this and related objectives closer to the forefront.) But even where decisions are made largely on political grounds—as will frequently be the case—a more explicit industrial policy could help frame the questions, bound the responses, increase the probability that individual policy instruments function as expected and intended. Given an international economy populated by countries experimenting with industrial policies, and learning to use them more effectively, a pragmatic orientation by the United States, grounded in empirical analysis, could be viewed—by Congress and the Federal Government as a whole, and by both parties—as a vital support for our own economy, Such an attitude toward industrial policy would help to ensure that the U.S. electronics industry and other high-technology sectors would get their fair share of the resources needed to compete effectively in world markets, It is also the best hope, in the longer run, for older industries ranging from primary metals to machine tools and textiles.

CHAPTER 2

Introduction

Contents

CHAPTER 2
Introduction

The U.S. electronics industry provides examples that can support almost any perspective on competitive trends in the American economy over the past decade. That portion of the industry manufacturing computers has been a champion of U.S. economic strength both domestically and internationally. Here and abroad, American computer firms—particularly IBM--have been symbols of technological prowess, market power, and multinational marketing and production. In Europe, U.S. computer manufacturers have been models to be emulated—for indigenous companies like ICL in Great Britain, or for joint ventures such as C II-Honeywell Bull in France—and targets to be displaced with the aid of national industrial policies. In Japan, American computer firms have been explicitly depicted as the enemy—IBM as a stateless, global giant, with Japanese firms urged to mount fierce efforts against it. Meanwhile, in the United States, the Department of Justice had in ***1969*** begun an antitrust suit aimed at dismembering IBM, a suit that was finally dismissed 13 years later.

American consumer electronics firms have been pictured much differently-particularly the old-line manufacturers of televisions and other home entertainment equipment, such as Zenith and RCA, Many firms in this part of the industry have seen themselves as victims of unfair trade practices by overseas rivals, primarily Japanese. Foreign firms selling TVs in this country have been accused of dumping (and found guilty of this), attempted monopolization, and of receiving subsidies from their own governments. To other observers, the U.S. consumer electronics industry has been a victim of management failures, has lacked the will to compete internationally, has ceded some segments of its markets too easily to imports, and has lagged in adopting manufacturing methods that could have cut costs and increased the quality and reliability of its products,

Semiconductor manufacturers in the United States have, over the past several years, pointed to the consumer electronics industry as a possible harbinger of their own fate if the U.S. Government does nothing to support them in their competitive battles with foreign (i. e., Japanese) rivals. At the same time, American semiconductor firms share with our computer manufacturers a deserved reputation as worldwide leaders in technology, innovation, and entrepreneurial zeal—a reputation which the ***1980-83*** round of new startups in Silicon Valley can only enhance.

These three portions of the electronics industry—computers, consumer electronics, and semiconductors—are the focus of this report. But other parts of the industry could illustrate many of the same themes, Electronic component production—switches, resistors and capacitors, printed circuit boards—has been moved to offshore locations as part of the response to competitive threats from imports. Professional and industrial equipment—instrumentation, industrial process control, medical electronics—is a continuing U.S. strength, but again the technological leads that American firms once held have narrowed. In telecommunications, American firms have lost out in several promising developing country markets. While boundaries between information processing and information transmittal have been blurring for years, and communications is certainly one of the central electronics-related portions of U.S. industry, this report touches on communications only in passing—not because this portion of the industry is unimportant, but only to keep the study to manageable proportions.

The breadth and diversity of the electronics industry contrasts with industries such as steel, which are often pictured as monolithic. Even here, however, specialty steel and nonintegrated "minimills" have proved notable exceptions to the commonly accepted notion of declining U.S. competitiveness.[1] Steel is an old,

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[1] *Technology and Steel Industry Competitiveness* (Washington, D. C,: U.S. Congress, Office of Technology Assessment, OTA-M- 122, June 1980); *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles* [Washington, D, C.: U.S. Congress, Office of Technology Assessment, OTA-ISC-135, July 1981),

established industry compared to electronics; yet the electronics industry has roots going back to the early part of the century, in contrast to biotechnology and genetic engineering —for which international competition has hardly begun-though here, too, there are roots in fields like plant breeding and pharmaceuticals. Emerging industries like biotechnology are important for *future* economic growth; *electronics is critical right now*. Moreover, lessons learned from electronics might apply to older, "mature" industries such as steel, as well as to nascent sectors like biotechnology.

What can be learned from electronics, particularly the last 10 or 15 years? That is one of the questions this report attempts to answer. Is the apparent decline of the American consumer electronics industry irreversible? Are the threats to U.S. computer and semiconductor firms real, or are they better considered natural consequences of the growth and maturing of these portions of the industry? How have policies adopted by the Federal Government affected the industry? How do public policies here differ from those of foreign governments, both in their forms and in their effects? To what extent have foreign industrial policies succeeded in strengthening the electronics industries of other countries, in affecting the investment and export strategies of American firms, in replacing tariff and nontariff barriers to international trade with less visible but no less effective constraints? Can governments create comparative advantage? If the United States were to pursue a more consciously developed industrial policy, what should be the objectives in the context of a high-technology industry like electronics? How might the policy tools be formulated and implemented?

Electronics as a High-Technology Industry

The electrical equipment and electronics industries have been known for technical leadership and innovation since their beginnings at the close of the 19th century. While progress in electrical equipment—that which produces or utilizes electric power—is now mostly incremental, electronics—referring to devices and systems that operate on the information content rather than the power transmitted by an electrical signal—remains a technology in rapid flux. Developments in electrical machinery such as practical applications of superconductivity can still promise significant gains in the efficiency of energy conversion and power transmission; advances in electronics will have effects that reach further, and affect the American economy—indeed, society as a whole—more deeply. An obvious case will be the continuing applications of distributed computing. The impacts will be broad as well as deep–manufacturing industries as a whole will be transformed by applications of electronics to automated production equipment. Productivity will rise, the skill mix needed by the work force continue to shift, In service industries, office and workplace automation will also displace people while creating new jobs needing new skills.

Patterns of Development

The portions of the electronics industry where American firms remain preeminent are just those where the pace of technological change continues to be most rapid—e.g., computers and semiconductors. The United States has been a leader in both the technology and the science that underly these sectors: electronic properties of solids and the materials sciences more generally; electrical engineering; computer science and software engineering—and also in the development of new and successful commercial products, Nonetheless, although Americans have been among the leaders in the technology and science of electrical machinery and electronics, many of the important prewar developments—e.g., understanding of band gaps in solids and the dynamics of conduction--originated in Europe.

The Second World War pushed electronics to the forefront of engineering science, creating a momentum that still exists. Developments in radar and computing, both analog and digital, proved especially significant.[2] Again, many of the advances came from Europe, particularly the United Kingdom, where considerable strides were made in radar technology, s However, American industry was in a far superior position to capitalize on these new technologies in the aftermath of the war, By the late 1950's, the United States had what appeared to be an unchallengeable lead in fields such as digital computers and semiconductors.

Hindsight shows the more temporary nature of this lead, the result of an infrastructure for technology and science that emerged from the war not only intact, but strengthened, coupled with an industrial base that was likewise far stronger than in countries that had been either allies or enemies a few years earlier, The push created by new technologies, coupled with the pull of war-starved markets in the United States—markets that were eager recipients of the products of these technologies, rather than devastated—created an environment for growth and innovation unmatched in the rest of the world. Meanwhile, trading partners and potential competitors such as Japan, Great Brit- a in, and West Germany had to rebuild. Nations like Taiwan, South Korea, Brazil, and Mexico —now factors in at least the lower technology segments of the electronics industry—were, before 1960, simply irrelevant,

Rising Competition

Much of the impetus this strong postwar start gave to the U.S. electronics industry has now dissipated. Gloomy predictions for the future competitiveness of even the strongest sectors, such as semiconductors, have been heard. The business press reminds us incessantly that Japanese firms captured 40 percent of the U.S. market for 16 kilobit random access memory circuits (integrated circuits called 16K RAMs), more than 50 percent for 64 kilobit circuits. Market analysts predict that Japanese manufacturers could have 30 percent of the world computer market by the end of the 1980's.[4]

In the past, competitors in countries like Japan relied to considerable extent on electronics technology first developed by U.S. firms; now they have independent capabilities and need not follow paths broken here, As Japanese electronics companies have become less dependent on American technology, their exports of microelectronic devices to the United States have grown faster than their imports of U.S. semiconductors. And, where once they exported mostly discrete semiconductors and the simpler integrated circuits, now firms based in Japan are exporting—or assembling in the United States—large-scale integrated circuits

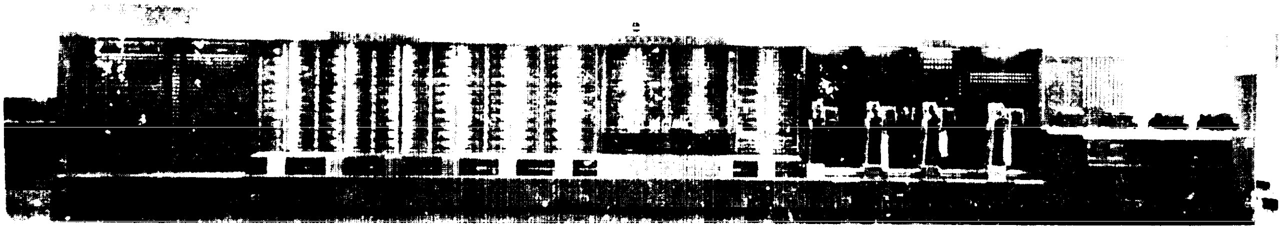

Photo credit Smithsonian *Institution*

Harvard Mark I electromechanical computer, 1939-44

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[2] H. H, Golds tine, The Computer *From Pascal to von Neuma In* (Princeton, N.J.: Princeton University Press, 1972), especially Part Two.

[3] J Kraus, "The British Electron-Tube and Semiconductor Industry, 1935-62," *Technology and Culture*, vol. 9, 1968, p 544.

[4] "No. 1's Awesome Strategy, " *Business Week*, June 8, 1981, p. 84.

(ICs) at the leading edge of the technology. * Japanese computer firms are not yet exporting large numbers of systems to this country, but clearly intend to try. The government-supported fifth-generation computer project is only one recent signal of the seriousness of Japan's efforts.

Needless to say, this resurgence by America's competitors has not been an overnight phenomenon, nor should it be unexpected. The Japanese presence in consumer electronics began to be felt in the 1950's with the transistor radio; by the late 1970's, firms based in Japan held strong positions worldwide in audio equipment, digital watches, calculators, and TV receivers. Their burgeoning capability in high-technology electronics builds naturally on earlier developments.

Interactions within the industry often stimulate technological and commercial developments; ICs have made possible new families of consumer products, such as hand calculators, as well as cheaper and more powerful computers. Semiconductor devices are becoming indispensable for the products of more and more industries outside electronics; emissions control systems for automobile engines depend heavily on microprocessors and related devices; more than half the cost of an airplane can be electronics. As one result, electronics technology—and particularly microelectronics—has come to be widely regarded as critical to a modern, competitive economy, hence access to this technology a vital strategic weapon of national industrial policies. Government attention to computer industries goes back to the early years of this technology; a number of countries began in the 1970's to subsidize semiconductor research and development; others have felt applications of ICs—rather than capability for designing and manufacturing the circuits themselves—to be more important, and have channeled government funds to this end.

Technological and Structural Change

The rather complex structure of the electronics industry in the United States is described in more detail in chapter 4. The diversity of the industry has already been pointed out; there are more than 6,000 electronics firms in the United States. Only a small fraction could legitimately be called "high-technology" companies. But this smaller fraction—companies building computers, designing and manufacturing large-scale ICs, supplying capital equipment such as microprocessor development systems or plasma etchers, developing software packages for computers—is a driving force for the rest of the industry, as well as for much of the rest of the economy.

By the standards of computers or microelectronics, consumer electronics cannot be considered high technology. Yet the manufacture of cathode ray (picture) tubes is a sophisticated process, and TV receivers are now designed around ICs, some of rather advanced design. Digital TV and digital audio are on their way to commercialization, while consumer products are providing some of the first applications of speech synthesis; the same will be true of voice recognition. Solid-state displays as replacements for picture tubes are a demanding technical challenge. Indeed, the low costs required for practical consumer applications create technological constraints that are, in their own way, more severe than those imposed on designers in portions of the industry more commonly associated with high technology. At the same time, consumer electronics products such as table radios or conventional TV receivers are simple enough that they can be manufactured and marketed competitively by firms in industrializing countries such as South Korea and Taiwan; the same is true of many types of discrete semiconductor devices and small-scale ICs.

As such examples indicate, even consumer electronics is changing more rapidly than industries like steel or automobiles. Despite the pace of technological change, electronics is not only much larger and better established but

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*Small-scale ICs incorporate of the order of hundreds of circuit elements, large-scale ICs of the order of thousands to tens of thousands, very large-scale ICs—e. g., 64K RAMs, 16 bit microprocessors—of the order of a hundred thousand. See ch. 3.

more stable and predictable than, for instance, biotechnology. But again, the industry is far from monolithic. Consumer electronics has origins in the 1920's, when radio broadcasting became widespread. The computer and semiconductor sectors are basically post-world War II phenomena, though many of the leading companics-e. g., IBM, Western Electric, Motorola —have prewar origins. Thus, the three portions of the industry on which this report concentrates include examples of both well-established, "mature" sectors, and more volatile, rapidly growing, technology-driven sectors. There are lessons to be learned from each.

One of the lessons that even a superficial look at the computer industry teaches is the importance of marketing, sales, customer support and service, and related nontechnical factors even in a technology-driven industry. IBM has been a dominant force worldwide in computers since the beginning of the 1960's. But IBM's strength has been—not only hardware—but marketing, software, and customer support. In many cases, IBM's competitors have offered considerably more computing power for a given price, but IBM has only slowly lost market share because of its many strengths beyond hardware technology. In some contrast, other U.S. electronics firms have sometimes seemed to rely primarily on advanced technology to win markets. As other countries catch up in technical capability, a technology-based marketing strategy may no longer be enough. In microelectronics, for example, the ability to pack many circuit elements onto a single integrated circuit chip is still important, but competition is more and more a matter of the systems which the ICs comprise or can be integrated into. Moreover, as microelectronics technology continues to evolve, one path to competitive success will be the creation of new end-products incorporating ICs. The skills required for this differ from those needed to establish and maintain leadership in the underlying technology, as shown by the examples of pocket calculators or digital watches—and also by the failure of the West German electronics industry, which has access to excellent fundamental technology, to develop into a strong international competitor,

Although many of the major technological innovations in electronics have originated in the United States—e.g., color TV, computer time-sharing, most of the important developments in semiconductor devices—American firms have not always been the leaders when it comes to product innovations that depend, not necessarily on new technology, but on product planning, engineering design, production skills, and marketing. Although transistor radios were developed in the United States, it was Japanese products that reshaped the entire audio market.[5] Analogous strategies—concentrating on product design and engineering, originally perhaps imitative, rather than high technology—have led to success by the Japanese in fields such as cameras and automobiles. Japanese firms, aided by their skills at low-cost manufacturing, have recently done much better at this than companies in the European nations with which the United States also competes.

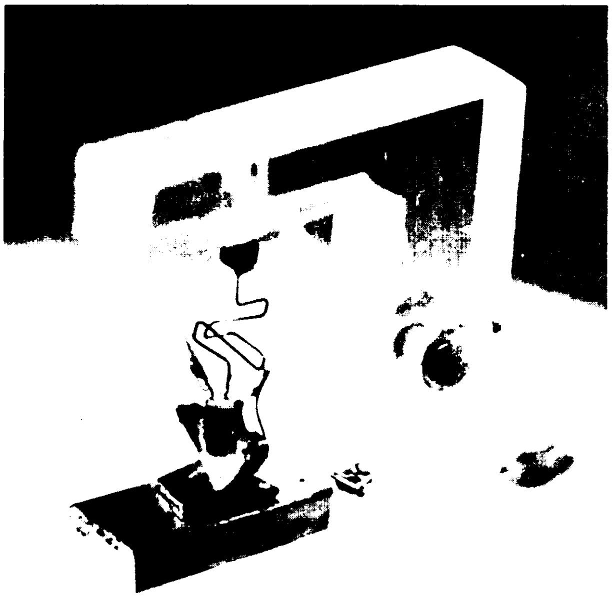
Photo credit: Bell Laboratories

The first transistor, 1947

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[5] G. R. White, "Management Criteria for Effective Innovation, " *Technology Review*, February 1978, p. 15.

Thus, overall, the cushion that greater technical capability once provided U.S. products is eroding. And of course, in some technologies the United States has never had an advantage. In optical communications, for example, Japanese companies have always been near the forefront. Leadership in electronics equipment used for certain types of scientific research has long resided overseas—one example being electron microscopes. That this need not always be a handicap is shown by current developments in electron-beam lithographic equipment. Electron-beam lithography is now essential for making the masks that are, in turn, used to fabricate large-scale ICs (in a few cases electron-beam lithography is applied directly in fabricating the chips). Although the equipment has its roots in technology developed for scanning electron microscopes—virtually all of which are designed and built in Europe or Japan–the United States has not thus far been handicapped. Several U.S. firms are, in fact, leaders in electron-beam lithography,

The Importance of Competitiveness

OTA's earlier comparison of steel, electronics, and automobiles provides background and illustrations for many of the questions concerning competitiveness, economic efficiency, and industrial policy that remain of concern to Congress, to employees of the U.S. electronics industry, and to the public at large.[6] The practical meaning of "competitiveness" in the context of electronics is discussed in chapter 5. In essence, the term refers to the ability of electronics firms located in one country to design, develop, manufacture, and market their products—domestically and by exporting—in competition with foreign enterprises. (For some purposes, subsidiaries of foreign firms that produce and sell electronics products in the United States are considered part of the U.S. industry, but in general the consequences of foreign direct investment must be treated on a case-by-case basis.)

The competitiveness of an industry like electronics is important not only intrinsically, but also because of interactions with other parts of the economy. Still, there is no meaningful way of measuring the competitiveness of an entire economy, Competitiveness must be examined on an industry-specific basis, although it can also be difficult to generalize about an industry as large and diverse as electronics, which for many purposes must be further disaggregated.

Considering the electronics industry itself, competitiveness is one of the factors that determines, among other things: employment patterns within the industry (size of the work force, wage levels, skill mix); balance of trade for electronics products; and the value that purchasers of electronics products receive for their money. Electronics products are used by many industries—whether components such as semiconductors costing a few cents, or capital equipment that sells for hundreds of thousands, even millions, of dollars—and can affect their competitiveness. Computers are the most prominent example, but are far from alone. Nor do they always fill the role of capital equipment; many smaller computers are integrated into more complex electronic systems. Industrial process control, scientific equipment, office machines, and communications apparatus are further examples where electronics or electronics-related products can affect the competitiveness—more generally, the economic performance—of other parts of the economy.

On the broadest levels, then, the competitiveness of the electronics industry affects aggregate employment levels, trade balances (more importantly, the ability to pay for imports), and living standards. How this industry fares in in-

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[6] *U. S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles,* op. cit.

ternational competition influences the types of jobs available, the country's military strength, and overall rates of economic growth. In turn, the health of the aggregate economy, the quality and quantity of employees available to firms in the industry, the market provided by the military, are among the factors that determine the competitiveness of American electronics firms.

Ultimately, however, the competitiveness of any industry—in the United States or elsewhere—depends on the efforts of individual firms. Policies adopted by the Federal Government influence these efforts in many ways, often indirectly. Foreign industrial policies are part of the same context. Among the more important domestic measures are those dealing with taxes, Government spending, and monetary policy, as well as research and development (both basic and applied), international trade, and many types of regulatory policies. Sometimes Federal policies affect only one or a few industries—e.g., regulation of TV broadcasting. others are broader. Tax treatment of income from overseas investments affects firms with multinational operations regardless of industry. Some policies affect the entire economy—macroeconomic policies or those dealing with education.

Generally within the province of individual firms are factors associated with manufacturing—including costs, the quality and reliability of finished products, and decisions to manufacture domestically or overseas (offshore assembly, wherein some but not all manufacturing operations are carried out in other countries to take advantage of low labor costs, is common in electronics). The ability to raise external capital—whether equity or debt—and to generate capital for reinvestment through sales, is crucial to firms in any industry, but particularly when markets grow as fast as those for semiconductors and computers. As with offshore manufacturing, which is favored by U.S. tariff laws, sources and costs of capital for electronics firms are affected by public policies—tax policies and many others, including those aimed at controlling inflation.

With respect to *consequences* of shifts in competitiveness, employment receives the most attention in this report—both in terms of job opportunities and in terms of the skills needed. This and many other topics are discussed, where possible, in the context of international comparisons drawn between the United States and its trading partners and rivals—usually one and the same. Japan, at present, is the home of the strongest competitors, in electronics as in many other industries. Japanese firms are likely to continue to be the chief rivals for U.S. electronics manufacturers over the remainder of the century, But several European nations have strong technological bases in electronics, as well as supportive governmental policies. And rapidly industrializing countries will rise in competitive strength in the future; TVs from Taiwan and South Korea are growing factors in the U.S. market,

Industrial Policy

Public policies that affect competitiveness can be considered elements of "industrial policy. "[7] The term is intended to embrace Federal Government policies of whatever origin that affect the activities of private industry, particularly its competitiveness, productivity, and economic efficiency,

The United States does not at present have a coherent or consciously developed industrial policy, in contrast to nations such as Japan or France, This is not to imply that industrial policies like those of the Japanese are necessarily effective in promoting international competitiveness, but simply that the United States has not *attempted* to develop a coherent industrial policy. Instead, policies affecting industries—

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[7] Ibid,, ch. 8.

and their competitiveness-have been formulated and implemented on an ad hoc basis. As a result, industrial policy in this country has been fragmented, sometimes contradictory, often inconsistent and lacking in continuity.

These characteristics of U.S. industrial policy—reflecting our pluralistic political traditions—have sometimes served the American economy well, lending flexibility and the potential for innovative response to changing circumstance. But the OTA report cited above concluded that this approach to industrial policy—while it might have been well-suited to an earlier period when U.S. industries were relatively isolated from foreign competition, and possessed advantages in technology—in more recent years has too often contributed to declines rather than improvements in competitiveness.

Foreign industrial policies often include direct subsidies to industries—perhaps to maintain employment, or for reasons of national security. Export incentives and protection for domestic industries are common. Foreign investors may face a complex set of carrots and sticks. Cooperation among nominally competing firms may be encouraged. Governments in some countries have engineered "national champions" in attempts to increase competitiveness. Restrictive business regulations may be relaxed, government procurements channeled to favored companies, which in some cases may be publicly owned. Nationalized enterprises-an increasing presence in sectors like banking or energy production although not a major factor in electronics—couple industry and government even more tightly.[8] American businessmen increasingly complain of the difficulties involved in trying to compete with such ventures, which need not make profits, or may have unusually long profit horizons.

The variety and complexity exhibited by present-day national industrial policies—particularly the difficult questions of when government support measures should be judged subsidies that distort international trade—have hampered efforts by international organizations such as the General Agreement on Tariffs and Trade (GATT) to fit remedies for many of the possible means of "unfair" competition into the body of international trade agreements. As one result, bilateral agreements are becoming more common—exemplified by the Orderly Marketing Agreements negotiated by the U.S. Government to control imports of TV receivers from several Far Eastern nations.

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[8] For a survey, see R. P. Nielsen, "Government-Owned Businesses: Market Presence, Competitive Advantages and Rationales for Their Support by the State, " *American Journal of Economics and Sociology, vol. 41, 1982,* p. 17.

Issues

As emphasized above, a vast number of Federal Government policies in some way affect the international competitiveness of the U.S. electronics industry. Among the more important are:

- Government support for commercial (as opposed to military) R&D, ranging from tax policies intended to increase levels of research spending or encourage commercialization to direct support;
- trade policies dealing with exports as well as imports—e.g., the ways in which measures that affect the the electronics industry fit within the overall framework of U.S. foreign economic policy, the meaning of "reciprocity" for an industry like electronics, barriers to investment in foreign electronics industries;
- Government policies affecting capital formation for the economy as a whole, and, more directly, the ability of firms in the electronics industry to generate and attract capital for expansion;
- regulatory policies that may affect the competitiveness of the U.S. electronics industry—e.g., antitrust enforcement;

- the availability of enough people with adequate levels of education and training, particularly engineers and skilled workers such as technicians, as well as the Government role in supporting technical education;
- economic adjustment policies intended to encourage shifts of resources from declining industries to those with better prospects for future competitiveness, and to aid workers, communities, and regions that have suffered because of shifts in international competitiveness—e.g., in consumer electronics.

These examples all involve complex issues, with effects that may differ among various parts of the electronics industry, and from firm to firm. The remainder of this report attempts to deal with such complexities; at the same time, of course, public policies continue to evolve and change—witness the 1981 tax act, or the expiration in July 1982 of the Orderly Marketing Agreements covering imports of color TVs from Korea and Taiwan. The objective is not to be exhaustive but selective—to try to differentiate the factors influencing competitiveness in electronics that are primarily under the control of managements of individual firms from those that are strongly affected by the Federal Government, and to examine the latter in the context of a high-technology industry that has been one of the mainstays of U.S. competitiveness during the postwar period.

CHAPTER 3

Electronics Technology

Contents

List of Tables

List of Figures

CHAPTER 3

Electronics Technology

Overview

This chapter outlines the technology on which the consumer electronics, semiconductor, and computer industries depend, covering them with enough depth to provide background for discussions later in the report concerning the role of technology as a force on competitiveness. Except for occasional examples, competitiveness itself is left to later chapters.

The primary function of electronic components and systems is to manipulate and transmit *information* in the form of electrical signals—either analog or digital, The transmission and utilization of electric power are integral to these processes, but constitute only secondary functions of electronic equipment. Even in the case of a 50,000-watt radio broadcasting station, the high power simply increases the area coverage of the information in the signal. The information manipulated and conveyed via an electronic system can range from a simple sequence of numbers—e.g., a zip code, or the balance in a checking account—to the sounds conveyed by radio, images such as television pictures or weather maps, or the information contained in radar or sonar signals.

Changes in electrical voltage are the most common carrier of information in electronic systems. In an analog system, the signal takes the form of a voltage or some other electrical parameter that varies continuously over a range, while *digital* information is encoded in the form of a string of binary “bits.” Each binary bit can take on one of a pair of discrete values, again usually voltages. The magnitude of these is unimportant, so long as they can be distinguished from one another. A bit can be visualized as having values of “O” or “l, ” or “+” as opposed to “ – .“ In a digital circuit, the signal normally takes the form of a string of discrete voltage levels—e.g., any voltage between –2 and i-l volts might represent a binary “O, ” any value from + 2 to + 5 volts, a binary “1. ”

Regardless of the simplicity or complexity of the information content in a signal, either analog or digital technology can, in general, be employed. The choice turns on the practical advantages and disadvantages for a given application. A complex system may use analog circuitry for some tasks, digital for others. In geophysical exploration, for instance, an analog signal—essentially a mechanical pressure pulse or sequence of pulses—is transmitted into a geological formation. The reflected pulse from the subsurface strata is sensed by transducers analogous to microphones. These transducers respond to the mechanical energy of the reflected pulse by generating a proportional analog electrical output. Analog-to-digital converters—typically integrated circuits (ICs)—then convert these signals to digital information that can be processed and analyzed by a digital computer.

Both analog and digital technologies have a place in the three sectors of the electronics industry covered in this report, But while most consumer electronics equipment is still based on analog technology—radio and TV receivers, phonograph records, magnetic tape players—virtually all computers process information in digital form. At the same time, computer peripherals such as terminals and printers contain analog circuitry, while digitally based consumer products are becoming more common. Semiconductor devices come in both analog (often termed “linear”) and digital varieties. A few ICs combine analog and digital circuitry on the same “chip. ”

Consumer Electronics

The most common consumer electronic products are radios, TVs, and audio equipment such as "stereo" systems. Electronic toys and games, electronic watches, pocket calculators, and home computers are other familiar examples. These are all "systems" in the sense that they contain more than a single electronic component, but some are much more complex than others. An electronic watch may consist of little beyond a single IC and a display—itself a solid-state device—plus a battery, Television receivers contain several hundred components. Video cassette recorders (VCRs) are complex mechanically as well as electronically,

Radio broadcasting provided the foundation for the development of the consumer electronics industry. Despite a real cost much higher than today, there were well over 10 million radio receivers in use in the United States by ***1930,*** with annual sales exceeding ***$1*** billion. '

Research and development (R&D) on television began in the 1920's, with limited broadcasting prior to World War 11. Large-scale commercialization had to await the end of the war, but by 1949 5 million TV sets were sold in the United States—all black-and-white. Color television—for which most of the early work was performed by RCA—followed the next year, but color TV sales in the United States did not pass the 5 million mark until 1967, and first exceeded black-and-white sales in 1972.[2]

With more than ***11*** million color sets sold in 1982, and about half as many black-and-white sets, the TV receiver remains the largest selling consumer electronics product, accounting for nearly half the dollar value of consumer electronics sales in the United States (ch. 4). Monochrome TV sales have been rather static for a number of years, with the market for color sets expanding only slowly; cable TV and direct satellite reception may spur future sales, but much of the growth in consumer electronics markets is now in new generations of products, notably VCRs. Still, in many respects —e.g., the relatively standardized design approaches and critical importance of production costs—color TV continues to typify consumer electronic technologies.

Television signals are broadcast via amplitude modulation of a high-frequency carrier signal, much like AM radio, But the bandwidth requirements for TV are far greater—about ***6*** MHz, versus 10 KHz for AM radio. Bandwidth, which is expressed in terms of frequency—6 MHz being equal to **6 x** 10^6 cycles per second, 10 KHZ to 10 x 10^3 cycles per second—is a measure of the *rate* at which information can be conveyed, hence must increase with the *amount* of information in a signal. The pictorial image in a TV signal has a much higher information content than sound, hence television's high bandwidth requirements, In principle, the analog information in either a radio or a TV signal could be conveyed in digital form without changing the bandwidth requirements greatly.

A home antenna receives the amplitude-modulated TV signal at a microvolt level (1 microvolt equals 10^{-8} volts). To produce a visual image, this signal is amplified to control an electron beam which scans the front of the picture tube—or cathode-ray tube (CRT) —forming a new image **30** times each second (the number of frames per second can vary abroad). The circuitry in a TV receiver is quite complicated (fig. 1) and now entirely solid state (the chassis includes both discrete transistors and ICs) except for the picture tube, The CRT is the most expensive single component in the set, accounting for about 40 percent of the cost. Producing picture tubes is a highly specialized activity; smaller firms often buy CRTs from manufacturers such as Zenith or RCA,

Conventional picture tubes are not only bulky and expensive, but account for much of the power consumed by TV sets; in Japan and Europe particularly, consumer electronics manufacturers have devoted considerable effort to reducing power consumption. This not

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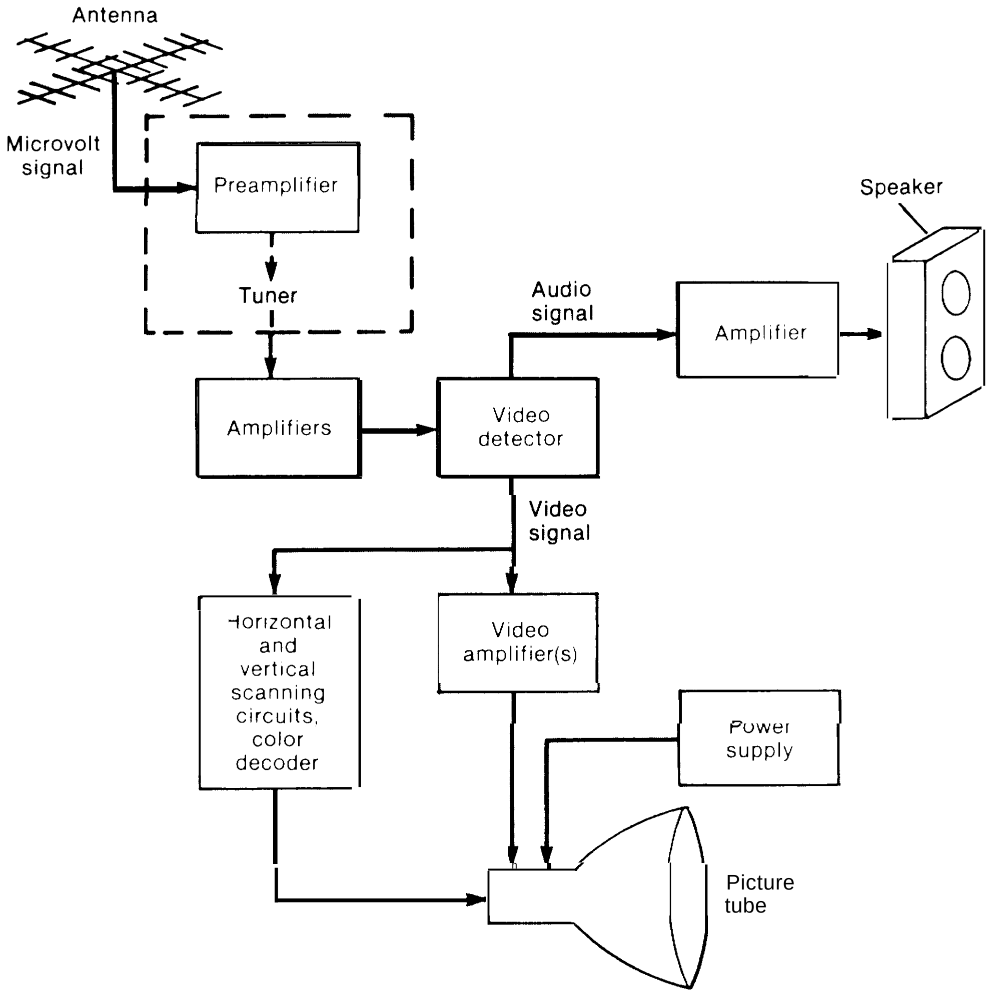
[1] *Electronics* Apr. 17, 1980, pp. 44, 78.

[2] *The U.S. Consumer Electronics Industry* [Washington, L). C,: Department of Commerce, September 1975), p. 20,

Figure 1.—Simplified Diagram of TV Receiver Componentry



SOURCE" Adapted from K Henry (ed), Radio *Engineering Handbook,* 5th ed (New York McGraw Hill, 1959) ch 22

only reduces consumer electrical bills, but can lead to more reliable operation—one of the advantages that TVs imported from Japan have enjoyed over the years (ch. 6). The drawbacks of conventional picture tubes—principally bulk–have stimulated considerable R&D aimed at flat-screen television displays. Flat screens are not yet practical, but continued progress in solid-state technology will doubtless lead to eventual success.

Before 1960, most of the significant technical developments in television originated in the United States, but more recently important advances have come from Japan as well.[3] Television technology is now well diffused internationally, and no one country appears to enjoy a technological advantage. Product innovations continue to come from U.S. firms, but also from other parts of the world. European consumers, in particular, are often attracted by

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[3] Ibid., p. 27; also "International Technological Competitiveness: Television Receivers and Semiconductors, Charles River Associates Inc., Boston, Mass., draft report under National Science Foundation grant No. PRA 78-20301, July 1979, app. 2A. Studies of technological developments in an industry such as this are inevitably judgmental, and often biased by familiarity with one's own country.

new and different product features such as multiple image displays (several channels shown simultaneously on one screen). These have become important to product development strategies of firms in Western Europe. Continued progress in large-screen projection TVs has been stimulated by competition between Japanese and American producers for what could be a large new market. Japanese firms have been leaders in reliability, and may have tended to emphasize R&D directed at automation—and at rationalization of the manufacturing process in general—more than European or American producers (ch. 6). In particular, Japanese TV makers were leaders in adopting transistorized chassis designs in the late 1960's and in automating the insertion of discrete components such as transistors, ICs, capacitors, and resistors into printed circuit boards.

Although TVs still account for much of the consumer electronics market, they are a mature product in the sense that most American homes already have one or more. Thus, the great proportion of sales are now supplements or replacements. The market for VCRs, in contrast, is expanding rapidly (ch. 4), US. sales of VCRs during 1980 were less than a million units—all imported; sales nearly doubled in 1981.

Video recording on magnetic tape was pioneered in the United States by Ampex.[4] Although Ampex and RCA continue to manufacture video tape recorders for broadcast applications, consumer VCRs were developed largely by Japanese firms (ch. 5)–which now build about 95 percent of the world's VCRs. In Europe, Philips has a few percent of the market, but all the VCRs sold in the United States come from Japan.

While the commercialization of VCR technology by Japanese manufacturers is one sign that Japan may be taking over product leadership in consumer electronics, video disks thus far present a mixed, perhaps contradictory, picture. The optical video disk system developed in Europe by Philips reached the consumer market first. In the Philips system, a laser reads the digitally encoded signal on a spinning disk; microscopic depressions in the disk represent binary "0s" or "1s." While an elegant technical achievement—and one with potential for high-density digital data storage of other types (e.g., in conjunction with computer systems)—the optical video disk sold in the United States by Magnavox has not been a commercial success. RCA's video disk, introduced early in 1981, functions on analog principles—more like a phonograph record. Yet a third system, developed in Japan by JVC, may eventually reach the marketplace. As compared to VCRs, disk systems are cheaper but can only play back, not record. While the technology is evidently in hand, it is too early to tell how large the market for home video disk players will be–e.g., whether it will rival that for VCRs—or which systems will survive in the marketplace.

A number of trends in consumer electronics —e.g., recent introductions of "component" TVs analogous to component stereo systems, along with games and low-end home computers that use a conventional television as the display–point toward the eventual development of more-or-less integrated home entertainment systems. Such systems might incorporate TV and audio reception and reproduction, including various kinds of information services, along with applications of computing capability—not only games, but recordkeeping, home security systems, control of household appliances, and regulation of heating, ventilating, and air-conditioning systems. Such developments do not depend heavily on technological advances except as low production cost is necessary for mass market acceptance.

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[4] "Interactions of Science and Technology in the Innovative Process: Some Case Studies, " final report, Battelle Columbus Laboratories, National Science Foundation Contract No. NSF-C 667, Mar. 19, 1973, ch. 1 2.

Semiconductors

Strictly speaking, the term “semiconductor” refers only to the ***materials*** from which semiconductor devices are made. Such materials have electrical conductivities intermediate between good conductors like copper and insulators such as glass. Silicon is the most common semiconductor material—virtually all ICs, and most discrete transistors, are based on silicon, In this report, the term “semiconductor” will be loosely applied to the products of the “semiconductor industry” as well as to the materials that are the starting points for these products. The broader designations “microelectronics” or ‘‘microelectronic devices’ include semiconductor products-which have replaced vacuum tubes in nearly all applications—as well as other types of solid-state devices that process, manipulate, or display information.

The most familiar example of a vacuum tube application that solid-state technology has not yet been able to match is the CRT—not only the common TV picture tube, but the display screens of computer terminals. In other cases, solid-state devices are not only much smaller than vacuum tubes, but cheaper, more rugged, and longer lasting. They also offer higher operating speeds; indeed, on almost any measure of performance, microelectronic devices offer order-of-magnitude improvements over the components they have replaced. Modern digital computers would be quite impossible without semiconductors. Although a computer otherwise like current models could, in principle, function with tubes instead of ICs, such a machine would fill a building and probably not execute a single program without one or more tubes failing. Solid-state circuits have made ***practical*** many electronic systems that would earlier have been too big, too costly, or otherwise in fact unthinkable.

Although virtually all commercial microelectronic products are now made from semiconducting materials, considerable R&D has been devoted to classes of solid-state technologies with potential for transmitting and processing information based on principles other than conventional semiconductor physics. Such devices might function on magnetic or optical principles, rather than being strictly “electronic, although the materials involved are sometimes semiconductors. * Boundaries between electronic, magnetic, and optical technologies tend to blur as device technologies move toward microstructural and submicrostructural size ranges. (Microstructural sizes are large compared to interatomic distances but small compared to objects that can be easily seen and handled, like an IC chip itself; the feature sizes of microelectronic devices are currently in the range of 1 to 10 micrometers, or less than a tenth the diameter of a human hair—fig. 2.) Because solid-state devices based on magnetic or optical principles are often used as components in systems that are broadly electronic in nature, no fine distinctions will be made.

Figure 2.—Comparative Feature Sizes of Microelectronic Devices Such as Integrated Circuits

	Representative feature sizes (design rules)	Examples	Dimension in micrometers
		Human hair	100
		Red blood cell	7
1978	5 micrometers		
1980	2 micrometers		
		Yeast cell	1
1985*	0.5 micrometer		
		Smallest bacteria	0.2
1990*	0.1 micrometer		
		Polio virus	0.01
			0.001
		Atom	0.0002

1 micrometer = 10^{-6} meter

*Projected.

SOURCE: Adapted from G. B. Larrabee “Materials Characterization for VLSI,” *VLSI Electronics: Microstructure Science*, vol. 2, N. G. Einspruch (ed.) (New York: Academic Press, 1981), p. 38.

“Optical data transmission can give bandwidths much higher than electronic signals; this, along with the low raw material cost, is one of the advantages of optical fibers. Systems based on laser light sources, with optical fibers for signal transmission and thin-film integrated optical devices for signal processing, could replace many types of electronic circuits and systems.

Among these solid-state devices—table 1—are:

- transistors, ICs, light-emitting diodes (LEDs), all of which are semiconductors;
- bubble memories, which depend on the magnetic rather than the electronic properties of materials;
- liquid crystals (as in alphanumeric displays for watches or calculators), chemicals that change colors when their temperature changes;
- integrated optics, in which information is transmitted and processed in the form of light, Integrated optics and prospective future technologies such as organic semiconductors are not commercially important at present, but could have impacts on future success in international competition.

Transistors

While most of the fundamentals of semiconductor physics were known prior to World War II, the transistor itself was developed at Bell Laboratories after the war, and first demonstrated in late 1947.[5]

In contrast to passive electronic devices such as resistors, capacitors, and inductors—which can only respond to electrical signals—active circuit elements like transistors control and regulate the flow of electricity in a circuit. As a result, they can amplify electrical signals—a function that earlier could only be performed by vacuum tubes.

Transistors come in many varieties to serve different functions, just as for the vacuum tubes they superseded, To make a transistor, a semiconducting material such as germanium or silicon is "doped" with small amounts of elements—arsenic, boron, phosphorus—that locally affect its conductivity. The transistor, to the naked eye, is then just a small piece of, say, silicon with two or three wires attached. In fact, however, the purity, chemical composition, and perhaps crystal structure have been carefully tailored on a microscopic level.

Integrated Circuits

An IC is made by fabricating several circuit elements—transistors, capacitors, and such—on a single substrate. Integrated circuits were independently developed in the 1950's at Texas Instruments and Fairchild Camera and Instrument, still two of the leading semiconductor manufacturers in the United States (Fairchild is now French-owned). The two companies approached the problem quite differently during 1958-59, but their developments shared the common characteristic of an IC—two or more distinct transistors fabricated on a single substrate,[6] Thus they were monolithic circuits.

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[5] W. Shockley, "The Path to the Conception of the Junction Transistor," *IEEE Transactions on Electron Devices, vol. ED-23,* 1976, p. 597; E. Braun and S. MacDonald, *Revolution in Miniature: The History and Impact of Semiconductor Devices* (Cambridge, Mass.: Cambridge [University Press, 1978), ch. 4.

[6] M. F. Wolff, "The Genesis of the I ntegrated Circuit, " *IEEE Spectrum,* August 1976, p. 45; Braun and MacDonald, op. cit., ch. 8. The depths of the transistors fabricated on a chip are small enough that ICs can be considered two-dimensional. Often the silicon substrate—a few millimeters on a side and less than a millimeter thick-is called a chip, as is the resulting circuit.

Table 1 .—Examples of Solid-State Technologies Used in Information Processing

Technology and examples	Description	Current status
Semiconductor electronics: Transistors Integrated circuits	Depends on electronic properties of semiconducting materials such as silicon, germanium, gallium arsenide.	Production
Magnetic devices: Bubble memories	Depends on magnetic rather than electronic properties of materials.	Bubble memories in limited production.
Solid-state optics: (sometimes called optoelectronics)	Depends on electro-optical properties of materials, some of which are semiconductors.	LEDs widely used for displays; integrated optics experimental.
Light-emitting diodes (LEDs)	LEDs are lighted when a current passes.	
Integrated optics	Thin-film devices in which signals are transmitted by light (photons) rather than electrons.	

SOURCE Office of Technology Assessment

Other types of ICs can also be built—e.g., hybrid or thin-film circuits—but monolithic devices comprise the bulk of production,

At present, the market for ICs is more than four times the size of that for discrete semiconductors. Because of this, and because very large-scale circuits pace the industry and are a major focus of international rivalry, this report gives much more attention to ICs than to other microelectronic devices.

Appendix 3A discusses IC technology in some detail. The significance of the technology itself for international competitiveness resides largely in the commercial advantages that can accrue from innovative and/or widely accepted chip designs (ch. 5), as well as from mastery of processing technology. Being first on the market with a new design gives a firm the opportunity to build market share before competitors can offer similar products. The advantage of a particularly well-accepted design is that it may become a de facto industry standard. A manufacturer whose design becomes such a standard not only has the assurance of a relatively large and stable market, but also the prospect of a broad range of licensing and/or second-sourcing agreements. The firm may also get a headstart in the competition to design the next generation replacement. Processing capability is just as important to competitive success as design, because advanced circuit designs are often limited by what can be built at acceptable yields. (The yield is the fraction of "good" circuits coming off the production line.) In semiconductors, advances in circuit design and in processing capability are interdependent to a greater extent than in almost any other industry.

The first of the two major types of ICs to be developed, bipolar, has been replaced for many applications by MOS (metal oxide semiconductor, app. 3A). Over the course of the 1970's, MOS technology—which is denser, cheaper, and consumes less power, but which does not offer speeds as high as bipolar—became dominant for large-scale integration (LSI). Very large-scale integration (VLSI) will be mostly MOS. Firms that were slow to master MOS tended to fare poorly in sales growth and profitability over the past decade. For the foreseeable future, competition in ICs will continue to center around MOS devices.

System Design and the Microprocessor

In designing a digital system, the engineer has several options:

1. to assemble a number of ***standard logic*** circuits like those of the transistor-transistor logic family described in appendix 3A;
2. in cases where large production volumes are anticipated or performance requirements are specialized and demanding, to call for one or more custom ICs;
3. to use a standard microprocessor or microcomputer with software written for the particular application.

Assemblies of standard logic circuits—typically small- or medium-scale ICs—may be economical in limited production volumes, despite relatively high design and development costs. In such cases, the system is implemented in *hardware---e.,.,* its functioning can only be altered by changing the circuit components and/or their interconnections.

Specially designed custom circuits—analog as well as digital, bipolar as well as MOS—have a place in high-volume applications ranging from consumer products like TVs and electronic watches to telecommunications systems. They are also employed where performance requirements such as operating speed cannot be met in other ways-e. g., in some military and aerospace applications, or in mainframe computers. Custom circuit design is expensive: hundreds of thousands of dollars, sometimes running into millions. Here the designer is also working in hardware, but new custom hardware rather than standard ICs.

In contrast, when a system based on a ***micro-*** processor or microcomputer is designed, the logic is implemented largely through *software* —i.e., a computer program stored in memory. Although ***microprocessors*** and single-chip *microcomputers* can function as central processing units for general-purpose computer systems—such as the small machines sold by Apple or Radio Shack—they were originally conceived as replacements for custom ICs to circumvent the high costs of designing, developing, and producing custom parts, The first commercial microprocessor was introduced by Intel Corp. in late 1971 to implement the arithmetic functions in an inexpensive calculator. Faced with the request of their Japanese customer for a group of custom chips to be used in a line of calculators, Intel instead proposed a simple 4-bit microprocessor chip.[7] Rather than hard-wiring the operations required for the different calculator models—addition, multiplication, printing, and so on—software programs permanently stored in memory implemented these functions. Money was saved in design and production compared to the custom IC alternative.

Subsequent experience has shown that microprocessors may prove the low cost alternative for systems that could be built with as few as two or three dozen standard logic circuits. Figure 3 illustrates a typical application of a microcomputer, control of a microwave oven, where the chip contains memory for program storage along with a processor. In such an application, production volumes might be high enough to justify a custom LSI chip design—tens of thousands of identical parts, at a minimum, are normally called for. But the microprocessor/microcomputer alternative has a big advantage in flexibility; design changes are simple, different models simply need different programs. And, in the microwave oven example, there is no need for high performance.

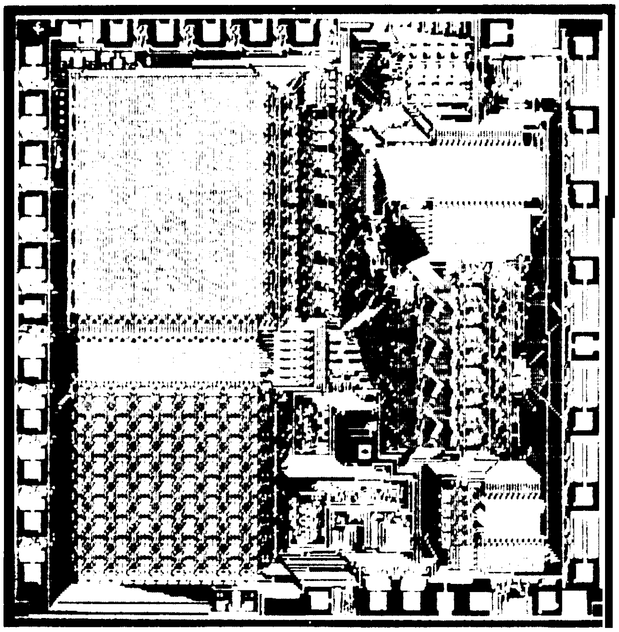

Photo credit Texas Instruments

A single-chip microcomputer

Before the advent of the microprocessor, system designers had only two choices: assemblies of standard parts or custom ICs. The microprocessor/microcomputer introduced a third option, one that proved highly attractive. As a result, several hundred different models of microprocessors and single-chip microcomputers are now marketed (many differ only in details), and custom microprocessors are sometimes designed for special applications.

Microprocessors and Memory

Microprocessors cannot be used by themselves; they must be supported by other chips, at a minimum for program storage. Memory circuits are described in some detail in appendix 3A, particularly table 3A-2. Memories, in fact, comprise the largest single market category for ICs; the majority go into general-purpose computer systems, but large numbers are also used in dedicated applications of microprocessors and microcomputers (i.e., applications where the computing function is invisible to the user of the system).

Technological progress is easier to measure for memory circuits—e.g., RAM chips (random access memory)—than any other type of IC. Densities have increased steadily over time—figure 4–while the cost of a chip has remained roughly the same, As a result, the cost per bit of information stored goes down, This opens up new applications, not only for memory circuits, but for IC-based systems of any type that

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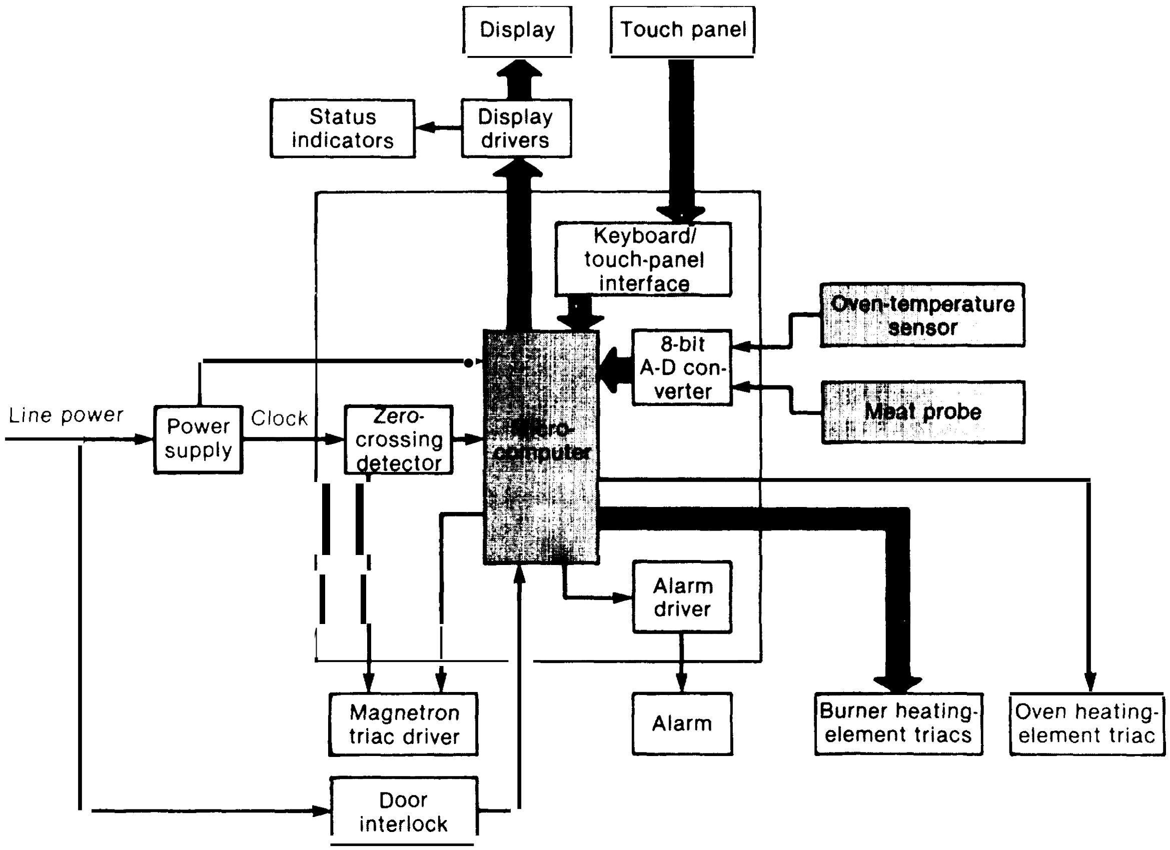
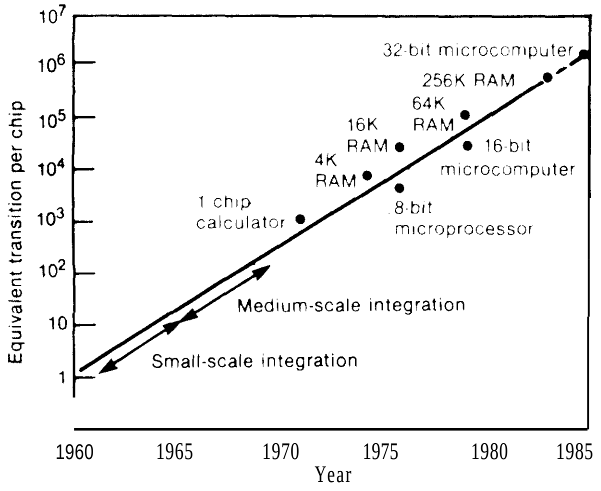
[7] R. N. Noyce and M. E. Hoff, Jr., “A History of Microprocessor Development at Intel Corporation, ” *IEEE MICRO,* February 1981, p. 8. Parallel developments took place at Texas Instruments,

Figure 3.—Controller for a Microwave Oven Based on Single-Chip Microcomputer



SOURCE R Walker 'Analog/Digital LSI ' 1979 Electro Professional Program, New York, Apr 2426, 1979

Figure 4.—Increases in IC Integration Level



SOURCE D Queyssac, "Projecting VLSI's Impact on Microprocessors," *IEEE Spectrum* May 1979 p 38

rely on memory—notably microprocessor systems. Likewise, as semiconductor memory becomes cheaper it will continue to substitute for alternative storage media such as magnetic disks in general-purpose computer systems. It was widely noted in the early 1970's that the cost per bit of memory had fallen below the cost of a jelly bean. According to some estimates, a jelly bean (at 1¢) may buy as many as 1,000 (1K) bits of memory by 1990.

Memory and microprocessors are the most visible products in domestic and international competition. While it would be wrong to consider these the only important categories, they do constitute half the total market for ICs. Moreover, significant advances in both device technologies and process technologies have often found their way into production via circuits of these types.

Learning Curves and Yields

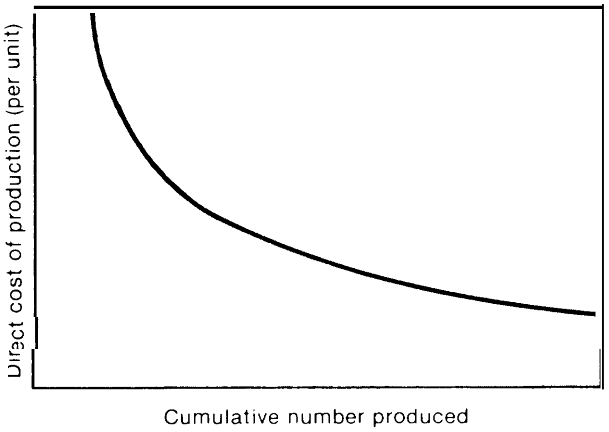
Making ICs is demanding, more so at higher levels of integration, Forty or more processing steps may be required for a VLSI chip, a figure that will continue to grow. Designing VLSI circuits is also complex, and becoming steadily more time-consuming and expensive, while product design and process design go hand-in-hand. For consumer electronic products like TVs, decisions on product features often hinge on the *costs* of production; for a new IC, the first question is: Can it be made at all?

Once a semiconductor firm has designed an IC and carried it through the pilot production stage they can normally assume that production costs, even if initially high because of low yields, will decrease over time. Figure 5 is a schematic learning *curve,* sometimes called an experience curve, showing cost declines with cumulative production volume. Learning curves typical of IC manufacture show that when cumulative production doubles, costs decrease by about 28 percent.[8]

Learning curves as in figure 5 apply to manufactured products of many kinds, but their impacts on pricing decisions have been particularly noticeable among semiconductor firms; they are a major factor in forward-pricing—setting prices below the initial costs of production to gain market share, Because firms feel confident that costs will decrease as production experience accumulates, forward-pricing has been a common competitive tactic,

These cost declines—which can be considered equivalent to increases in productivity—stem from much more than simple learning or experience by the labor force; other causes include better equipment performance and utilization, greater understanding and control of the many steps in the production process, smoothing of work flows, and perhaps changes in the design of the part itself. Control of the process is particularly important, and often depends on subtle variations in parameters influencing phenomena such as diffusion, etching, or polymerization (of photoresists—IC fabrication steps are described in more detail below). In many cases, the physics and chemistry of such phenomena are only poorly understood, and cannot be modeled theoretically; process control models tend to rely on empiricism, hence on accumulated experience, Denser and more complex ICs call for a better grasp of processing fundamentals.

Figure 5.—Schematic Learning Curve for the Production of an Integrated Circuit or Other Manufactured Item



SOURCE Office of Technology Assessment

In general, learning improvements show up as increased yield, the percentage of chips that pass final test and function satisfactorily. When a new IC goes into production, the yield is generally low—perhaps only a fraction of a percent—but rises as experience accumulates and processing can be better controlled. As a rule-of-thumb, products are seldom marketed, except for sampling purposes, until yields have risen to about 10 percent—which may take as much as a year of production-line experience.[9] For mature products, yields can rise to well over 50 percent, Increased yields are a power-

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[8] "Boom Times Again for Semiconductors)" *Business Week*, Apr. 20, 1974, p. 65; *A Report on the U.S. Semiconductor Industry* (Washington, D. C.: Department of Commerce, September 1979), pp. 48-50. The 28 percent figure is an average from which the cost experience for a given IC can deviate substantially. Production volumes typically rise rather slowly at first, because it takes time for customers to design the new part into their systems. In comparison to other types of manufactured products, learning curves for semiconductors are not particularly steep, but continue to fall over very long production runs.

[9] R. Bernhard, "Rethinking the 256-kb RAM, " *IEEE Spectrum*, May 1982, p. 46.

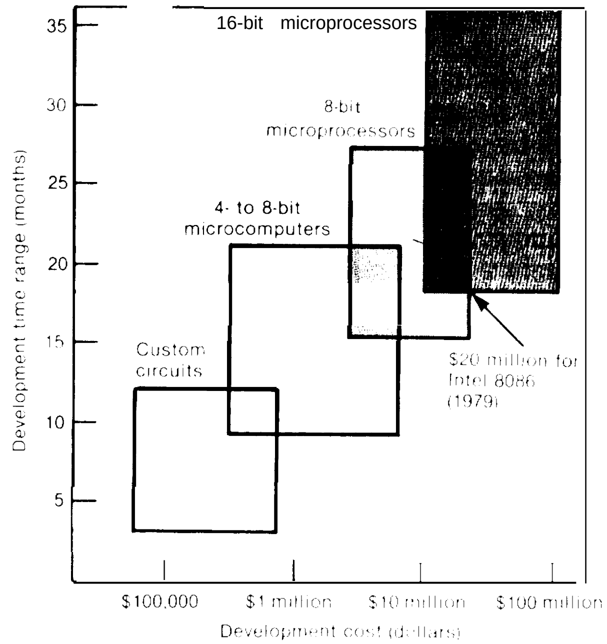
ful force in driving down the costs and prices of ICs; in effect, doubling the yield halves the production cost.

Because processing capability is so critical to commercial success, the specialized equipment used in fabricating ICs is one of the keys to competitive ability. Much of this equipment is designed and built by independent suppliers —many of them American firms—selling to customers throughout the world (ch. 4). The technological capability and competitiveness of the portion of the U.S. electronics industry that designs and manufactures equipment has been just as important to the international position of the United States in semiconductors as the efforts of semiconductor firms themselves. Because of the interrelations of device technologies and process capability, and the dependence of costs and yields on process control, a number of the more important steps in producing ICs—beginning with circuit design—are described in more detail below.

Integrated Circuit Design

The task of the circuit designer is to define an arrangement of circuit elements—transistors, capacitors, logic gates, interconnections—that will satisfy the functional requirements of the IC. The more complex the circuit and the higher the level of integration (a 64K RAM contains more than 100,000 circuit elements) the more difficult the designer's job, and the higher the cost of design and development. Figure 6 illustrates ranges of development time and cost —including hardware, software, and peripheral chips—for several types of ICs.

Figure 6.— Ranges in Cost and Time for Design and Development of Integrated Circuits



SOURCE: P. M. Russo, "VLSI Impact on Microprocessor Evolution, Usage, and System Design," *IEEE Transactions on Electron Devices*, vol. ED-27, 1980, p. 1339.

As a rule-of-thumb, circuit design costs historically have been rather stable at about $100 per gate. Thus, a microprocessor with 10,000 gates will have a hardware design cost of perhaps $1 million, and may represent 10 man-years of effort. Software costs add to this. It may well be possible to make chips with 1 million gates within a few years, but the costs of designing them will be prohibitive unless the design costs on a per-gate basis can be reduced; one estimate has been that an IC with a density of a million devices would require about ***200*** man-years for design and development using the conventional methods of the past decade.[10] Computer-aided design—i.e., the use of specialized computer programs by the design engineers—is the principal hope for cost reduction, and is increasingly necessary just to handle the logical complexity as the number of devices per chip goes up. Designing a microprocessor with ***100,000*** transistors would ***be*** impractical without computer aids. R&D aimed at more regular —even modular—chip designs is also underway, again intended to reduce the time, hence the cost, of IC design. Modular approaches are particularly attractive for custom logic circuits.

As pointed out above, the microprocessor itself originated as a way to reduce the costs of custom circuit design; in essence. choosing a microprocessor means replacing hardware design by software design, and in many cases lowers costs, But as logic complexity goes up,

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[10] C. L. Hogan, cited by F. Ogden, "Audience Gives Mixed Reception," *Electronics Weekly*, Mar. 28, 1979, p. 5.

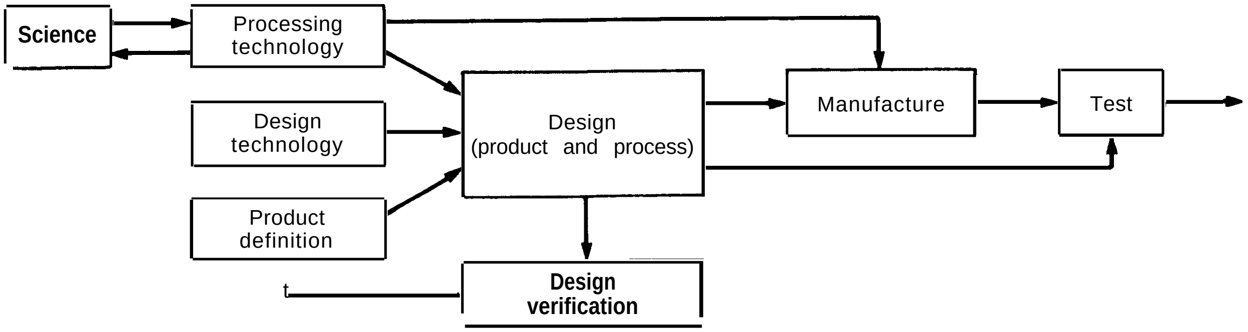
the software costs for programing the microprocessor escalate rapidly. In part, this simply reflects the more sophisticated processors—e.g., a 16-bit rather than a 4- or 8-bit device—needed for demanding applications. Although software production can also be automated, the two basic paths toward implementing logic—hardware via custom chip design, or software via a standard microprocessor with a program embodying the logic—will continue to compete. Design cost, flexibility, and performance are all factors. But if computerized design aids for hardware and software advance sufficiently far and in tandem it may eventually make little difference, perhaps even to the designer, whether the logic is embodied in hardware or soft ware.

Although much of the engineer's work revolves around the logic that the circuit will implement, IC design also calls for intimate knowledge of processing and fabrication[11]—figure 7. Designs that can be implemented in n-MOS might be impossible in c-MOS (see app. 3A, table 3A-1, for an explanation of the types of MOS devices). One company might have n-MOS process capabilities beyond the reach of another. The design team must consider factors such as the spacing between transistors and the widths of the lines that interconnect them. In contrast, when designing a system to be built from discrete components it was often enough to be familiar with the performance characteristics of off-the-shelf devices. At the same time, IC designers—typically electrical engineers—must be at home with the logical concepts and software orientation of the computer scientist; the need for software skills will grow as ICs come more and more to resemble integrated systems. This melding of hardware (including process technology) and software skills, and the rapidity of technical change, make unusual demands on the people who fill such jobs—one reason that the electronics industry has been experiencing shortages of qualified engineers (ch. 8). Although neither the circuit designer nor the process specialist can be fully conversant with *all* aspects of IC design and manufacture (fig. 7), some knowledge of each is needed.

Manufacturing Integrated Circuits[12]

The design process culminates in a pattern or layout-a large drawing, several hundred times the size of the circuit itself—that must be translated into the "tooling" for producing the chip. In simple terms, the procedure for making an IC resembles a series of photographic processes—lithographic patterns are created in layers on a silicon wafer. Each layer is made by exposing a polymeric chemical called a photoresist to light or other radiation, the light

Figure 7.—Steps in Designing and Manufacturing an Integrated Circuit



SOURCE: G. Moore, "VLSI: Some Fundamental Challenges," *IEEE* Spectrum, April 1979, p.30.

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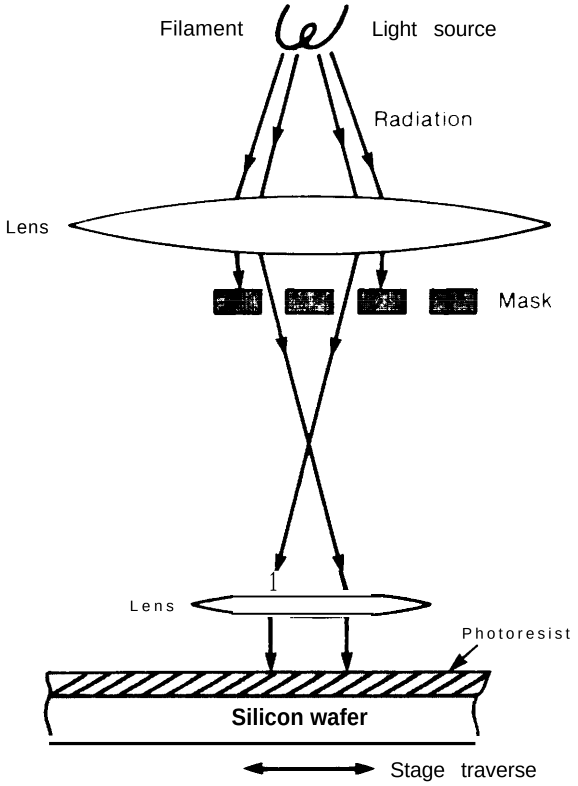
[11] P. W. J. verhofstadt, "Evaluation of Technology Options for LSI Processing Elements," *Proceedings of the IEEE,* vol. 64, 1976, p. 842; C. Mead and L. Conway, *Introduction to VLSI Systems* (Reading, Mass.: Addison-Wesley, 1980).

[12] See, in general, F. W. Voltmer, "Manufacturing Process Technology for MOS VLSI," *VLSI Electronics: Microstructure Science, vol.* 1, N. G. Einspruch (cd.) (New York: Academic Press, 1981), p. 1.

passing through a grid-like mask as shown schematically in figure 8. More than a dozen such masking steps may be needed to build up a VLSI part. Many other processes besides lithography are involved in IC fabrication, with more detail given in appendix 3A, but lithography is critical for future increases in circuit density. While advances at many stages in the manufacturing process take place in an interdependent way—e.g., laser annealing is replacing furnace annealing because it does a better job of restoring the crystal structure of the silicon which is disturbed by ion implantation —lithography is the major factor in determining how small individual devices and interconnections can be on a production as opposed to laboratory basis. Already, transistors can be packed much more closely in an IC than neurons are packed in the human brain; it is the technology of lithographic processing that makes this possible.

Figure 8.—Step-and-Repeat Process of Photolithographic Pattern Formation on Silicon Wafer



SOURCE Office of Technology Assessment

Lithographic line widths in production ICs have been reduced an order of magnitude over the past decade, from about 20 micrometers in the early 1970's to 2 to 4 micrometers currently. (A micrometer is about 40 millionths of an inch,) Thinner lines give higher operating speeds as well as denser packing. The 16K RAMs designed in the early to mid-1970's were based on 5 micrometer "design rules," 64K RAMs on 3 micrometer rules (design rules, which are directly related to lithographic line widths, comprise the full set of geometric constraints that designers follow). The next-generation 256K RAMs are based on 1.5 to 2 micrometer design rules.[13] Continued progress in reducing line widths—more generally, feature size—is thus a major driving force in moving further into VLSI. For this reason, a principal R&D target of the Defense Department's Very High-Speed Integrated Circuit (VHSIC) program has been lithographic technology—an objective paralleling commercial R&D efforts, one reason the program is likely to have a positive effect on nonmilitary portions of the semiconductor industry. The VHSIC program goals include two stages of lithographic improvements: the first stage calling for line widths of 1,25 micrometers; the second, lines of 1 micrometer and below.

While feature sizes of ½ to 1 micrometer are well above the range for which the physics of electron devices will begin to constrain performance, such feature sizes do demand significant developments in lithographic capability, particularly for mass production .[14] In the past,

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[13] "Rethinking the 256-kb RAM, " op. cit. On design rules, see Mead and Conway, op. cit., p. 47.

[14] I E. Sutherland, C. A. Mead, and T. E, Everhart, *Basic Limitations in Microcircuit Fabrication Technology,* Defense Advanced Research Projects Agency Report R-1956-ARPA, November 1976; R. W. Keyes, "The Evolution of Digital Electronics Towards VLSI," *IEEE Transactions on Electron* Devices, vol. ED-26, 1979, p. 271, The ultimate limit to reductions in the sizes of electron devices will perhaps be thermal noise, although a variety of practical concerns may intrude first. Feature sizes are likely to decrease to the range of 0.01 to 0.1 micrometer before fundamental physical limitations are encountered.

visible light—generally ultraviolet—has been used to expose photoresists (fig. 8). But even deep ultraviolet, which has a wavelength of about ½ micrometer, cannot produce line widths much below a micrometer because optical considerations limit the lines to about twice the wavelength of the radiation.

To achieve 1 micrometer lines with visible light requires very sophisticated lithographic equipment—positioning and layer-to-layer registration of the sequential masking steps must be held to a small fraction of a micrometer. A single machine of the direct-step-on-wafer type diagramed in figure 8 now costs about half a million dollars—table 2. As the table shows, the earlier generations of equipment replaced by direct-step-on-wafer machines were much less expensive. Finer patterns will be still more costly—whether the technology of choice is electron-beam lithography (table 2), X-rays, or ion beams (see app. 3A). The rapidly rising costs of IC processing equipment—whether for lithography, for ion implantation, or for testing—along with higher costs for design and development, are the most important causes of the rapidly increasing capital intensity in the semiconductor industry (ch. 7). Entry costs are now roughly $50 million, versus $5 million to $10 million in the early 1970's.

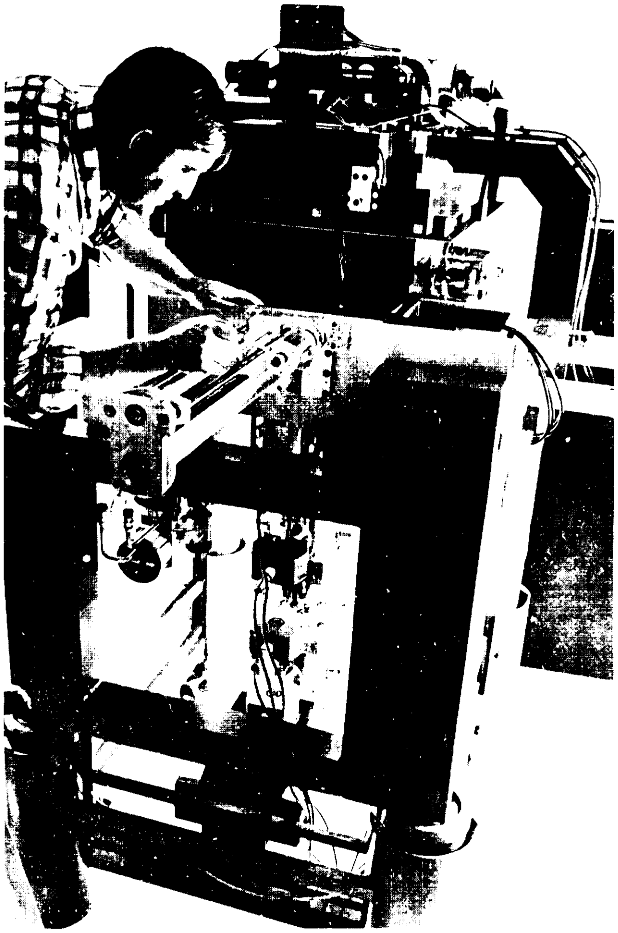

Photo credit GCA Corp

Electron-beam lithography system

Some firms have already moved to electron-beam lithography for critical circuit layers. Electron-beam lithography is also a routine tool for making masks. X-rays and electrons have wavelengths much less than light, and so offer greater resolution—at the expense of high first cost for the equipment, and low production rates.[15] Because of its importance in driving IC technology, R&D on high-resolution lithographic techniques (see app. 3A) has been a principal target of government-funded programs in other countries—e.g., Japan's VLSI project—as well as the VHSIC program funded by the U.S. military.

Table 2.—Cost Increases for Fine-Line Lithography

Lithographic system	Line width (micrometers)	Throughput (wafers per hour)	Approximate cost per system	Approximate capital requirements for production capacity of 1,000 wafer starts per week
Light				
Contact printing	10	60	$15,000	$30,000
Projection	2-5	60	$240,000	$400,000
Direct-step-on-wafer	1-2	30	$480,000	$1.6 million
Electron-beam	0.5-1.0	6	$1.5 million	$25 million

SOURCE Adapted from A J Stein, J Marley, and R Mallon, "The Ire-pact of VLSI on the Automobile of Tomorrow, " *VLSI Electronics Microstructure Science*, VOl 2, N G Einspruch (ed) (New York Academic Press, 1981), p 295

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[15] G. R. Brewer, "High Resolution Lithography," *Electron-Beam Technology in Microelectronic Fabrication*, G. R. Brewer (cd.) (New York: Academic Press, 1980), p. 1.

More cost comes with the “clean rooms” needed for VLSI processing. Even micrometer-size dust particles can ruin the lithographic patterns; cleanliness is vital to high yields. In a clean room, the air is filtered and people must wear special clothing. As circuits become denser, and feature sizes smaller, not only is cleanliness more important, but the whole range of processing equipment used in making ICs becomes more sophisticated and expensive, adding to the capital requirements for semiconductor manufacturing, a matter discussed in chapter 7.

Future Developments

Semiconductor devices need not be based on silicon. One alternative is gallium arsenide, a material that offers considerable potential for improvements in packing density and speed—one to two orders of magnitude compared to silicon—but is still largely a laboratory technology. Whether gallium arsenide circuits will become commercially important depends on rates of improvement compared to silicon, and also on developments in other prospective technologies-e. g., Josephson junctions. Josephson device--also experimental, and much further from demonstrated practicality than gallium arsenide ICs—promise still better speed and density.

To illustrate the importance of speed, as well as power consumption, consider the technology embodied in a current-generation mainframe computer. The central processor for one such computer—the Amdahl 470-V—employs 1,680 ICs, with a total of about 100,000 logic gates. As is typical in large computers, the chips use silicon bipolar technology to give high computing speeds. Replacing these bipolar chips with gallium arsenide may offer the potential for increasing computational speeds by a factor of 10 to 100, and reducing the power consumed by the processor from about 3,000 watts to perhaps 30 watts—less than most light bulbs.[16] Comparable improvements in other applications of ICs carry implications for competitive trends in many industries if some companies or some countries manage a headstart in reducing such technologies to practice.

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[16] R. C. Eden, B. M. Welch, R. Zucca, and S. I. Long, “The Prospects for Ultrahigh-Speed VLSI GaAs Digital Logic,” *IEEE Transactions on Electron Devices*, vol. ED-26, 1979, p. 299 About 1 percent of the electricity consumed in the United States now goes to computers, mostly for cooling—“CBEMA Prediction: Say Energy Crunch Could Cut EDP Growth Rate 50%,” *Electronic News*, Mar. 17, 1980, p. 32. On Josephson junctions, see J. Matisoo, “Overview of Josephson Technology Logic and Memory,” *IBM Journal of Research and Development*, vol. 24, 1980, p. 113.

Computers

Computer technology has many roots, including military needs during the Second World War for fire control tables and other complex and/or repetitive computations. The United States had no great advantage over other nations during the early development of computers; significant innovations also originated in several European countries, particularly Great Britain .[17] But as computing technology progressed, the lead swung decisively to American firms, much as happened over roughly the same period of time for semiconductors.

The Bureau of the Census was an early non-military customer for American computers, census data processing requirements remaining a typical example of computer applications. When a Univac I was delivered to the Bureau of the Census in 1951, some observers predicted that the market for digital computers might eventually total a dozen; a few years later, when sales to private industry began, the estimates were that the potential market in the

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[17] *Gaps in Technology: Electronic Computers* (Paris: Organization for Economic Cooperation and Development, 1969), p. 61. For a concise summary of developments during the first three generations of computing technology, primarily in the United States, see S. Rosen, “Electronic Computers: A Historical Survey,” *Computing Surveys*, vol. 1, 1969, p. 1.

United States consisted of perhaps 50 corporations.[18]

Needless to say, as computer technology advanced many more firms became customers, and the ranks of computer manufacturers swelled. Among the entrants were a number of companies that had become established in the office equipment market. International Business Machines Corp., Burroughs, and National Cash Register (now NCR) joined firms like Univac that had been set up specifically to manufacture digital computers. By the end of the 1960's, computer applications had spread well beyond numerical computations and data processing. The great part of computing power is still devoted to data processing for business and government—accounting, sales, production, inventories, recordkeeping of all kinds—and to scientific and engineering calculations. In addition, many individual computers, mostly microprocessors and microcomputers, now perform "invisible" functions in applications ranging from aircraft flight control systems to the microwave oven example shown in figure 3.

The spread of computing power has sometimes been technology-driven, sometimes driven by user demands. Technology-driven developments arose when more computing capability was available than people knew how to use productively—i.e., before the applications were well-defined. Under these circumstances, the availability of more powerful machines or greater performance per dollar tends to generate new applications, or, more broadly, serve needs earlier unmet. As in many instances of technological change, what the technology could do, at any given time and for a given cost, evolved in conjunction with applications, with one or the other temporarily in the lead, Much the same has been true for ICs. In the period when demand from military and space programs in the United States was high, the market drove the technology; but leaders in the semiconductor industry have periodically worried that applications for the full capabilities of new circuits containing greater numbers of devices, now VLSI, might not appear. Such fears seem to have vanished from the computer business, though not the perennial questions of which firms will get the largest share of the new markets.

Types of Computers

As pointed out in the earlier section on "System Design and the Microprocessor, " the essential elements of a small digital computer (exclusive of power supply and input/output devices) can be placed on one IC to create a single-chip microcomputer. A microprocessor is more limited in function, but when combined with the necessary memory and peripheral chips on a printed circuit board becomes a single-board microcomputer. From such products—selling for around $100 without cabinets and other auxiliaries—digital computers range upwards in size, speed, and cost to "supercomputers." Intended for complex scientific and technical calculations-e. g., modeling the Earth's atmosphere, designing airfoils or nuclear weapons—supercomputers are made by only a few manufacturers, and cost in the vicinity of $10 million each.

In between board-level microcomputers and supercomputers come a number of broad categories of machines: personal and small business computers like those made by Apple; minicomputers of various types; general-purpose mainframes. The latter, typified by many of IBM's larger models, can handle many different tasks at once. Table 3 outlines some of the conventional distinctions among these categories. The differences are not always clear-cut and will blur even more as microcomputers become more powerful, computing power still cheaper, and computers of all types more versatile.

The central processing unit (CPU) for a simple computer—in fact, just a microprocessor—is shown schematically in figure 12. A microprocessor functions like the CPU of any computer—it brings information (in the form of binary bits) into an arithmetic logic unit, manipulating the bits in accordance with instructions

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[18] L.M. Branscomb, "Electronics and Computers: An Overview, " *Science,* Feb. 12, 1982, p. 755.

Table 3.—Characteristics of Different Categories of Digital Computers

Family/Distinguishing features

Microcomputer: The central processing unit (CPU) consists of a microprocessor or single-chip microcomputer, sometimes several. The most common microcomputers use an 8-bit word and sell, without peripherals but otherwise complete and ready to operate, for under a thousand to a few thousand dollars. They will typically fit on a desk top—fig. 9—and do not require special training to operate. Examples include popular models sold by Apple and Radio Shack, along with the IBM Personal Computer,

Machines based on microprocessors or microcomputer chips with 16-bit word lengths are beginning to appear, particularly for business applications. These are nearer in performance to low-end minicomputers than to the &bit microcomputers originally developed for the hobbyist and personal computer markets.

Minicomputer: Microcomputers, by the definition above, could not have existed before the development of the microprocessor— i.e., before the early to mid-1970's. Minicomputers, in contrast, stem from the 1960's. A popular early mini introduced in 1965-the PDP-8, built by Digital Equipment Corp.—was the first low-cost, mass-produced computer of any type. It was designed around a 12-bit word and discrete transistors.

Minicomputers are small compared to mainframes, which can fill a room, As fig. 10 indicates, minicomputers are often about the size of a desk. Although not as portable as micros, many minicomputer models can be moved relatively easily within an office or factory environment.

Minis found much of their market as dedicated processors designed into more complex systems, or *in* specialized data processing tasks—e.g., industrial controllers, data acquisition systems for laboratory research, inventory management in factories. While such applications remain common, minicomputers are also widely used for general-purpose data processing. Often mainframes were needed in such applications only a few years ago; minicomputers tend to supplement rather than displace them.

At the lower end, it is increasingly difficult to distinguish minicomputers from the more powerful microcomputers. Many less expensive minis now rely on a single-chip processor. However, the smaller minicomputers typically use 16-bit words—e.g., the currently popular PDP-11 models made by Digital Equipment, or the Nova series of Data General. Larger, more powerful machines—sometimes called "superminis"--normally have a 32-bit word length. Examples of superminis are the Data General Eclipse series or the VAX models of Digital Equipment. In the 1960's, 32-bit words were found only in mainframes.

Most minicomputers carry prices in the $10,000 to $100,000 range. A principal distinction between minicomputers and mainframes is that minis seldom require either operators with a great deal of training or specially constructed facilities. Mainframes, in contrast, must usually be permanently installed; some large computers dissipate so much heat that air-conditioning is needed even in midwinter.

Mainframes: The CPU for a mainframe typically contains several thousand logic chips, usually bipolar for speed. Word lengths are commonly 32 to 64 bits. Mainframes often support multiple terminals and peripherals-fig. 11 —and generally require trained personnel onsite.

While IBM is the world's largest producer of mainframe computers, more than a dozen other firms build machines comparable in computing power. Mainframes can sell for $10 million or more–exclusive of peripherals–but the more popular general-purpose machines typically cost under $5 million.

SOURCE Office of Technology Assessment

from a program stored in memory, and sends information back to the memory or to an output device, The stored program, which made the modern digital computer possible by providing a means for telling the computer what to do without the need for hardware changes, accounts for a good deal of the information that enters and leaves the CPU. Even rather simple computer systems—figure 9—typically use several types of memory, which are described in more detail in appendix 3B.

Computers as Systems

In addition to CPU and memory, a computer system needs input and output devices (fig. ***13).*** In small computers, all the components may be integrated into a single self-contained unit. Peripherals such as disk and tape drives, terminals, and printers are made by large numbers of independent vendors, as well as by computer manufacturers. Nearly 90 American firms were producing terminals as of 1980, about half of these "smart" by virtue of embedded microprocessors, while nearly 30 had announced their intention to build 8-inch Winchester disk drives, a product just beginning to reach the marketplace at that time.[19] The market dynamics associated with the computer industry—rapid growth, intense competition, new entrants with new products—characterize peripherals and software as well as processors.

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[19] "The Digital Age," *Electronics,* Apr. 17, 1980, p. 387; G. Slutsker, "28 Rivals Eye 8-Inch Disks But None Lands Big OEM Pact Yet, " Electronic News, Jan. 21, 1980, p. 40.

Figure 9.—Typical Microcomputer Intended for Personal and Small-Business Applications

Photo credit: Apple Computer, Inc

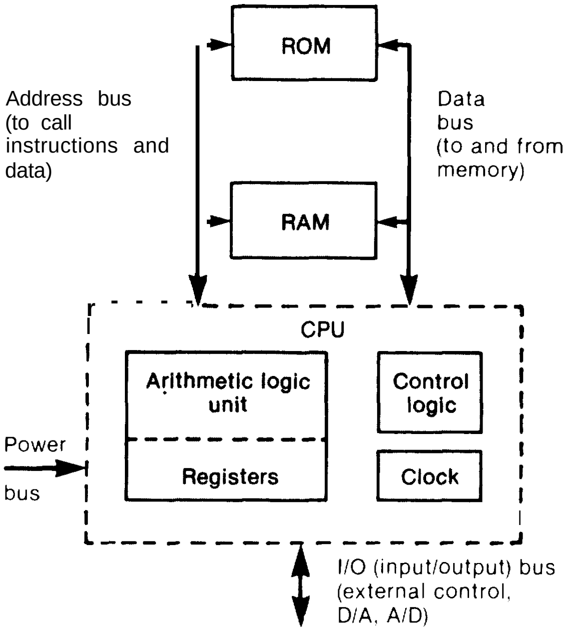
Figure 10.—Typical Minicomputer Installation Including a Pair of Terminals and a Printer

Photo credit: Digital Equipment Corp

Figure 11.—Data Processing Installation Built Around General-Purpose Mainframe Computer

Photo credit: Control Data Corp

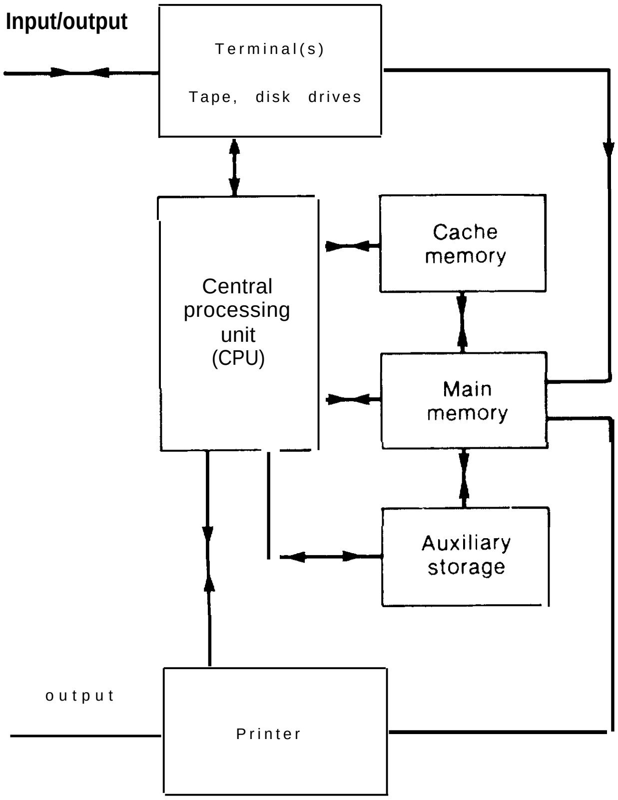
Figure 12.—Simplified Block Diagram of a Microprocessor System



D/A = Digital/analog conversion
A/D = Analog/digital conversion
ROM = Read-only memory
RAM = Random access memory

SOURCE Off Ice of Technology Assessment

Figure 13.— Elements of a General-Purpose Digital Computer System



SOURCE Off Ice of Technology Assessment

Technological change in computing has been rapid since the beginning of commercial production in the 1950's, but now the industry is perhaps facing the most comprehensive set of changes yet, These stem from "distributed intelligence," the dispersal of computing power to many farflung locations, In some respects, this trend began with the development of time-sharing in the early 1960's. Time-sharing permits users at remote terminals to interact directly with a central processor, extending the capabilities of a powerful computer to many people simultaneously, It also uses the processor more efficiently, Even during big jobs the CPU may be idle much of the time; with time-sharing, system software keeps the CPU busy by dividing its processing power among many people, each of whom is unaware of the others.

Conceptually, the next step beyond time-sharing—for which each user needs only a "dumb" terminal (an input/output device with no function other than to communicate with the central processor)—is to link a central computer to satellite machines which can share the processing load. Many such distributed ***processing*** schemes are possible, among the more common being a mainframe supported by minicomputers. A mainframe or mini can also communicate with "smart" terminals that carry out limited computations, compile programs, and otherwise relieve the central or host computer of some of the work. Point-of-sale terminals found in retail stores often function as parts of distributed systems. The terminal not only acts as a cash register, but sends data on purchases to a central computer that can manage inventory, compare sales volume by brands, and provide other information to managers. Automatic banking machines are another familiar example; each automatic teller functions as a smart terminal linked to the bank's central computer(s). These systems may include hundreds of machines spread over several States.

Networking is a related term, referring to dispersed machines that communicate with one another but are each autonomous. Any one machine can transmit data to any other; control of the network maybe distributed over the system or may reside in a designated processor. In some but not all cases, networked computers not only communicate and share control, but also share the processing load. Local networks serve a limited group of users, such as a single office. At the other extreme, a multinational corporation might link computers located in many countries to form a worldwide network.

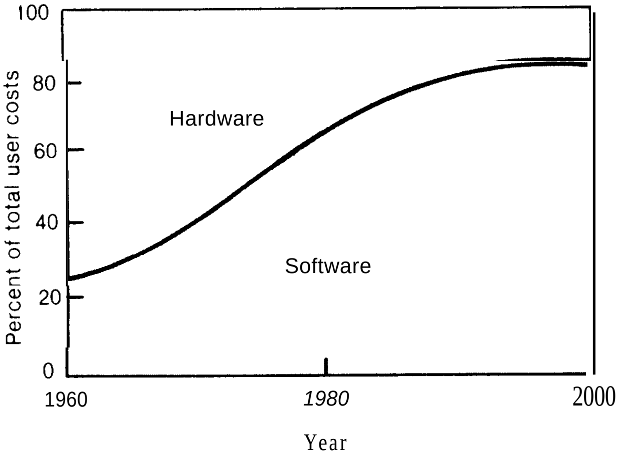
Computer Software

Physical equipment, or hardware—ranging from ICs, to disk drives, to networks—has been the primary subject above. But modern computers depend just as heavily on *software.* The programs that stand between user and CPU tell the hardware what to do. Arrayed in several levels, they range from applications software written in languages such as Fortran or Cobol —the only type of program that the typical user ever sees—to operating systems that supervise and coordinate both hardware and software elements. It is the software-architecture, operating system, compilers—that allows complex networks of computer and communications components to control steel mills, regulate air traffic, determine the path of a guided missile, distribute social security checks. Hardware and software in conjunction determine system performance, and customers weigh both aspects when making purchase decisions. In some cases this may entail buying software and hardware from different vendors and assembling a unique system. The spread of distributed intelligence, new applications of computers in homes and offices, shopfloor automation, computer-aided engineering analysis and design—all depend more heavily on versatile, reliable, user-friendly software than on hardware.

Since the beginnings of large-scale commercial production, computer hardware has become steadily cheaper relative to software. Costs for hardware have decreased by a factor of at least 1,000, holding processing power constant, over the past 25 years.[20] In marked contrast, software costs have not decreased appreciably, and may even have risen in real terms. A single line of programing, as a rule-of-thumb, costs in the range of $10 to $50—after inflation, about the same now as in 1955.[21] As a result, the largest part of the total cost to the user of a large computer system is now software, rather than hardware--figure 14. The chart applies to both purchased software-from computer manufacturers or independent vendors–and to user-developed programs; software maintenance is also included. At one time, many computer manufacturers provided system software such as control programs, language processors, and utilities free to hardware purchasers. Now, separate charges are the rule. For example, IBM currently sells about $1 billion worth of software per year, accounting for a little over 5 percent of the firm's total revenues; in newer systems such as the IBM 4300 series, nearly half the price of a typical installation is for software.[22] Similarly, more than half of the R&D commitment of a typical computer firm—measured either in terms of total expenditures or in terms of manpower—goes toward software.[23]

Cost trends for the development of software for dedicated applications—e.g., the logic for an embedded microprocessor—are similar. Even the simplest such application will require debugging and testing of the program to verify that it functions as desired. Software development for a microprocessor application may

Figure 14.—Relative Hardware and Software Costs Faced by Users of Larger Computer Systems



SOURCE' Office of Technology Assessment.

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[20] "Missing Computer Software," *Business Week*, Sept. 1, 1980, p. 46. The magnitude of the improvement depends on the type of system assumed.

[21] While productivity in programing-as measured in lines of code per unit of time—has probably increased, the rate of increase has been orders of magnitude slower than for hardware performance. Birbaum, for instance, points out that while programer productivity has increased by about a factor of 3 since 1955, system performance-to-cost ratios have gone up by roughly 10^5 over the same time period—J. S. Birbaum, "Computers: A Survey of Trends and Limitations, " *Science*, Feb. 12, 1982, p. 760.

In some programing tasks, productivity has probably remained rather stable—perhaps even decreased. Applications programing may now be somewhat more efficient because of improvements in higher level languages. Productivity in systems programing, or developing software for dedicated microprocessors, microcomputers, and minicomputers, has probably not improved as rapidly; when systems become more complicated, many of the stages in program development—from conceptual design to debugging—become more arduous. Even a relatively simple program may have of the order of 10^{20} different execution paths, depending on the number of loops, branches, and subroutines. Costs per line can escalate as program size and complexity increase. Another common rule-of-thumb is that a man-month of effort is required to demonstrate that 100 lines of code is, for practical purposes, error-free and functionally correct.

[22] "Missing Computer Software, " op. cit.

[23] "Computer Technology Shifts Emphasis to Software: A Special Report," *Electronics*, May 8, 1980, p. 142.

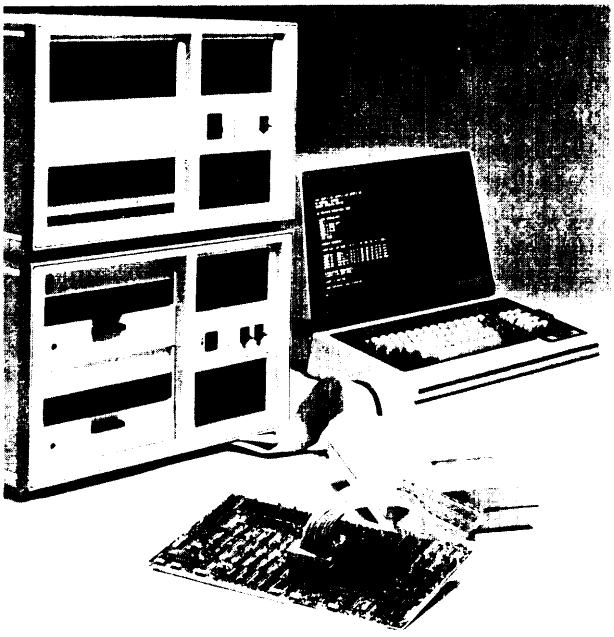

Photo credit Tektronix, Inc

Microprocessor development system

cost several hundred million dollars, with estimates for ***1985*** running to ***$3*** million or more.[24]

The rising relative costs of software have been one factor in the rapid growth of independent firms that develop and market programs of all types. Many computer manufacturers have traditionally been rather hardware-oriented, leaving an attractive market for vendors who concentrate on software (see app. C, "Computers: A Machine for Smaller Businesses," on the role of "systems houses" in the development of the minicomputer market). Even IBM—which has built its market dominance in larger machines on software as much as hardware—has turned to independent software firms to supply programs for its personal computer. Independent software vendors sell perhaps $1 billion in off-the-shelf programs per year, and twice that amount in custom programing.[25]

Growth of Computing Power

Figure 14 gave one picture of the rapidity of change in computer technology, and in the computer industry in general. But change extends far beyond the relative costs of hardware and software, the rapid growth in the microcomputer market (now about 50 percent per year), or continued increase in performance cost ratios for computer systems. And, while distributed intelligence may eventually have broader and deeper effects on the way people live and work than big machines, the absolute rise in computing power delineated in table 4 illustrates simply but dramatically how rapidly the capabilities of the most powerful digital computers have increased—nine orders of magnitude since the close of the Second World War, six orders of magnitude in the 30 years since the introduction of the first commercial machine, the Univac I. All the computers listed in table 4 would be classed as mainframes, and those of recent years as supercomputers—representing the maximum in computing power available at a given time. *

While the biggest computers have been growing in speed, smaller machines--like all computers—have been growing in performance per dollar. Table 5 compares an 8-bit single-board microcomputer representative of 1970's technology to the IBM 650—a first-generation vacuum tube processor of the mid-1950's. The two machines are roughly comparable in computing power, but the modern microcomputer is orders of magnitude smaller and cheaper,

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[24] "Missing Computer Software," op. cit. One supplier of microprocessors and microcomputers has estimated that a typical mid-l 970's application carried a software development cost of about $20, 000 ($20 per 1 ine of code], but by 1980 the cost was $100,000 to nearly half a million dollars ($35 per line of code, but also many more lines], Meanwhile the hardware costs have remained about the same—in the vicinit y of $100 per unit, See J G. Posa, "Intel Takes Aim at the '80s," *Electronics*, Feb. 28, 1980, p. 89.

‘SW. D. Gardner, "The Key to Greater Productivity," *Dun's* Review, August 1980, p. 74. The total value of computer software in use worldwide probably exceeds $200 billion.

*Arithmetic operations per second, the measure used in the table for comparing computing power, is not a perfect yardstick because many data-processing programs are limited by operations other than arithmetic— .g., inverting matrices, More sophisticated comparisons employ "benchmark" programs based on representative tasks. Arithmetic operations as used in the table have the advantage of being easy to understand and applicable to early model computers, some of which could not execute modern benchmarking programs.

Table 4.—increase in Computing Power Over Time

Year	Model	Computational speed (arithmetic operations per second)
1944	Harvard Mark I (electromechanical)	0.4
1946	Eniac	45
1951	Univac I	270
1953	IBM 701	615
1961	IBM 7074	33,700
1963	CDC 3600	156,000
1965	IBM 360/75	1,440,000
1972	CDC Cyber 176	9,100,000
1976	Cray 1	80,000,000
1981	CDC Cyber 205	800,000,000

SOURCES J R Bright, "Technology Forecasting Literature Emergence and Impact on Technological Innovation, " P Kelly and M Kranzberg (eds), *Technological Innovation: A Critical Review of Current Know/edge* (San Francisco. San Francisco Press, 1978) p 300, "The Digital Age," *Electronics*, Apr 17, 1980 p 382, P J Schuyten, "The Battle in Supercomputers " New *York Times*. July 22, 1980, p D1

and—at least as significant—vastly more reliable.[26] Note that these computers are separated in time by only two decades. Figure 15 gives an alternative picture of growth in performance per dollar. The plot shows the decline in price for a minicomputer family—after 1965 the pioneering PDP-8, although the first several years apply to an earlier model–the rapid fall stemming in part from learning curve phenomena as for semiconductor devices. Drops in prices for the semiconductors a machine contains—figure 16—also lead to cost reductions. Digital Equipment Corp. introduced the PDP-8 at $18,000; by the early 1970's some versions were priced as low as $2,500.[27]

"Generations" of computers can be distinguished based on advances in the technology. For example, the IBM 650 (table 5) represents a first-generation machine, the F-8 microcomputer third generation. Zeroth-generation systems were similar to the 650 in using vacuum tubes, but early computers such as Eniac lacked the ability to execute stored programs, the hallmark of the modern digital computer. To change a program in Eniac meant altering

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[26] Integrated circuits typically exhibit reliabilities—measured as mean times between failure (ch. 6)—of the order of 10^{11} hours/gate. Thus, a typical microprocessor containing 10,000 gates might have a mean time between failures of about 10 million hours, or 1,000 years. In contrast, mean times between failures for discrete transistors are about 10^8 hours, for vacuum tubes, less than 10^6 hours, See, S. Middelhoek, J.B. Angell, and D.J. W. Noorlag, 'microprocessors Get Integrated Sensors, " IEEE *Spectrum*, February 1980, p. 42.

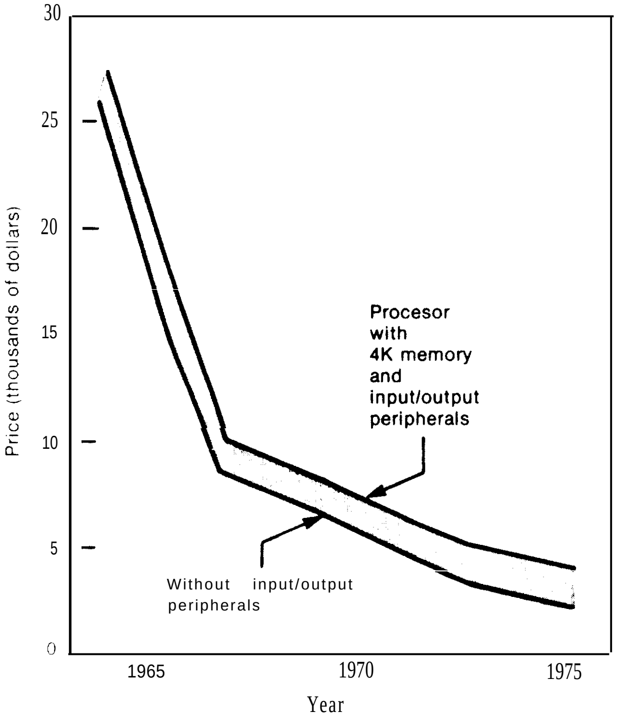
[27] G. Lewis, "Small Computers, " *Electronic News*, Jan. 25, 1982, sec. I I, p. 70.

Table 5.—Comparison of IBM 650 (1955) and Fairchild F-8 Microcomputer (1970's)

	IBM 650	F-8	Remarks
Physical volume (ft^3)	270	0.01	F-8 about 30,000 times smaller
Weight (pounds)	5,650	1	
Power consumption (waits)	17,700	2.5	F-8 consumes 7,000 times less power
Memory (bits)	3K main, 100K secondary	16K ROM, 8K RAM	
CPU . . ..,-. ..., ...	2,000 vacuum tubes	20,000 transistors	650 also needed many discrete resistors and capacitors
Time for adding two numbers (microseconds).	750	150	
Reliability (mean time between failures)	Hours	Years (3 million to 10 million hours is a typical mean time between failures for a current microprocessor—more than 300 years—but the subsystems with which the microprocessor communicates—e.g., terminals, printers—may be much less reliable)	F-8 at least 10,000 times more reliable
cost	$200,000 *(1955* dollars)	Under $1,000 with terminal	

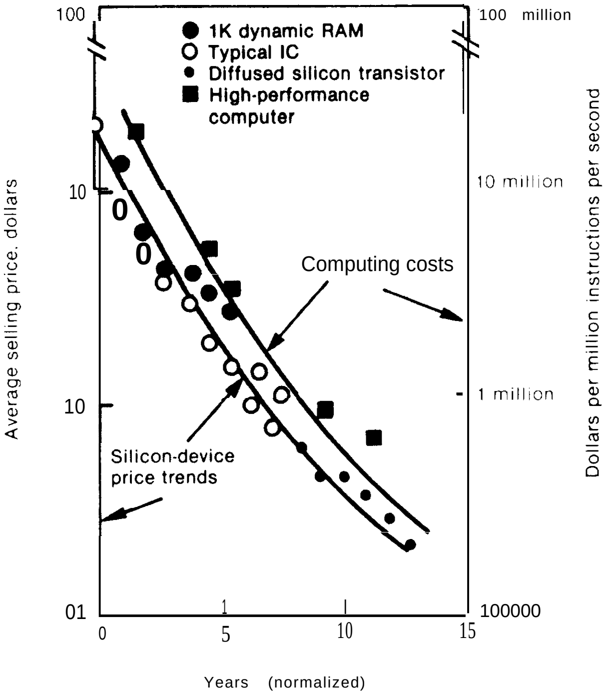
SOURCES IBM 650 information from "1978 First Quarter and Shareholders Meeting Report, Texas Instruments, Inc Fairchild F-8 information from" J G Linvill and C L Hogan, "intellectual and Economic Fuel for the Electronics Revolution, " *Science*, Mar 18, 1977, p 1107

Figure 15.— Minicomputer Price Trends (12-bit Digital Equipment Corp. models, PDP-8s after 1985)



SOURCE C G Bell J C Mudge, and J E McNamara, *Computer Engineering* (Bedford Mass Digital Press, 1978), p 194

Figure 16.— Parallel Decreases Illustrate How Costs of Computers Depend on Costs of Semiconductors



SOURCE I M Mackintosh, "Large-Scale Integration Intercontinental Aspects," *IEEE Spectrum,* June 1978 p 53

thousands of patchcords—in essence changing the hardware—a task that could take several days.

Current machines represent generation three-and-a-half or four, table 6, although the notion of generations has lost much of its meaning with the rise of distributed processing, A good deal of attention has recently focused on planning within Japan for fifth-generation technology—which, as the table indicates, might be characterized by major advances in software associated in a general way with "artificial intelligence." Among the goals of Japan's fifth-generation computer project are input and output in natural language—as ordinarily spoken or written. As the table indicates, the next generation may also be identified with new methods for communicating among computers, and perhaps some replacement of silicon ICs with higher speed devices. Hardware developments such as Josephson junctions would make natural language programing and related developments such as voice recognition easier to achieve by speeding the processing of the very complex algorithms required.

As noted in the table, the current generation is one of specialization, characterized by continuous rapid development on many fronts: minicomputers, microprocessors and microcomputers, distributed processing, new programing languages, improved peripherals, special-purpose machines such as array processors. As a result, it makes less sense to speak of "generations. " Computing power is becoming so widespread and pervasive that to focus on the characteristics that different systems have in common may obscure the true significance of specialization, and the distribution of machine intelligence to new applications—many of them quite different from those originally associated with "computers. "

Table 6.-Characteristics of Generations of Computer Technology

Generation	Period	Representative models	Description	Typical applications
Zero	1940's	Eniac	No stored program capability; vacuum tube processor.	Preparation of ballistics tables.
One	Early 1950's	Univac I	Stored program, but in binary machine language only. Vacuum tube processor.	Scientific and technical calculations (aerody - namics, nuclear weapons design) business (accounting, Inventories, payrolls); Government (census).
Two	Late 1950's	IBM 7090	Higher level languagessuch as Cobol; CPU uses discrete transistors. Magnetic core memory common, along with line printers for output. Punched cards used for data entry.	As above, but much more widespread.
Three	1960's	IBM 360 series; Burroughs 6500	Hybrid ICs—combining discrete transistors and integrated circuits on a single substrate (IBM 360 series) or small-scale ICs (Burroughs 6500 and others) used in CPU. Time-sharing available.	Continuing spread of data-processing applications as costs decrease. Real-time processing becomes more common.
Three-and-a-half or four	Late 1960's to present	IBM 370 series; DEC PDP-11	Large-scale ICs; distributed processing, networking. Proliferation of special purpose computers; rapid growth of minicomputer markets. Microcomputers developed.	Great Increase in specialized, dedicated applications, particularly for minicomputers. Data base management systems spread. Networking and distributed processing point toward merging of data processing and data communications, typical applications being electronic funds transfer, Microprocessors make many products "smart, " as well as substituting for custom logic,
Five	Late 1960's or 1990's	?	Natural language programing; voice recognition, speech synthesis. Gallium arsenide ICs or Josephson junction devices may replace silicon ICs in CPUs.	

SOURCE: Office of Technology Assessment. See, in general, S Rosen, "Electronic Computers: A Historical Survey, " *Computing Surveys*, vol 1, 1969, p 1, J T Soma, *The Computer Industry" An Economic-Legal Analysis of Its Technology and Growth* (Lexington, Mass. Lexington Books, 1976), PP 9-30, "Digital Computers: History," *Encyclopedia of Computer Science*, A Ralston and C.L. Meek (eds) (New York: Petrocelli/Charter, 1976), pp 474-495.

Applications of Computers

As pointed out earlier, the microprocessor was originally developed as an alternative to custom ICs for a line of hand calculators—an example of a dedicated or embedded application where the computer is invisible to the user, Such applications of small processors far outnumber generalized data processing. In most dedicated systems, the programs are permanently stored, and the user interacts with the machine through switches, control knobs, or—as in the case of a word processor—a keyboard. A large commercial aircraft may contain a dozen or more computers, but the pilot need never know of their presence. His interfaces are instruments and flight controls. In the same way, when a minicomputer or mainframe supports word processing applications, the typist may never see or be aware of the computer. As this example shows, dedicated applications need not be restricted to small machines. Furthermore, the distinction between dedicated and general-purpose applications is not always clear-cut. A mainframe computer might support dozens of word processing stations, while at the same time running data processing programs in both batch and time-sharing modes.

Table 7 illustrates something of the range of current applications of computing power, while an example from the field of industrial process control is described in more detail in appendix 3C. Note that even in the rather arbitrarily defined data processing category, several of the familiar examples—airline reservations and tickets, point-of-sale terminals—depend on dedicated machines. Also note that dedicated applications help make the data-processing systems themselves function; controllers for disk or tape drives are often based on microprocessors.

Leaving aside the overlaps among categories —because so many technologies blur and merge as intelligence is added—the breadth of

Table 7.—Typical Applications of Computing Capability

Example	Usual Type of Computer
Data processing	
Business records (accounting, payroll, order processing and billing, production control, inventories, taxes, banking).	Mainframe, mini, or micro, depending on size of business.
Government records and statistics (census and other data bases, tax records, social security, economic data).	Mainframe.
Scientific and technical (social science data bases, engineering calculations, modeling of complex systems).	Mainframes for batch and interactive processing; micros and minis for laboratory automation as well as specialized applications such as modeling chemical reactions.
Medical records.	Mini or mainframe.
Airline reservations.	Mini or mainframe.
Point-of-sale terminals, electronic cash registers.	Micro, but may be part of distributed system.
Communications and control	
Multiplexing and transmission of voice and alphanumeric data.	Varies.
Telephone exchanges.	Mainframes.
Private exchanges (PBX, PABX).	Micros and minis.
Facsimile transmission.	Minis and micros.
Teletext, viewdata.	Micros.
Air traffic control.	Mainframes.
Military systems	
Signal processing (radar, sonar).	Mainframe or mini, depending on need for portability.
Navigation	As above, or micros.
Fire control.	As above, or micros.
Flight control.	Micros.
Industrial systems	
Batch process control (machine tools, assembly robots, heat treating, materials handling, steelmaking, typesetting).	Minis and micros.
Continuous process control (petroleum refining, rubber and synthetic fibers, basic chemicals, paper products, foods).	Mainframes and minis.
Computer-aided design.	Mainframes and minis.
Energy production, conservation and control (turbine startup, electric utility load management, process heat, building heating, ventilation, and air-conditioning).	Varies.
Environmental monitoring and pollution control.	Minis and micros.
Education and training (computer-assisted instruction).	Varies.
Measurement and testing (medical diagnostics, nondestructive inspection, chemical analysis).	Minis and micros.
Office automation	
Word processors.	Micros and minis
Copiers.	Micros.
Calculators and accounting machines.	Micros.
Consumer products	
Automobiles (engine control, driver information, diagnostics).	Micros.
Home entertainment (electronic and video games, personal computers).	
Appliances (refrigerators, microwave ovens, sewing machines).	
Thermostats and environmental controls.	
Calculators.	
Cameras.	
Electronic watches.	

SOURCE Office of Technology Assessment

applications is striking. In fact, it is difficult to think of manufactured products or processes that could not use computing power in some form. In a recent 35mm camera design, the number of mechanical parts dropped from nearly 1,300 to 900 when a single-chip microcomputer was incorporated.[28] Some observers have predicted that a typical home will contain a dozen or more computers by the 1990’s

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[28] “Canon’s Fujio Matarai: Strategies for the U. S. Market,” *World Business Weekly,* Oct. 19, 1981, p. 20.

—a proliferation often compared to that of the fractional horsepower electric motor, Limitations on such new and specialized applications often stem from software engineering problems or total system hardware cost—but seldom the cost of the computing power itself. For example, to extend the use of microprocessors in automobiles to nonskid braking systems is possible, even straightforward, from an engineering standpoint, but nonetheless expensive—primarily because of the cost of the sensors and actuators required. On the other hand, the design of a practical collision avoidance system for ordinary driving is still limited by engineering problems that, broadly speaking, can be considered software. It is quite difficult to develop algorithms for unambiguously detecting collision hazards, and for adapting the output of a collision hazard identification system to the controls facing the human operator—steering wheel, accelerator, brakes.

Summary and Conclusions

Electronics technology—used for transmitting and manipulating *information* via electrical signals-has been evolving from analog toward digital, driven in the broadest sense by applications of computing power. Digital communications have advantages over analog, and as both computing and communications have moved toward digital technologies, the semiconductor industry has been called on to provide new kinds of building blocks, Even in the consumer electronics industry, digital equipment is being developed.

Although new products such as video cassette recorders and video disks have reached the marketplace in recent years, consumer electronics technologies move slowly compared to semiconductors or computers. Commercial viability depends on consumer appeal, which can come from technology but also from many other sources. The success of the Sony Walkman—a personal audio tape player—is more the result of a good match between the marketplace and the engineering development laboratory than of new technology. Coming generations of consumer electronics products—e.g., integrated home entertainment systems—-will continue to stand or fall on product design and marketing, with technology as only one dimension.

Still, the products of the consumer electronics industry have been transformed by semiconductor devices. Beginning with the transistor radio—and extending to the digital technology embodied in video games, pocket calculators, and electronic watches—products that people see and use every day are practical only because of semiconductors. As microelectronics technology has progressed from discrete transistors to small-scale ICs and then very large-scale circuits, new applications in electronic systems of all types have emerged. The growth of the computer industry has followed advances in semiconductors, as have military applications ranging from missile guidance to war gaming,

VLSI has brought forth the “system-on-a-chip”--a prime example being the single-chip microcomputer. While one IC can now accomplish more than a room full of computing equipment three decades ago, microprocessors and microcomputers are also used in large numbers for quite different purposes—namely for replacing “hard-wired” logic, Engineers can trade off the hardware costs of custom design and manufacture against the software costs of developing programs to be permanently stored in the memory associated with a dedicated microprocessor or microcomputer. The programed logic can then control a microwave oven or fly an airplane.

With advances in density and performance have come higher costs for IC design, and for the sophisticated processing equipment needed to make VLSI devices. These have driven the capital requirements for entering the semiconductor industry upward; firms striving to compete at the leading edge of the technology now depend on both computer-aided circuit design and computer-aided process control. In semiconductor processing, as in the development of computer software, fundamental understanding from the viewpoint of engineering science has lagged practice. Semiconductor fabrication is an art, as is programing, Putting these two technologies on firmer underpinnings will be critical for avoiding future bottlenecks in the development of the semiconductor and computer industries.

As digital computers evolved they grew bigger in processing power, smaller in size. The range in size and capability of digital computers is now truly awesome—from single-chip microcomputers costing ***$100,*** to supercomputers like the Cray-1 that operate at speeds limited in a very real sense by that of light (because electrical signals propagate at speeds that can be no greater, and the time to move signals within the processor limits computational speed). At the same time, the seemingly mundane problem of transferring the heat dissipated in the chips out of the system is one of the critical elements in the design of a high-performance machine.

Applications of computers have sometimes been driven by the availability of the technology, and its continually decreasing costs, sometimes by newly recognized needs—forces that interact continuously. A great deal of technical ferment is presently centered on software of all types, Markets for small computers—intended for personal use as well as applications in business and industry—are expanding rapidly. The most pervasive trend is the widespread distribution of intelligence to the points where needed. Machines of all types are getting smarter and more specialized, and computers (including microprocessors) already outnumber people in industrialized countries like the United States.

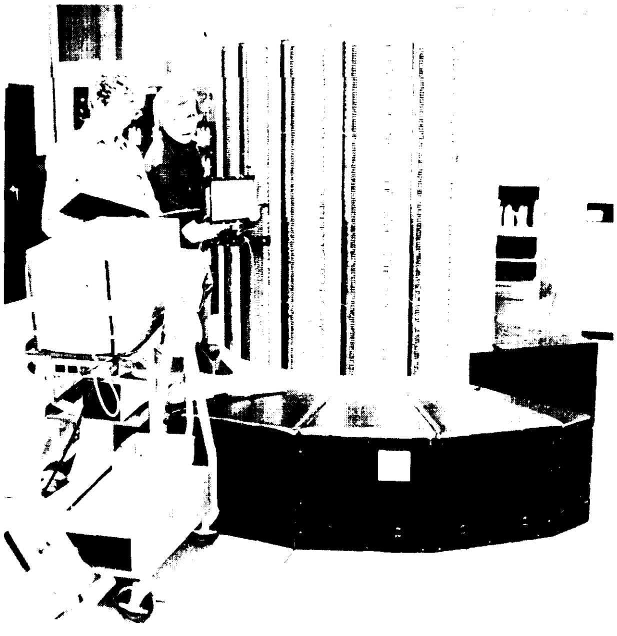

Photo credit Cray Research

Central processing unit for a supercomputer

Appendix 3A.—Integrated Circuit Technology

Types of Integrated Circuits

Table 3A-1 outlines some of the principal varieties of ICs.

As table 3A-1 indicates, ICs come in two major varieties: MOS and bipolar. Many small- and medium-scale circuits are bipolar, as are some LSI chips, but over the course of the 1970's MOS technology became dominant for LSI. Bipolar chips are less dense than MOS, typically by factors of about four—i.e., transistors and other circuit elements cannot be located as close together; they also consume more power—one of the reasons that the circuit elements cannot be packed more closely is the need for heat dissipation. The greater number of circuit elements that can be placed on a given area of silicon using MOS technology often ***leads to*** significantly lower costs. By contrast, the chief advantage of bipolar technology has been high operating speed. However, the speeds of MOS ICs have been improving more rapidly than the speeds of bipolar devices. Where high speed is critical—as in

Table 3A-1.—Common Terminology and Classifications of Integrated Circuits

Assembly

Monolithic--all circuit elements fabricated on a single semiconducting substrate (usually silicon).

Film—conducting layers are deposited on an insulating substrate to form the circuit.

Hybrid—combines several ICs and/or discrete transistors in a single package, often using film technology for components and interconnections.

Input-output Characteristics

Analog (also called linear)—levels (e.g., voltages) of input and output signals vary continuously over a range.

Digital—input and output signals have values limited to either of a pair of nominally discrete values (e.g., voltage levels of O or +5 volts).

Transistor technology

Bipolar—conduction takes place through motion of both electrons and holes (a hole is an electron vacancy—the absence of an electron where one would ordinarily be; the same current can be carried by electrons moving in one direction, by holes moving in the *opposite* direction, or by a combination of electron and hole motion); *control* of the transistor is through a *current* signal.

MOS (metal -oxide-semi conductor)— MOS transistors are *unipolar* rather than bipolar; conduction is by either electrons or holes, but not both, and the transistor is controlled by an impressed voltage (MOS transistors are actually subsets of the broader class of field effect transistors (FETs), but the MOSFET is by far the most common type of FET).

Digital device applications

Logic** circuits*— both bipolar and MOS ICs are used for digital logic circuits; the logical operations are performed by arrays of ***gates, each of which implements a Boolean function such as AND, OR, NOR, NAND; the gates themselves consist of groups of circuit elements typically including one or more transistors plus resistors and capacitors.

Bipolar transistors can be grouped by *logic families* such as TTL (transistor-transistor-logic) and I^2L (integrated-injection-logic), the names of which characterize the gate circuitry.

MOS circuits are classed somewhat differently; n-MOS, the most common, refers to circuits using “n-channel” MOSFETs, where the current is carried by electrons, p-MOS to “p-channel” technologies where the current is carried by holes, and c-MOS to “complementary” MOS where n- and p-channels coexist in the same IC.

Microprocessors—digital logic circuits that can serve as processing units for digital computers—i.e., can execute programs; most microprocessors are MOS ICs.

Microcomputers— ICs that contain a processing unit plus memory circuitry.

Memory--ICs that can store digital data in an array of logic gates, each storage location containing a “bit” of binary (“O” or”1”) information; the number of bits stored in a single IC presently ranges up to more than 64,000 (in a 64K random access memory (RAM)). (See table 3A-2 for more detail on memory circuits. Some types already have higher capacities than the 64K RAM.) Most memory chips are MOS ICs.

Circuit density

Levels of integration, or packing density, for ICs are grouped by order of magnitude of the number of devices on a chip.

Discrete—single individual y packaged active device—e.g., a transistor.

***Small-scale** integration* (SSI)—refers to ICs with of the order of 10 active devices.

Medium-scale integration (MSI)— ICs containing of the order of 100 devices. The simplest gates used in dynamic random access memory (RAM) chips consist of one transistor plus one capacitor, and IC density is sometimes referred to in terms of gates per chip rather than devices per chip. Because some gate designs use several active elements, devices per chip is more meaningful.

Large-scale integration (LSI)–ICs with roughly 1,000 to 10,000 or more devices. A so-called 1 K RAM can store 2^{10} or 1,024 bits of digital information. Each memory cell includes at least one gate. Thus, a 1 K RAM, which needs other devices for getting the bits into and out of the chip, is an LSI circuit. So is a 4K RAM, which includes about 5,000 devices. 16K RAMS (close to 20,000 devices) are usually considered LSI circuits, with 64K RAMs (2^{16} or 65,536 memory cells, plus several thousand devices for getting the bits into and out of the chip) the lower end of very large-scale integration.

Very *large-scale integration (VLSI)—ICs* containing of the order of 100,000 devices. In addition to 64K RAMS-which entered mass production during the late 1970’s—other VLSI devices include 16-bit microprocessors such as the Motorola 68000, which contains about 69,000 devices. By 1982, the densest circuit produced was a microprocessor built by Hewlett-Packard with 450,000 devices. Pilot production of next generation RAMs—256K chips—began during 1983. ICs containing on the order of a million devices will probably be given a name such as ultra large-scale integration.

SOURCE: Office of Technology Assessment

processors for large computers—bipolar ICs remain the technology of choice. For consumer products such as calculators and watches, for primary read/write memory in computer systems, and in other applications where cost is more important than speed, MOS is generally specified. Some of the distinctions between bipolar and MOS technologies may blur and disappear as IC technology continues to advance, with much of the impetus for such developments likely to come from R&D efforts focused on improvements in MOS.

A principal application of bipolar chips is digital logic; bipolar logic circuits are often used in conjunction with MOS microprocessors and memory circuits as parts of complex systems including many ICs. There is considerable demand for bipolar small- and medium-scale devices that can serve as universal building blocks; here, their low packing density is not necessarily a handicap. The great majority (perhaps 90 percent) of standard bipolar logic circuits belong to the TTL—or transistor-transistor logic—family (table 3A-l). Typical examples of small- and medium-scale TTL circuits would be counters, buffers, and digital/analog (D/A) or analog/digital (A/D] converters. Buffers store strings of binary data for short periods of time; they are used to adjust and coordinate data rates between different parts of a system. D/A and A/D converters serve as interfaces with analog components that provide input signals to the system or receive its output. A common output device is a cathode-ray tube, which must be driven by an analog signal and thus depends on D/A converters when fed digital information from a computer or word processor. A/D and D/A converters are also used in conjunction with many types of sensors and actuators (a familiar example of a sensor is a thermometer; an electric motor can function as an actuator).

How Microprocessors Work

A typical microprocessor is an MOS IC including an arithmetic logic unit, several registers, control logic, and paths for moving data among these (fig. 12). Within the arithmetic logic unit, groups of binary bits called words (or bytes) are added and subtracted by moving and manipulating the strings of bits among the registers. These operations are all performed on numbers represented in binary form; the conventional decimal (base 10) number 6, for example, is written in binary (base 2) as 0110.

In a 4-bit microprocessor, the standard word consists of 4 binary bits; an 8-bit microprocessor has a word length of 8 bits. In general, the longer the word, the faster and more powerful the microprocessor—but also the higher the costs for programing and system development, as well as for production or purchase. Four-bit microprocessors are suited to inexpensive pocket calculators or controlling a simple system like a microwave oven. Microprocessors with longer word lengths are used for more demanding applications. The most complex microprocessors now in common use have 16-bit words; 32-bit chips will follow. Large mainframe computers such as those produced by IBM are typically designed around words having 32 or more bits.

The control logic in a microprocessor [fig. 12) regulates the flow of binary information within the chip. Many microprocessors include a clock that synchronizes the operations performed, although sometimes a separate clock chip must be provided. The faster the clock speed, the faster the microprocessor can manipulate information, everything else equal, Typical 8-bit microprocessors operate at clock speeds in the range of 5 MHZ—5 million cycles per second—which does not mean that they can perform computations at this rate. The various instructions that the microprocessor carries out normally take several clock cycles, and the logical operations that these implement depend on the instruction set—more generally, on the architecture of the processor. These features of the design determine the permissible ways that binary data can be manipulated. The tradeoffs involved in defining the architecture and instruction set for a microprocessor mean that some microprocessors perform certain kinds of tasks faster or with simpler programing than others. But because all the binary operations performed in the arithmetic logic unit are primitive, a microprocessor with a clock rate of 5 or 10 MHz executes functions such as subtraction or multiplication at rates which are only a small fraction of this.

The microprocessor must also be able to pass binary information back and forth to chips that provide memory, A/D or D/A conversion, and a variety of specialized functions. This is done through input/output (1/0) ports, The circuit paths along which the bits travel are called buses (fig, 12). As implied, a microprocessor cannot function by itself, but must be supported by other circuitry. As a minimum, the microprocessor has to communicate with a ***memory*** sufficiently large to hold the program being executed, (A ***single-chip microcomputer*** includes on-chip memory for program storage, in contrast to a microprocessor, which does not have built-in memory.) The program itself consists of a set of instructions, coded in binary form, which tell the processor how to manipulate the bits in its registers, The processor uses an address to fetch the appropriate information from memory or to send information back to memory locations. Likewise, 1/0 buses and ports have associated addresses. Many of the operations performed by the processor are simply matters of getting the string of bits into or out of the registers.

In addition to memory, a microprocessor must be connected to a power supply, and it often communicates with external devices—e.g., ***sensors or transducers*** that generate electrical signals corresponding to the magnitude of parameters such as temperature, position, or pressure. Usually the transducer output is an analog signal—for example, a resistance thermometer produces a continuously variable voltage—and an A/D converter must be interposed. This can be built into the transducer–some microcomputers are also available with built-in A/D and D/A converters—but is usually an independent circuit. A/D converters (and D/A) tend to be limited in speed and precision; they are also expensive—a single converter may cost more than the microprocessor it is used with.

Peripherals are information-handling equipment external to the central computer, whether it be a microprocessor or a larger machine. Examples of peripherals are bulk memory (in the form of arrays of IC chips, or magnetic disks and tapes), terminals (typically keyboards with or without CRT display screens), and printers. *Interfaces* are generally needed to allow a microprocessor or computer to communicate with the peripherals. While in the past, most interface circuits were custom-designed from SSI and MSI chips, LSI parts are now available in standard form to implement common functions such as interfacing with and controlling a CRT terminal. Typically, interfacing is much more demanding from a software than from a hardware standpoint.

Memory Circuits

Microelectronic devices–generally ICs–that store information in binary form come in many varieties, as outlined in table 3A-2. Declining prices for RAMs, in particular, have led to rapid increases in demand for applications in computer-based systems of all types. As specialized memory chips—for instance, erasable-PROMs—become cheaper and easier to use, still more applications for microprocessor systems will open.

How Integrated Circuits Are Made

Circuit fabrication begins with a silicon wafer sawn from a carefully grown cylindrical crystal. The wafer itself is a fragile disk, as thin as 0,010 inches, on which hundreds of ICs will be simultaneously created before being cut apart into individual chips. Although a few large manufacturers grow their own crystals, most semiconductor-quality silicon is produced by independent firms. The composition—particularly the oxygen content—must be carefully controlled, as must the flatness of the wafers, which is critical for high yields in the subsequent lithographic processing. At present, the most common wafer diameter is 4 inches. Bigger wafers reduce production costs because more circuits can be made at once; therefore, as IC fabrication technology advances, wafer diameters tend to grow.

Table 3A-2.—Principal Types of IC Memory Circuits

Designation/Function
Read-only memory (ROM): Contents are permanently stored during manufacturing; memory can thereafter be read but not altered. Commonly used for program storage in microprocessor-based systems, the memory contents in a ROM are normally determined by the masking patterns used in fabricating the circuit (IC manufacture is described in the next section).
Read-write memory (RWM): Memory contents can be written over and changed, as well as read. Applications include storage of data, output, programs, and other general memory requirements.
Random-access memory ***(RAM):*** Common name for IC read-write memory chips. Strictly speaking, random-access means only that any particular memory cell can be addressed directly and the contents retrieved. By this meaning, ROM chips, for example, are also random-access. Nonetheless, in common usage the term random-access or RAM now applies only to read-write memory. In contrast to IC RAMs, a bubble-memory device is not random access because data is stored in a string of magnetic bubbles which can only be read or written sequentially by passing the string through a detector until the desired address is located. The time to access any memory location in a RAM is nominally the same; in a serial device such as a bubble memory, the time depends on where in the string the memory location happens to fall with respect to the detector. RAM circuits can be static or *dynamic.* The basic difference is that dynamic RAMs store data in memory cells that rely on capacitance. As the charge gradually leaks off capacitors, they must be “refreshed” several times a second by a voltage pulse. (Many microprocessors provide built-in refresh capability because the need is so common.) Static RAMs, in contrast: do not require refreshing; each cell will retain its contents as long as power is supplied to the chip. Both static and dynamic RAMs are ***volatile*** memory devices. This means that their contents are lost when electrical power is removed. In contrast, magnetic tapes or disks are *nonvolatile* because they retain the data stored whether or not supplied with power. Bubble-memory devices are nonvolatile, as are ROMS and magnetic core memory.
Programmable ***read-only memory (PROM):*** ROMs with memory cells in which data can be stored after manufacture are called—in contrast to a ROM—PROMS. Some PROMS are permanently programed by a process analogous to blowing fuses, after which the contents of the memory cells cannot be altered. In other types, the contents of the cells can be erased—e.g., by exposing them to ultraviolet light—and then rewritten. PROMS are widely used in *system development—i.e.,* preparing the software on which a microprocessor-based system functions—as well as in low and medium volume production applications. In a typical development project, software is stored in PROMS for testing and debugging. Once the software functions properly, and the system is ready for production, programs might continue to be stored in PROMS, which would be programed during the manufacture of the system. Alternatively, they could be transferred to ROMs. The choice between PROM and ROM is a matter of manufacturing cost. PROMS are generally cheaper in small volume production, ROMs at high volumes.

SOURCE Office of Technology Assessment

Limitations centered around wafer flatness and lithographic capability prevent more rapid movement toward large wafer diameters.

After polishing, an epitaxial layer is sometimes grown on the wafers, followed by heating in a furnace to produce a layer of silicon dioxide, Oxidation produces the insulating layers that separate various parts of the circuit from one another, Portions of the oxide layer are later selectively etched away, leaving windows open to the silicon beneath.[1] As well as isolating various parts of the circuit from one another, the oxide serves to protect parts of the wafer from dopants during diffusion or ion bombardment (see below).

In preparation for lithographic pattern formation (illustrated earlier in fig, 8), the wafer is next coated with a thin layer of photoresist—a material analogous to a photographic emulsion which changes chemically when exposed to light (or occasionally, beams of electrons, X-rays, or ions—the latter mostly in laboratory stages of development, as indicated below). The masking and lithographic steps must create the same patterns many times over—figure 3A-1. Masks are typically glass, carrying a grid-like pattern of aluminum or chromium so the mask is transparent to radiation in some areas, opaque in others. SSI and MSI circuits can be made with masks containing hundreds of identical patterns, one for each IC; the entire wafer is then exposed at once. While such a procedure is fast, it cannot produce the narrow lines needed for VLSI; instead,

Figure 3A-1.—Silicon Wafer Showing Patterns Formed by Photolithography

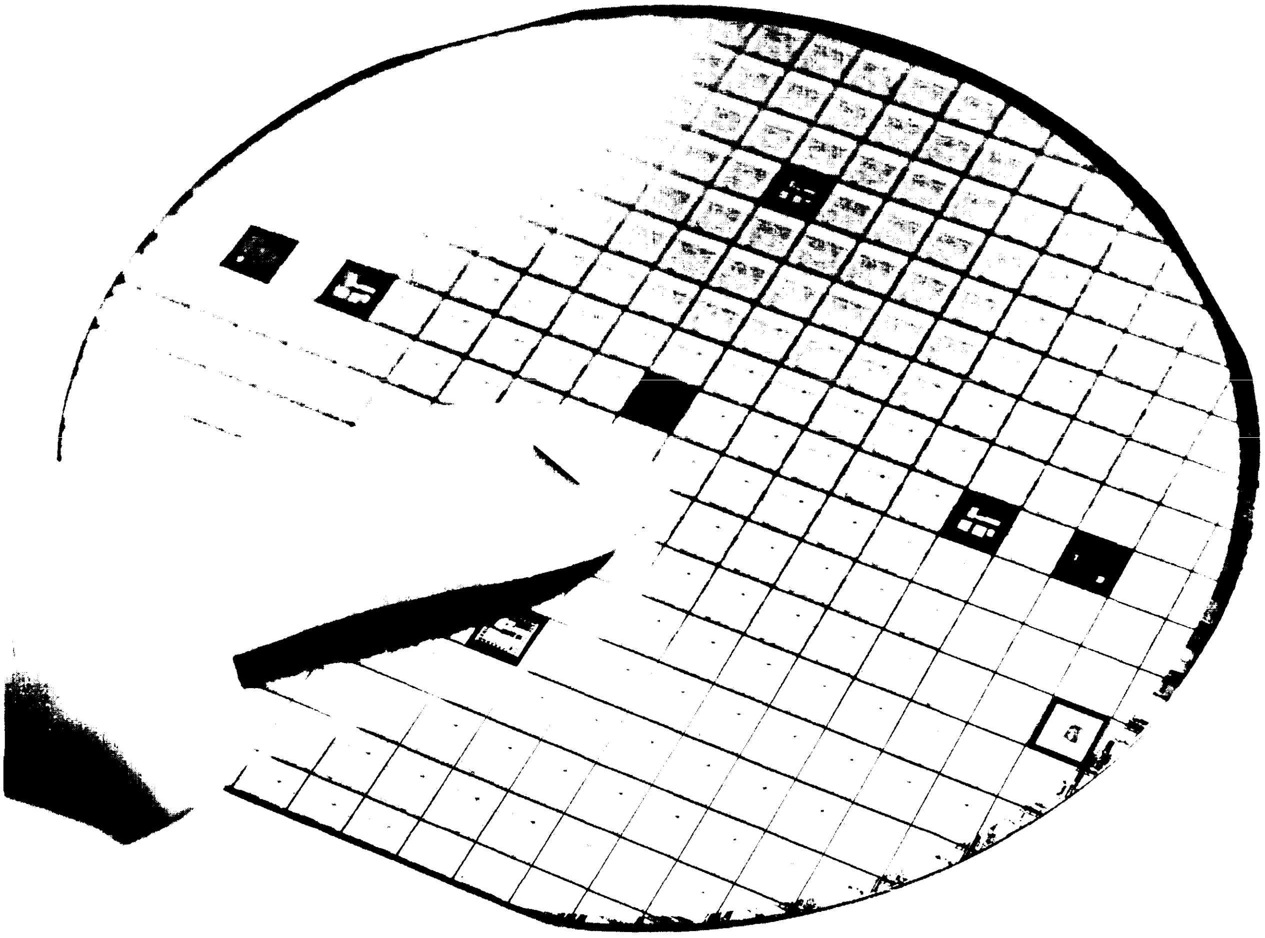

Photo credit. General Motors Corp

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[1] A. R. Reinberg, "Dry Processing for Fabrication of VLSI Devices," *VLSI Electronics: Microstructure Science,* vol. 2, N. G. Einspruch (cd.) (New York: Academic Press, 1981), p, 1.

the step-and-repeat approach diagramed in figure 8 is commonly adopted. The mask—which maybe 10 times the size of the image on the wafer—creates patterns for only one circuit at a time, after which the wafer is "stepped" beneath the mask and lens. As this process is repeated, a series of identical images in the resist layer is created. The equipment must precisely position and aline the wafer.

Exposure to light or radiation chemically alters the polymeric photoresist. The next step is to dissolve away those portions of the photoresist that have been exposed, creating a pattern identical to that carried by the mask—or, alternatively, to dissolve away those portions that were not exposed. The purpose of creating patterns in the resist is to permit selective etching and doping through the windows that remain. Etching is used to dissolve away material—e.g., portions of the oxide layer—accessible through these windows. In addition to removing oxide, sections of metal layers that have been deposited earlier can be etched away. The metallic layers—fabricated by processes called *metallization—produce* electrically conductive paths to interconnect circuit elements. *Doping* refers to the controlled introduction of foreign elements for altering the conductivity of the silicon. The dopants—e.g., boron, phosphorus—enter the silicon via diffusion or ion bombardment.

During the steps described above, termed wafer fabrication, the entire wafer is processed as a unit. While wafer fabrication can be automated, hand labor is still common; even with automation, the human element is just as important to high yields as the equipment used. When the steps which create the electronic devices and interconnections within each circuit have been completed, the circuits are individually tested—before separation from the wafer—via probes that make input/output connections. Circuits that fail these tests are marked and discarded when the wafer is sawn or broken apart to separate the individual chips. Each good chip is mounted on a chip carrier, which includes pins or prongs for connections to external circuitry, then packaged. An encapsulated IC is shown in figure 3A-2.

By far the largest fraction of defective circuits—hence yield losses—are uncovered at the conclusion of wafer fabrication. These often originate with mechanical flaws such as dust particles settling on the resist, pinholes in the mask, improper spacing of devices so that adjacent circuit elements interfere with one another, or oxide layers that are too thin to provide the necessary insulation, Most such flaws originate in lithography; as the overall size of the chip increases, the probability that it will contain a flaw also rises. This is one of the pressures that leads to greater levels of integration—i.e., making the devices and interconnections on the chip physically smaller, rather than making the chip itself larger, A variety of tradeoffs exist; as chip size increases the yield tends to decrease, but the chip can contain a greater number of functions. When 16K RAMs were coming into mass production, balancing these factors pointed to a chip that was 7 to 8 millimeters square; this gave yields in the range of 20 percent and minimized costs.[2]

Figure 3A-2.—Integrated Circuit Chip Before (top) and After (bottom) Final Encapsulation

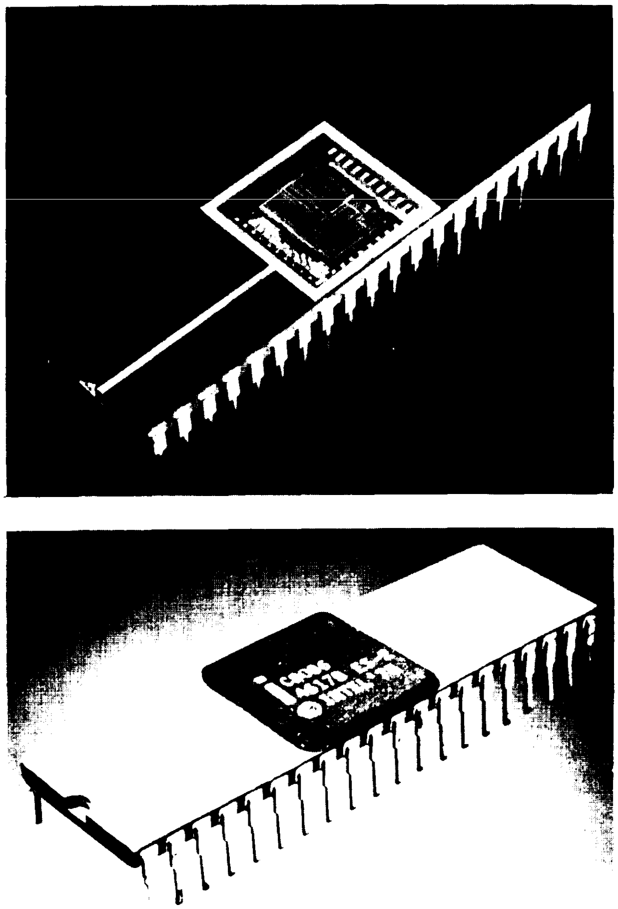

Photo credits: *Intel* Corp

Beyond the testing that occurs when the wafer is probed before sectioning lie other inspection and testing steps ranging from visual inspection to functional performance checks after the chip has been

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[2] J. A. Rajchman, "New Memory Technologies," *Science,* Mar. 18, 1977, p. 1223,

packaged. As ICs become more complex, such tests—many of which are performed under computer control—also become more complicated and expensive. It may be impractical, for instance, to check each memory cell in a large RAM or ROM under conditions that simulate actual operation, much less check all the possible operating states of a VLSI microprocessor. * Algorithms and sampling procedures are used to shorten testing while exercising circuits in realistic fashion. As integration levels increase, designers have greater incentives for building test logic onto the chip to make it self-testing. A parallel trend is to add redundant circuit elements that can be called into play in the event of partial failures.

The lithographic processing described earlier is now done mostly using light. Sometimes critical circuit layers are defined by electron beams, and electron-beam lithography is also used for making masks; in either case, a narrow (micrometer width) beam of electrons "writes" directly on a resist-covered wafer or glass substrate (for mask-making), much as the beam in a cathode-ray tube writes on the phosphor-covered screen. This process is inherently slower than focusing a broad beam of light through a mask to expose the entire chip at once. Moreover, the throughputs—in terms of wafers per hour (table 2)—that can be achieved with electron beam systems are limited by the characteristics of the available resists. Chemical resists that are sensitive to exposure by electron beams require lengthy exposure times, limiting the speed at which the electron beam can write. Electron beams are not the only alternative to light. Among the other candidates are X-rays and ion beams.[3] X-rays have potential advantages in throughput compared to electrons because area exposure through a mask is possible. Unfortunately, intense X-ray sources are not widely available; as for electron beams, resists that can be exposed with X-rays are relatively insensitive, and require long exposures unless the X-ray intensity is high. One source is a synchrotron ring, as used for research on the structure of matter—a very expensive piece of equipment.

Although synchrotron-based lithography for fabricating ICs would be even more capital-intensive than electron-beam lithography, the potentials of X-rays have stimulated considerable R&D. X-ray lithography is likely to become a production tool in the future; electron-beam equipment is already available, and X-rays may move out of the laboratory by the late 1980's. Ion beams have received less attention thus far, but might be able to give resolutions—hence line widths—considerably smaller than either electrons or X-rays.[4] R&D in high-resolution lithographic techniques has been a principal target of government-funded programs in other countries—e.g., the VLSI project in Japan—as well as the VHSIC program funded by the U.S. military.

•A 16K RAM can take on $2^{16,384}$ different logical states—an immense number, nearly $10^{5,000}$. Fortunately, the only likely interactions between memory cells involve those adjacent to one another, practical ways do exist to determine whether turning "on" one cell will affect data stored near it. The problem is much more complicated for microprocessors or random logic chips, which lack the regular, repetitive structures characteristic of memory.

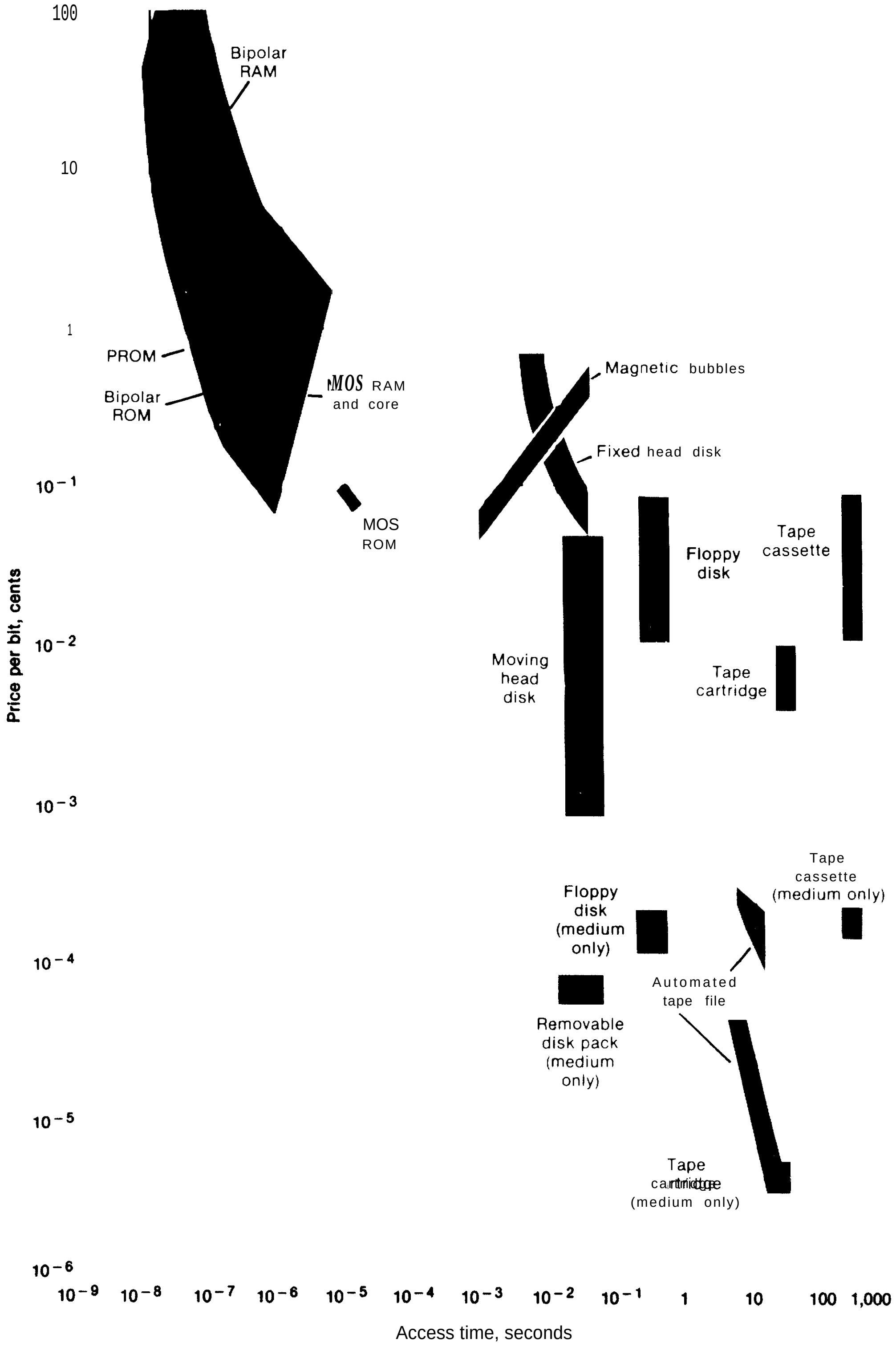
[3] M. P. Lepselter and W T Lynch, "Resolution Limitations in Submicron lithography, " *VLSI Electronics' ,Wi[.restructure Science,* vol 1, op. cit, p. 83, R. K Watts and J R Maldonado, "X-Ray Lithography," *VLSI Electronics. Microstructure Science,* VOI 4, N. G Einspruch (ed) [New York: Academic Press, 1982), p 55

[4] M P. Lepselter, "Submicron Lithography—Limits of Resolution, " *Proceedings, NSF* Workshop *on Opportunities for Microstructures in Science, Engineering and Technology.* Airlie, ['a., Nov 1 9-22, 1978, p. 187.

Appendix 3B.—Computer Memory

Computer systems make use of different kinds of memory or data storage for different purposes. High-speed cache memory—figure 13 (p. 85)—provided in more powerful computers typically consists of bipolar RAM chips. As figure 3B-1 indicates, these give the fastest practical access times—needed, for instance, for buffering between the main memory and the central processing unit (CPU). Main or primary memory–for storing programs, along with the data being manipulated—generally consists of MOS RAM chips. As figure 3B-1 shows, MOS RAMs are considerably less expensive than bipolar RAMs, though not as fast. A typical IBM model 370/168 mainframe—a large, general-purpose data-processing computer—might have a main memory capacity of 6 megabytes. A byte is equal to 8 bits; thus, the main memory capacity consists of 48 X 10^6 bits—which would require 3,000 16K RAM chips. In contrast, the cache memory for this machine holds 32 kilobytes, or a little over a million bits. The access time for the bipolar cache memory is 80 nanoseconds (80 x

Figure 3B-1.—Performance of Computer Memory Alternatives



SOURCE G C. Feth, "Memories Smaller, Faster, and Cheaper, " *IEEE* Spectrum, June 1976, p 36

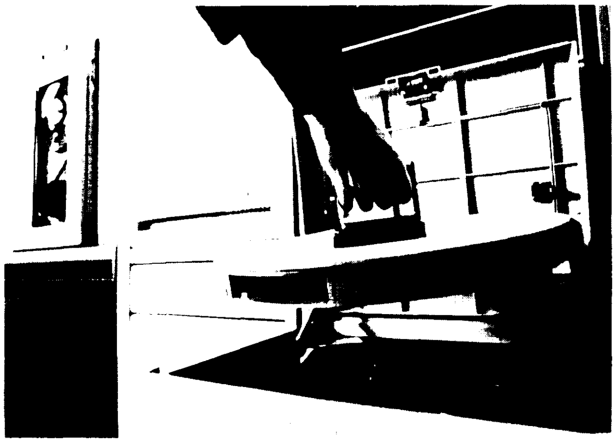


Photo credit Ted Spiegel, 1983

Disk pack for computer data storage

10^{-9} seconds)—corresponding to the cycle time for the 120,000 logic circuits in the CPU—compared to an average of 400 nanoseconds for the MOS main memory.[1] In earlier years, primary memory consisted of magnetic cores (table 3B-1, also fig. 3B-1), wound wire magnets for which the direction of magnetization corresponds to a "O" or a "l." By the mid-1970's memory chips had become cheaper than magnetic cores, largely replacing them except for nonvolatile storage.

IC RAMs are generally supplemented by magnetic disks of various types—table 3B-1. These can store large amounts of information inexpensively; they also provide a form of random access, but are much slower than IC or magnetic core memory (fig, 3B-1).[2] Magnetic tapes are slower yet, but cheaper; large data bases, or records that must be retained for long periods of time, are often stored on tape.

In the future, archival storage may be even cheaper using optical disks. Similar to the Philips video disk, a laser-scanned optical disk about the size of a phonograph record could hold more than 10^{10} bits of information.[3] The 20 million books in the Library of Congress could in principle be stored on 7,000 such optical disks.[4]

Table 3B-1.—Computer Memory

Magnetic core: Small wire-threaded toroids are switched between binary states ("O" and "1") by reversing the direction of magnetization. Developed during the 1950's, and now largely replaced by MOS RAMs, magnetic cores were the first inexpensive computer memory that offered fast access times (i.e., microseconds).

Semiconductor: While computer memory could in principle be designed and built using discrete transistors, this would have been much more expensive than magnetic cores. Only when MOS integrated circuit RAMs became available at low cost in the early 1970's did semiconductor memory come into widespread use. By the mid to late 1970's, ICs had become the technology of choice wherever relatively high speeds were called for. Other solid-state storage technologies —e.g., magnetic bubbles—have yet to prove competitive for computer memory.

Magnetic tape: First used with the Univac I in 1951, tape memories are relatively slow but provide inexpensive storage for large amounts of data. The tape is read or written by a recording head much as in an analog audio or video recorder; 1/2 -inch tape drives recording on either seven or nine tracks are common.

Magnetic disk: Digital data can be stored magnetically on rigid or flexible disks. Magnetic drums are also used in specialized applications.

Rigid disks, introduced in 1956, consist of a metal platter coated with a magnetic medium. The disk surface is divided into tracks, which are read and written by a head. In some disk drives, the head is fixed, while in others it moves with respect to the disk surface. Access to particular blocks of data is much faster than for a tape, which must be scanned sequentially.

Removable, or cartridge, disks remain the most common variety of rigid disk, but hermetically sealed "Winchester" drives have also been widely accepted. These can store more data on a disk of given diameter, and are relatively inexpensive, but the disk media cannot be removed for archival storage.

Flexible or floppy disks are made from mylar (a plastic). In function they are similar to rigid disks, but have much lower storage density; they are inexpensive as well as easy to handle and store

SOURCE Office of Technology Assessment

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[1] W. Anacker, "Computing at 4 Degrees Kelvin, " *IEEE Spectrum,* May *1979,* p 26.

[2] See, in general, R. B. J. Warnar, P. J. Calomeris, and S. A. Recicar, *Computer Peripheral Memory System Forecast,* National Bureau of Standards special publication 500-45 [Washington, D. C.: Department of Commerce, April 1979),

[3] K Bulthuis, et al , "Ten Billion Bits on a Disk, " *IEEE* Spectrum, August 1979, p 26.

[4] See L. M Branscomb, "Future Computer, " *Across the Board,* March 1979, p *61,* who estimates that the books in the Library of Congress are equivalent to about 70 X 10^{12} bits,

Appendix 3C.—A Process Control Example

Many of the illustrations of computer applications given earlier in table 7 involve multiple processors, either networked or in distributed processing systems. Typical examples include electronic mail or a word processing system with a minicomputer supporting several work stations, Multiple computers are also common in process control. Figure 3C-1 diagrams a portion of the control system for a chemical plant that converts petroleum feedstocks into products like ethylene and butadiene—the latter, in turn, feedstocks for making plastics. Sensors measure parameters such as temperature, pressure, and chemical composition on a continuous basis and send electrical signals to the process control computer. This computer employs a process model and control algorithm—the latter a program that compares the sensor outputs to target values and calculates appropriate adjustments—to monitor and regulate the process in real time. As such, it is a typical example of a feedback control system built around programmable logic rather than hard-wired controllers, Future process control systems will incorporate distributed logic to a greater extent, including smart sensors and actuators, and local controllers linked through networks.

Included in figure 3C-1 is an orifice for measuring flow rate, along with a flow-control valve. The transmitter sends a signal—in this case a voltage proportional to pressure drop across the orifice plate—to the control instrument, which converts it to a flow rate (e. g., pounds per minute). To do so, the control instrument logic must include the relationship between voltage and pressure drop, and the relationship between pressure drop and flow rate—the latter depending on the characteristics of the orifice, In the past, a control loop of this type would normally have relied on analog technology—perhaps even manual readings and adjustments. Now, hard-wired analog systems can be replaced by microprocessor-based digital controllers which are not only much more flexible but also more precise.

The controller in the figure could have a display -e.g., a panel meter—for the plant operators to read, but its primary function is to transmit flow rate data on a continuous basis to the process control computer. This computer monitors many such instruments that read temperatures, pressures, chemical compositions, liquid levels, and other process parameters and adjusts the process according to the control algorithm. In this example, if the flow rate was too high, the computer would return a signal commanding a lower value. The control instrument would convert this to a message that would close down the valve.

In addition to sensors, a typical process control system also includes a number of interlocks analogous to safety valves. If the pressure or liquid level in a reaction vessel or distillation column exceeded preset limits—indicating that the process was out of control, and that the computer had been unable to return the system to the desired condition—the system would automatically shut down so that the plant operators could diagnose the problem, Feedback loops and interlocks improve the control over the composition of the product, as well as helping to maximize yields, efficiency, and safety of operations. Redundancy, reliability, and a system design that allows the plant operators to take manual control quickly and directly in the event of system failures are critical requirements.

The process-control computer—still in figure 3C-1—can also gather, analyze, and report information on a continuing basis, transmitting it, for example, to the office computer. Once stored, it becomes available for purposes such as recordkeeping or analysis by the engineering department, along with information from the group of other process-control computers spread over a large chemical plant. The instrument CRT in the figure permits a remote operator to monitor a group of control instruments, while the computer CRT is the primary 1/0 device for the plant technicians. The analyzer computer provides off-line modeling and analysis of the process as necessary.

Despite the considerable sophistication of systems like that shown in figure 3C-1, and the further advances expected in the future, some engineers are less than optimistic about the prospects for fully automated plants and factories–where the human operators would be out of the control loop except in emergencies, their usual responsibilities limited to oversight and maintenance. Computerized process control is a field where progress has seldom lived up to expectations; reliability has been a particular problem, and the software available has seldom permitted systems to perform up to the levels promised by hardware developments.[1] The

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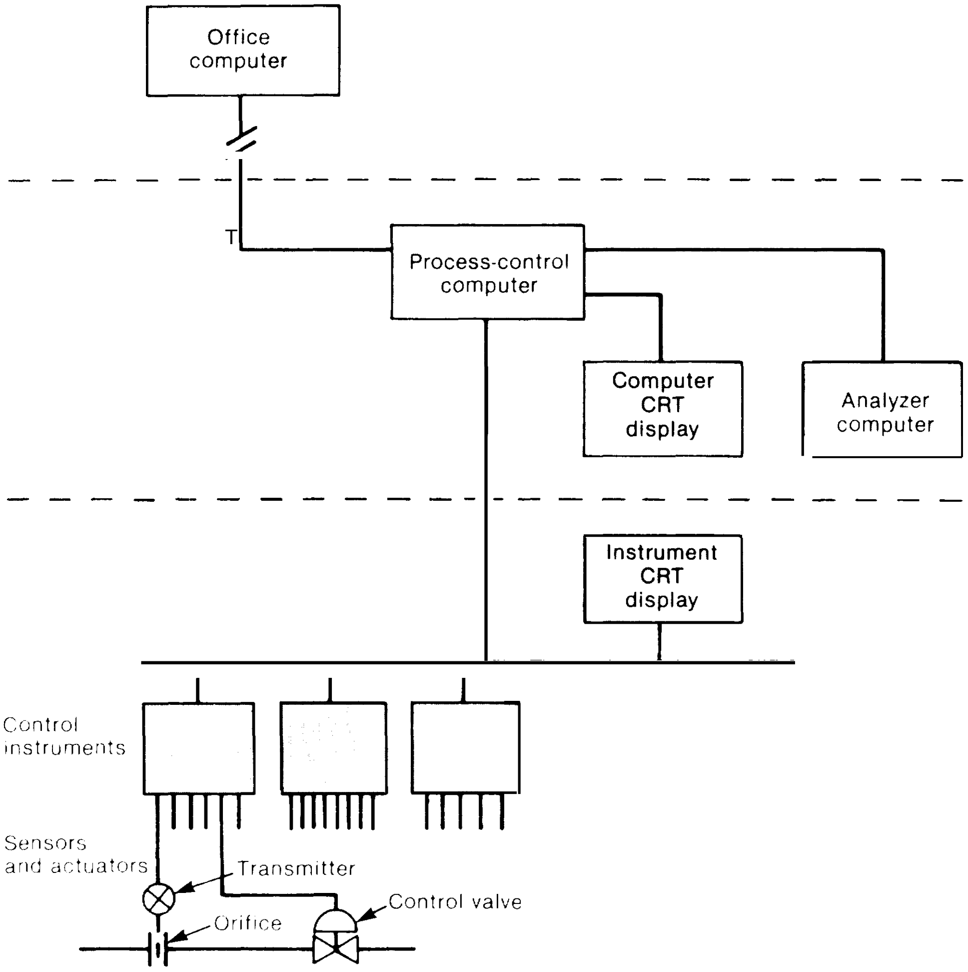
[1] J J Casso, "Developing a Successful Process Computer System" *Advances in Computer Technology-- 1980,* vol 2 (New York ,American Society of Mechanical Engineers, 1980), p 109

Three Mile Island nuclear powerplant accident provides a good example, Total reliance on a computerized system for controlling a nuclear (or nonnuclear) powerplant was then—and is still—impossible. Processes that go out of control are *by* definition system failures—if the process algorithm were adequate, and the system sufficiently robust to withstand equipment failures, control would not be lost. When system control is lost, human operators must intervene,

Figure 3C-1.— Portion **of Process Control System for a Chemical Plant**



SOURCE Adapted from R. Weber and W. F. Floyd, "Processing Plant: A Hierarchy of Computers and Instrumentation Controls Petrochemical Production," *IEEE Spectrum*, October 1981, p. 56

CHAPTER 4

Structure and Trade in the International Electronics Industry

Contents

List of Tables

List of Figures

CHAPTER 4

Structure and Trade in the International Electronics Industry

Overview

The wide international dispersion of manufacturing and sales in electronics means these activities take place in an environment heavily conditioned by global political currents and the industrial policies of competing nations, Episodes such as the NTT (Nippon Telegraph and Telephone) procurement dispute, which came to symbolize a much broader range of U.S.-Japan trade frictions, are only one example. More striking is the rhetoric common in the Japanese press, in which international competition in electronics is continually described in terms of the "semiconductor war" or the "computer war."[1] The context for investment and production, as well as trade, can be highly politicized. In developing countries, investment may be contingent on performance requirements calling for certain percentages of local value-added, export targets, or employment levels. Companies that do business on a worldwide basis try to manipulate these political currents to their own advantage.

American firms have frequently transferred labor-intensive production operations to low-wage countries as a means of cutting costs; prominent examples include assembly of circuit boards and chassis for television receivers, as well as wire bonding and assembly of integrated circuits (ICs). Sometimes overseas production contributes to foreign sales; American firms can market within the European Economic Community more easily if they produce there rather than exporting. Along with foreign investments for manufacturing, U.S. semiconductor companies have established R&D centers in Europe, with ***similar*** efforts in Japan planned or underway; a number of American computer firms also maintain substantial engineering operations in Europe. The patterns are quite different in consumer electronics, where U.S. companies operate offshore assembly plants but market almost exclusively at home.

Just as American electronics firms market and invest overseas, foreign-owned enterprises are extending their activities to the United States. Of the 15 manufacturers of TVs in this country, 11 are now foreign-owned (3 of the 4 largest remain American). All the consumer-model video cassette recorders sold in the United States—including those marketed by GE, RCA, and Zenith—are made in Japan, Japanese semiconductor manufacturers not only distribute their products here but are setting up assembly plants and R&D organizations. Several leading American semiconductor companies have been purchased by European concerns. Japanese computer manufacturers are selling in the United States through joint ventures with American firms like National Semiconductor, while planning independent marketing efforts for the future. As good an example as any of the ties linking electronics industries in various parts of the world can be found in the genesis of the computer language Ada—recently adopted by the U.S. Department of Defense as a standard, Ada was developed in France by an employee of CII-Honeywell Bull, a company at the time owned 47 percent by the American computer manufacturer Honeywell.

Electronics technology now flows both into the United States and out, although transfers overseas by American firms remain much more frequent. Semiconductor patents owned

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[1] See, for example, *Japan Report*, Joint Publications Research Service JPRS L/10662, July 16, 1982, in which seven articles from Japanese publications are translated under the heading "U.S.-Japan VLSI War." The media in Japan are not unique in this tendency; an NBC news special aired Aug. 14, 1982, carried the title "Japan vs. USA: The Hi Tech Shootout."

by Bell Laboratories have been licensed worldwide. RCA continues to receive about $50 million per year from Japan consumer electronics firms for its color TV technology, a sum comparable to RCA's annual profits from making and selling television sets. Computer manufacturers in many countries—including the Soviet Union–design systems to run on IBM software. Apple computers have been widely counterfeited in the Far East. Japanese firms are accused of purchasing stolen information concerning IBM computers, Much of the lithographic equipment for fabricating large-scale ICs is produced in the United States by firms that depend on Japan and West Germany for optical components; one major producer is based in Liechtenstein. ICs that sell in large volume—such as microprocessors or computer memory chips—become commodity items produced to essentially the same specifications in the United States, Japan, and Europe, Sometimes the circuits are identical because of formal licensing agreements, occasionally because the designs have been copied. In other cases, chips may differ internally but function interchangeably, Second-sourcing of ICs often entails agreements for the design and development of peripheral or support chips. Licensing and alternate sourcing arrangements of all types link semiconductor firms throughout the industrialized world; these linkages help define the forms of competition without affecting its intensity.

In such an environment—one increasingly common to many sectors of the world economy, automobiles as well as electronics—issues of international competitiveness and national interest are seldom clear-cut. Trade flows, one of the traditional measures of international competitiveness, can become ambiguous when substantial fractions of imports and exports consist simply of intracorporate transfers. What does it mean when Japanese firms export ICs to the United States that were originally designed here, or when competitors like National Semiconductor and Oki Electric announce a joint venture in which National will manufacture Oki-designed 64K RAMs (random-access memory circuits) in the United States? Should it matter to the Federal Government that TV or semiconductor plants formerly controlled by American interests now belong to Japanese or European concerns? If U.S. companies chose to export nonmilitary technologies, is this anyone else's business? Organized labor would answer yes to this last question, out of concern for American jobs. So might some businessmen—but more likely with reference to a rival's exports of technology than their own.

This chapter explores the background for such questions without attempting to answer them (they seldom have definitive answers). As for the preceding chapter, the approach is largely descriptive, aimed at giving a picture of the world electronics industry that will serve to frame issues of policy and competitiveness.

The U.S. Electronics Industry: Introduction

Electronics is, first of all, a large and diverse industry. Sales of the more than 6,000 electronics manufacturers in the United States exceeded $125 billion in 1982 and are growing rapidly; the industry employs more than 1½ million people. Most of these 6,000 plus companies are small. Nearly three-quarters have annual sales of less than $5 million; about half produce components of various types. As figure 17 indicates, domestic shipments—the plot includes the value of both imports and exports—have expanded more than 25 times over the past 30 years, an annual growth rate exceeding 11 Percent, Recent expansion has been even faster: the growth rate over the past decade reached nearly 15 percent. U.S. output of durable goods came to about $500 billion in 1982; thus electronics, broadly defined, accounted for nearly 25 percent of the total.[2]

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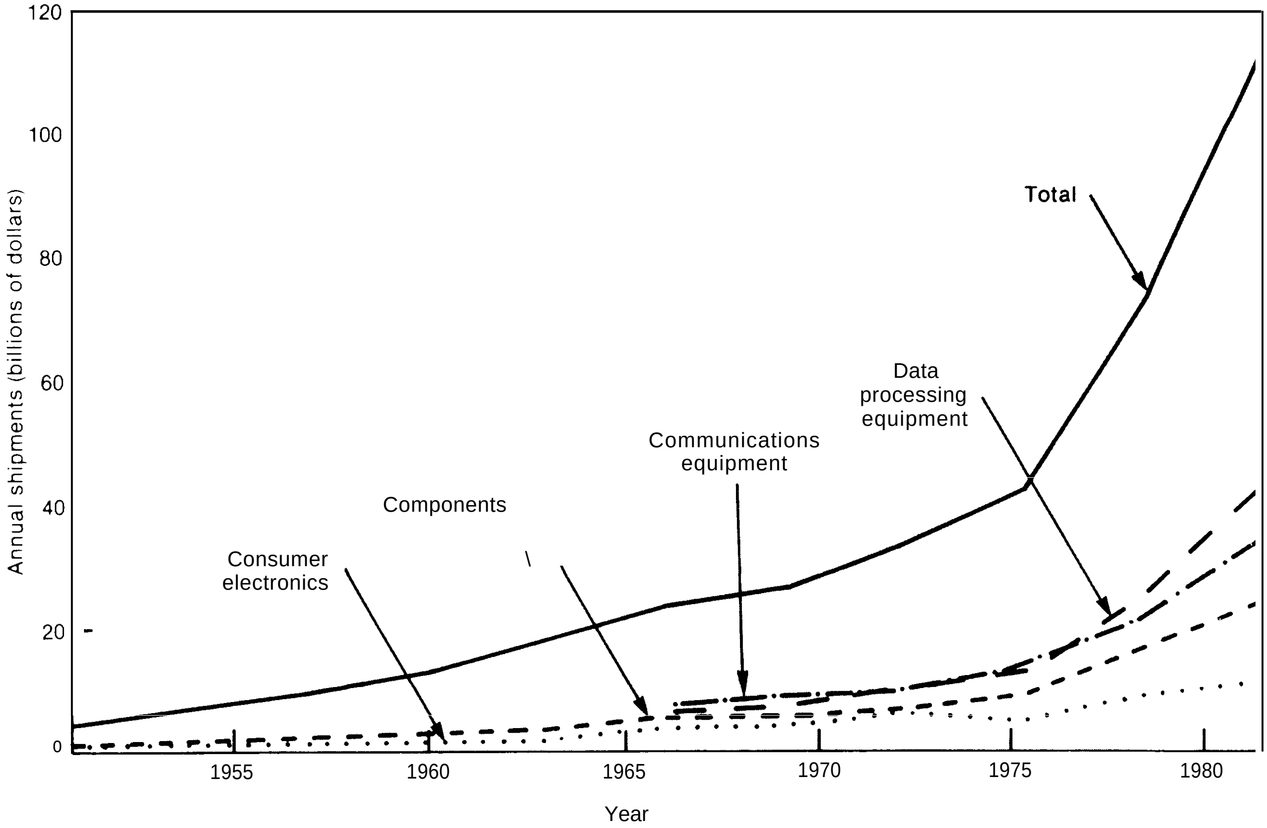
[2] *Economic Report of the President* (Washington, D. C.: U .S. Government Printing Office, February 1983), p. 170. If nondurable are included, electronics output accounted for about 10 percent of U.S. manufactures. Sales of communications equipment and other classes of electronics products that are not the subject of this report are included in these comparisons and in figure 17 to illustrate the overall size of the industry.

Figure 17.—Sales Trends in the U.S. Electronics Market



SOURCE” *Electronic Market Data Book* 7982 (Washington, D.C Electronic Industries Association, 1982), p. 4.

In fact, the sales totals in figure 17 involve some double counting because manufacturers of final products purchase components from other electronics firms. Examining value-added data, figure 18, which subtract the value of intermediate goods inputs from final sales figures, shows the industry to be somewhat smaller but the growth trend remains about the same.

Throughout its history the electronics industry has been one of the most technologically dynamic in the U.S. economy. Applications of computing power and smart electronics have become widely diffused both within the industry and outside it—products from supermarket checkout terminals to Boeing 767s now depend on microprocessors.[3] The diversity found among American electronics firms is, in its own way, as impressive as the technical virtuosity of the industry’s products. These products—which range from CB radios to satellite-based communications systems, carbon resistors to vastly powerful computers—are probably distributed more widely through the rest of the U.S. economy than the output of any other industry. This pervasiveness has the corollary of involving almost all parts of the Nation’s distribution system. There are few manufacturing firms, even fewer wholesalers and retailers, virtually no individuals, who do not buy electronic products.

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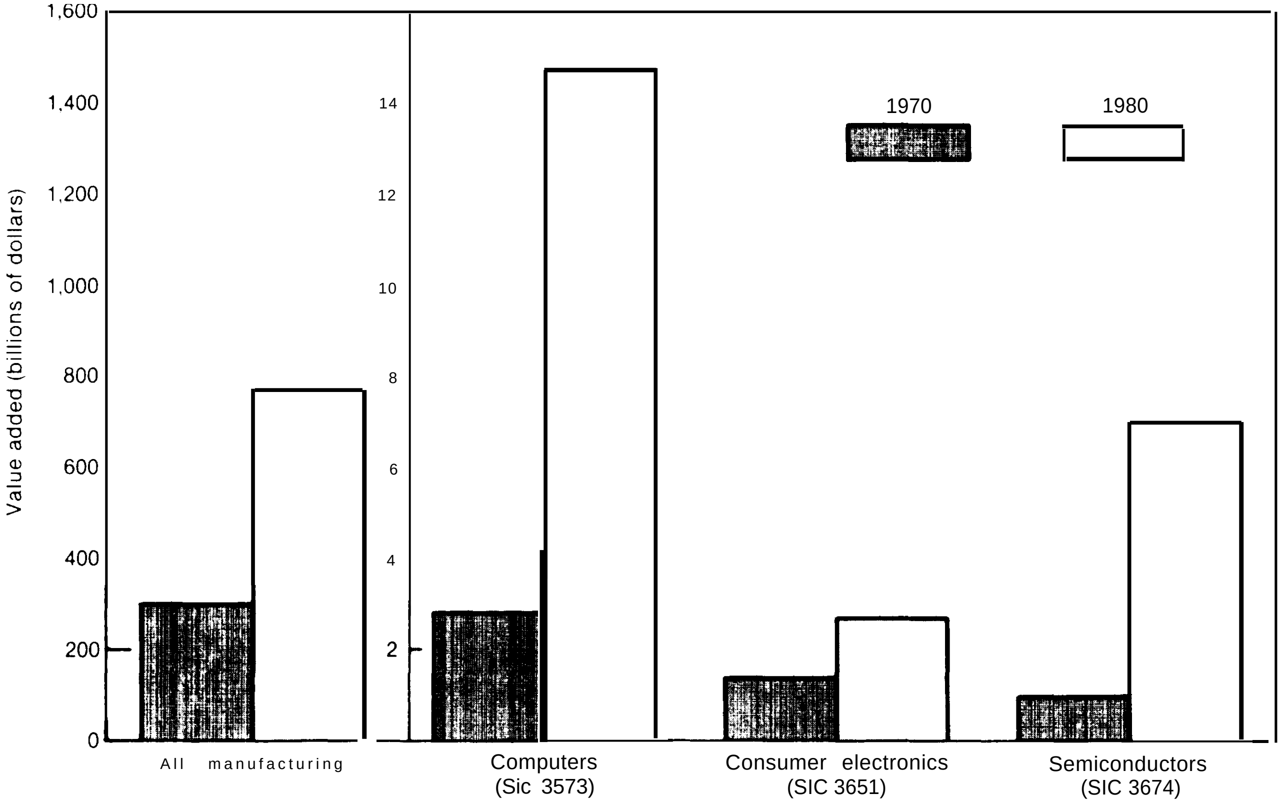
[3] About 180 microprocessors go into each 767, A Cadillac Seville uses 10, along with nearly 100 other ICs, an even larger number of discrete transistors, and about 1,000 other electronic components. See A. R. Karr, “FAA Is Making Stiff Demands on Boeing To Prove the Safety of Its New 767 Jetliner, ” *Wall Street Journal*, July 23, 1982, p. 36; L. Givens, “Engineering Highlights of the 1983 Automobiles, ” *Automotive Engineering*, October 1982, p. 31.

Figure 18.—Value Added in U.S. Manufacturing



SOURCE 1977 Census of Manufactures, 1980 Annual Survey of Manufactures

Because of this diversity, the industry cannot be meaningfully discussed as a whole—a difficulty even more acute when the topic is international competitiveness, which implies examining the behavior of individual corporations to at least some extent. This is not the steel industry—where the firms active in a given market are easily defined, their competitive postures well known, the paramount considerations production costs and delivery. Nor is it automobiles, where the domestic industry consists of three or four corporations—again with clear identities, well-understood strengths and weaknesses—and their suppliers. Among the companies that populate electronics, some are as large and well known as U.S. Steel or Ford, while others—including many of the technological and market leaders—are small concerns with relatively specialized product lines, companies little known to outsiders. Three random examples: VisiCorp, which supplies software for small computers; GCA Corp., which designs and builds semiconductor fabrication equipment; John Fluke Manufacturing Co., specializing in instruments. While electronics is certainly better defined than the emerging biotechnology industry, in a sense there is little point in speaking of an electronics "industry" at all. Rather, there is a large group of companies sharing certain characteristics such as the relevance of their products, whether hardware or software, to the processing and transmission of information. Moreover, when subsets of the larger group are examined, boundaries shift and blur as a result of time and technical change—semiconductor firms move into systems, computer firms into data communications. As a result, classifications and subclassifications for reporting production and trade data are not always useful, sometimes lagging years behind major developments in the industry and its products. *

In part for such reasons, OTA's examination of electronics covers only three portions of the industry: consumer electronics, semiconductors, and computers. In capsule form, these can be described as follows:

- ***Consumer electronic*** products are sold through retail distribution channels; they include radios, TV sets, sound reproduction equipment, video games, digital watches, and calculators, Most of these products fit within the "home entertainment" category. Personal computers—which could be classed as consumer products—also have utilitarian applications, In this report, personal computers are included with other data processing systems because–except at the very bottom of the price range—they are similar to machines sold for business applications.
- ***Semiconductors*** are one species of electronic component, sold to manufacturers of final products or used internally (30 to 40 percent of U.S. output falls in the latter category, produced by "captive" facilities). Included are discrete devices, such as power transistors, as well as an immense variety of ICs, some of which were described in the preceding chapter. Needless to say, marketing and distribution channels for semiconductors differ greatly from those for consumer electronics. Because of their importance for competitiveness, *semiconductor equipment manufacturers–firms* that develop and supply the equipment needed to produce microelectronic devices—are discussed separately below.
- The *computer* industry, for purposes of this report, includes 'manufacturers of mainframe machines, minicomputers, and personal or desktop units, as well as peripheral equipment. While peripherals are not covered in detail—nor are independent software vendors—the many smaller firms in these portions of the industry are an important source of competitive strength for the United States. Except for personal machines, data processing equipment manufacturers sell almost exclusively to other businesses, as well as to institutions such as Federal, State, and local governments. With the dramatic cost reductions of recent years, computers are now found in even the smallest organizations, personal machines, sold both for business and household use-–mostly through retail channels—promise a further enlargement of information processing markets.

Many electronics firms do business in more than one of these sectors of the industry. IBM makes both computers and semiconductors, as do NCR, Digital Equipment Corp., and Texas Instruments, The latter firm also sells consumer products, Zenith builds personal computers as well as TVs; although 80 percent of its business is in TV, the company is trying to diversify. RCA is a major force in satellite communications as well as consumer electronics; in fact, the company is a conglomerate with substantial interests quite divorced from electronics. Hewlett-Packard makes a variety of instrumentation and measuring equipment, as well as computers—and, like many other electronics companies, some of its own semiconductors. Firms like IBM, GE, and Texas Instruments have substantial military sales, while some companies thought of mostly as defense

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"Beyond the official 4-digit SIC system (Standard Industrial Classification; see ch. 9 where employment is discussed by SIC category) for reporting production and consumption within the United States, the Department of Commerce has subdivided the category for Semiconductors and Related Devices (SIC 3674) into 27 narrower subgroups. Of these, six apply to bipolar ICs, only three to MOS ICs—despite the fact that the latter have long since reached greater sales levels. For computers, the SIC subdivisions have not kept up at all: of the two categories, virtually all computers-from 8-bit personal machines costing a few thousand dollars to supercomputers—fall in SIC 357311 (general purpose); the second category is reserved for military and other specialized systems, Much the same is true of the somewhat different classifications and categories used by the United States for imports and exports (other countries have their own reporting systems). One result is that data on production can seldom be directly compared with that for trade; although concordances are available, one-to-one correspondence does not always exist, Apparently, none of the systems as yet makes explicit provision for software except as a service item, yet software accounts for a substantial and increasing fraction of the value of computer systems and is frequently sold separately from hardware.

contractors play small but significant roles in the broader world of commercial electronics. Hughes and Lockheed, for instance, are known and respected for their R&D in microelectronics; research performed by aerospace contractors often finds eventual commercial application, although in recent years more electronics technology has flowed from commercial developments into military hardware and software than the other way.

These three portions of the electronics industry are described next in more detail, from the viewpoint of structure and on a world basis.

Consumer Electronics

The United States, With Particular Attention to Color Television

American consumer electronics firms have had great difficulty retaining their competitiveness. U.S. producers of TVs and other home entertainment equipment have shared the plight of firms manufacturing components like capacitors, switches, and circuit boards: these rather simple products can be made overseas with the aid of cheap labor at highly competitive costs. Of a total consumer electronics market exceeding $20 billion, a market that recently has been expanding by nearly 10 percent annually, imports today account for the majority of sales in many product categories (table 8),[4] Virtually all production of some types of consumer goods—portable radios and video cassette recorders (VCRs) are examples—takes place abroad, mostly in the Far East. For other products, such as black-and-white TVs, American manufacturers remain viable competitors in only narrow segments of the market. A parallel decline in color TV production was averted in part through orderly Marketing Agreements (OMAs) which limited imports from three Asian nations. OMAs encouraged investment in the United States by Japanese and Taiwanese manufacturers of color televisions. *

The remaining American consumer electronics manufacturers have been forced by the pressure of import competition—pressure that has led to frequent accusations of unfair trade practices, including charges of dumping that were upheld after lengthy investigations (see

Table 8.—U.S. Sales and Imports of Selected Consumer Electronic Products, 1982

	US. sales (millions of dollars)	Imports (millions of dollars)	Import penetration (percent)[a]
Color television	$.4,253	$546	12.80/o
Black-and-white TV	507	344	67.9
Video cassette recorders. . .	1,303	1,032	100.0[a]
Home and auto radios[b]. . . .	1,579	1,207	76.4
Stereo systems[c].	1,754	1,342	76.5
	$9,396	$4,471	47.60/o

[a] Because many items Imported in a given year are not sold until the following year, dividing imports during a given calendar year by sales in that same year may give only a rough indication of import penetration, for instance, *all* video cassette recorders sold in the United States are imported even though 1962 sales figures exceed 1982 import figures.

[b] Including auto tape players.

concluding audio tape units and other component equipment

SOURCE” *Electronic Market Data Book 1983* (Washington, D.C.: Electronic Industries Association, 1963), pp 6, 19, 23, 31

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[4] For radios and TVs as defined by SIC 3651, the value of imports exceeded 50 percent of the value of total sales for the first time in 1981—1982 *U.S. Industrial Outlook* (Washington, D. C.: Department of Commerce, January 1982], p. 344. Note that data collected and reported by different organizations may represent different definitions of consumer electronics. For instance, the $21.4 billion figure given by *Electronics* magazine for 1982 sales is about a third greater than that reported by the Electronic Industries Association (EIA) largely because the magazine's survey covers many product categories left out of the EIA total—*Electronics,* Jan. 13, 1983, p. 136.

*The 3-year OMA with Japan was allowed to expire in 1980 after a finding by the U.S. International Trade Commission that the domestic industry had adjusted so that protection was no longer needed. At that time, the OMAs with South Korea and Taiwan were continued, one reason being the much lower labor costs these countries enjoyed compared with Japan, giving them potentially greater competitive advantages; these two OMAs expired in July 1982 and were not renewed. Events leading up to the import quotas are discussed in ch. 11.

chs. 5 and 11)—to switch tactics in order to survive, The two largest American manufacturers of color TVs, Zenith and RCA, now carry out many of their assembly operations abroad, The move to offshore assembly, although resisted for some years by Zenith, ultimately became necessary to lower costs.

Americans buy more color TVs than any other consumer electronic product (table 8); televisions have also been a center of controversies over U.S. trade policy. For many purposes, color TV can stand for the U.S. consumer electronics industry as a whole. Table 9 summarizes data on domestic production and imports of color sets, broken down into three screen-size categories. The figures show that market growth—in terms of both domestic production and imports–has come in the small and intermediate screen sizes, while production of large screen sets has dropped considerably since the late 1960's. In 1967, when imports took only a little over 5 percent of the market, large screen models accounted for more than three-quarters of all sales. By 1981, the market share of large screen color sets had dropped to less than one-quarter; meanwhile, the overall color TV market had more than doubled. From the beginning, ***imports have** been concentrated in the smaller screen models where sales have been growing.* Most large sets are still made in the United States, but as sales swung toward second and third sets where portability and low cost are major selling points the large screen market shrank.

Table 9 also illustrates the effects of OMAs which took effect in 1977 (with Japan) and 1979 (with Taiwan and South Korea). Imports of small- and medium-size sets dropped by more than a million units between 1977 and 1979, a decline of nearly ***50*** percent. Imports have since stayed well below the 1977 level, but assembly in the United States by foreign firms has made up much of the difference:

Table 9.—U.S. Production and Imports of Color TV Receivers (thousands of sets)

Screen size[a]	1967	1969	1971	1973	1975	1977	'1979	1981
Small								
U.S. production	373	579	645	1,267	905	1,040	1,710	2,220
Imports	157	480	780	936	637	1,148	818	1,238
Total small	'530	1,059	1,425	2,203	1,542	2,188	2,528	*3,458*
Imports as percent	29.6°/0	45.30/0	54.7%	42.5%	41.3%	52.5%	32.4%	*35.8 %*
Medium:								
U.S. production	624	1,000	1,851	3,182	2,167	3,014	4,559	5,668
Imports	171	399	413	379	562	1,350	49?	503
Total medium	795	1,399	2,264	3,561	2,729	4,364	5,050	6,171
Imports as percent	21.5%	28.5%	18.2%	10.6%	20.6%	30.90/0	9,70/0	8.2 %
Large:								
U.S. production	4,295	3,653	2,902	3,379	2,317	2,951	2,743	2,626
Imports	—	2	[b]	[b]	16	40	60	116
Total large	4,295	3,655			2,333	2,991	'2,803	2,742
Imports as percent	—	0.050/0			0.7%	1 .3 "/0	2.1 %	4.2%
All sizes:								
U.S. production	5,292	5,232	5,398	7,828	5,389	7,005	9,012	10,514
Imports	328	881	1,193	1,315	1,215	2,538	1,369	1,857
Total all sizes	5,620	6,113	6,591	9,143	6,604	9,543	~i3,381	12,371
Imports as percent	5.8%	14.40/0	18.1 %	14.40/0	18.4%	26.6%	13.2 %	1 5.0%

[a] Screen sizes are defined as follows ***Small:** 1967,* **1959-16** inch and under 1971$1–17 inch and under *Mad/urn: 1967, 1%9–17* 19 inch *1971-81*—18 and 19 inch ***Large:** All years—20* inch and over

[b] Not available but very small

SOURCES. ***1967, 1969**—Television* Receivers *and Certain Parts Thereof* (Washington, D C U S Tariff Commission Publication 436, November 1971), p A-57

1971 -79- Television Receiving Sets From Japan (Washington, D C U S International Trade Commission Publication 1153, June 1981), pp H-6, H-7, H-1 7, H-18

1971 ***and*** 1973 *Import* data— *Television Receivers,* Color *and Monochrome, Assembled or Not Assembled, Finished or Not Finished, and* Subassemblies *Thereof* (Washington, D C U S International Trade Commission Publication 808, March 1977), p A-91

1975 ***Import data—Color*** *Television Receivers and Subassemblies Thereof* (Washington, D C U S. International Trade Commission Publication 1068, May 1960), p D-7

1981 product/on-Co/or Television Receivers U S Production, Shipments, Inventories, Exports, Employment, Manhours, and Prices, First Calendar Quarter 1982 (Washington, D C U.S international Trade Commission Publication 1245, May 1982), table 1

1981 Imports — *Electronics Foreign Trade Five- Year Summary* 1977- *1981* (Washington, D C Electronic Industries Association, March 1982), p 49

Employment

Even while domestic production and sales of TVs have expanded, employment has, since the mid-1960's, been falling (see ch. 9, especially fig. 57). There are two major reasons: increases in productivity and in foreign value-added. Productivity growth has come from simplifications in chassis design and from automation, both reducing labor content. At the same time, U.S. firms have moved some of their operations offshore, reducing domestic employment. Assembly in the United States by foreign firms compensates only in part; foreign-owned plants import many components and subassemblies. Although import quotas were justified in part on the basis of preserving American jobs, the employment data examined in chapter 9 shows that the OMAs had little apparent effect in arresting job losses.

Structure

Domestic TV production has most recently been accounted for by about 15 companies (the roster is fluid) that undertake some part of their manufacturing in the United States. These firms are listed, with their approximate share of color TV sales and the locations of their principal U.S. production facilities, in table 10. Zenith and RCA have, between them, held around 40 percent of the color TV market for many years. Imports and foreign manufacturers with production facilities here have taken sales primarily from smaller American manufacturers.

These sales have recently been growing a good deal more rapidly than many observers had anticipated, confounding those who predicted that the market was approaching saturation. The Electronic Industries Association forecast for 1980 had been 9.2 million color sets, a figure that was exceeded by nearly 1½ million. Sales in 1981 and 1982 were likewise affected much less by economic conditions than might have been expected. One reason seems to have been new demand stimulated by video games; rather than tying up the family TV, many households purchased second (perhaps third) sets. Derived demand of this type is at work in numerous electronics markets; home computers may also help expand color TV sales.

Table 10.—Firms With Color TV Manufacturing Facilities in the United States

Company	Ownership	Location(s)	Approximate market share, 1982 (percent)[a]
RCA Corp.	Us.	Bloomington, Ind.	20.0%
Zenith Radio Corp.	Us.	Chicago, Ill.	19.4
General Electric Co.	Us.	Portsmouth, Va.	8.0
Curtis Mathes Manufacturing Co.	Us.	Dallas, Tex.	1.2
North American Philips Corp. (Magnavox, Sylvania)	Netherlands	Jefferson City, Term. Smithfield, N.C.	11,5
Matsushita Industrial Co. (Quasar, Panasonic)	Japan	Chicago, Ill.	7.5
Sony Corp. of America	Japan	San Diego, Calif.	7.0
Hitachi Consumer Products of America, Inc.	Japan	Compton, Calif.	2.3
Sharp Electronics Corp.	Japan	Memphis, Term.	2.0
Sanyo Manufacturing Corp.	Japan	Forrest City, Ark.	1.5
Mitsubishi Consumer Electronics America, Inc.	Japan	Santa Ana, Calif.	1.5
Toshiba America, Inc.	Japan	Lebanon, Term.	1.4
Gold Star Electric International, Inc.	South Korea	Huntsville, Ala.	0.8
Sampo Corp. of America	Taiwan	Atlanta, Ga.	0.5
Tatung Co. of America, Inc.	Taiwan	Long Beach, Calif.	0.3
Private brands:			
Sears (mainly Sanyo)			7.3
Montgomery Wards (mainly GE, also N. A. Philips)			2.5
J. C. Penney (RCA and others)			1.5

[a] Company market shares do not include private brand sales. Market share figures do not total to 100 because of uncertainty concerning private brand market shares and suppliers of private brand sets. Nor are Importers without U.S. production facilities listed,

SOURCES *Television Receiving Sets* From *Japan* (Washington, D.C : U.S. International Trade Commission Publication 1153, June 1981), p. A-13; information from Department of Commerce and individual firms. Market share estimates from *Television Digest* surveys, July 1981 -June 19S2

Competition has kept margins between prices and costs in color TV small. Absent data on manufacturing costs, this can be gaged in at least two ways. First, profits have been modest compared with other sectors of the economy. Net operating profit as a percentage of sales—not a particularly good measure, but the only one available (return on equity or on total capital would be better)—has been substantially lower than in most other U.S. industries. As table 11 shows, profitability in TV manufacture has, since the early 1970's, been far below that in electrical and electronic equipment, which itself has shown profitability levels quite close to the average for all U.S. manufacturing. An expanding market has not meant high profit margins for American producers.

The second indication of the efficiency of the market comes from data on relative price movements. Figure 19 shows retail prices on an index basis for TVs (both monochrome and color) compared with other consumer durables. The flat price history for TVs demonstrates that productivity improvements have been passed through to consumers as lower prices. This figure—along with the profitability data in table n-indicates the strength of the competitive forces at work. Fierce price competition has been a characteristic of the TV industry in the United States for many years.

Table 11 .—Profitability in U.S. Color TV Manufacturing

	Net operating profit (or loss) as a percentage of net sates	
Year	All U.S. color TV manufacturers	All U.S. electrical and electronic equipment manufacturers
1971	8.7%	7.0 "/0
1973	5.8	8.4
1975	0.6	6.2
1977 ......, .	2.8	8.7
1978	1.5	8.1
1979	0,8	7.5
1980	1.9	7.5
1981	(0.1)	7.3

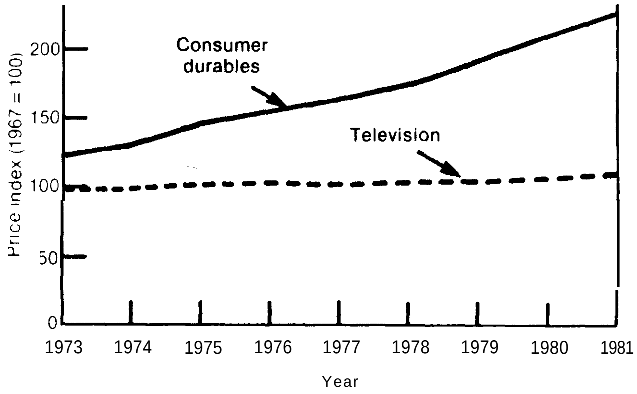
[a] Includes monochrome IV manufacturing for 1971 to 1975. Covers firms manufacturing In the United States regardless of country of ownership.

SOURCES *1971-75—Television Receivers, Color and Monochrome, Assembled or Not Assembled,* F/n/shed or *Not F/n/shed, and Subassemblies Thereof* ('Washington, D. C." U.S. International Trade Commission Publication 808, March 1977), p. A-59

1977-80—Television Receiving Sets From Japan (Washington, D.C: U S. International Trade Commission Publication 1153, June 1981), pp A-53, A-56,

1981 and revised 1979—Color Television Receivers: Quarterly Profits and Capacity and Certain Annual Expenditures of U S Producers (Washington, D.C.: U S. International Trade Commission Publication 1235, March 1982), table 1

Figure 19.— Price Index for TVs Compared to All Consumer Durables



SOURCES *Consumer* ***Durables****— Economic Report of the President 1982* (Washington, D C U S Government Printing Office February 1982), p 294

Televisions —Electronic Market Data Book 1982 (Wash ington, D C Electronic Industries Association 1982), p 29

This competition has led rather directly to major structural change in the U.S. industry: replacement of American-owned by Asian- and European-owned production facilities. Japanese and Taiwanese companies that previously exported to the United States have established assembly operations here; foreign interests have also purchased existing plants. The OMAs encouraged both types of investments, but at least some would have been made in any case. Sony's factory in San Diego antedates the OMA with Japan by 7 years. Matsushita's purchase of Motorola's Quasar operations came in 1974, and Sanyo's rescue of Warwick Electronics, a primary supplier to Sears, in 1976,

The American TV plants purchased have generally been in competitive difficulty and seeking some sort of financial reprieve. When Motorola decided to leave the consumer electronics business, the company approached both RCA and Zenith before finding a buyer for its Quasar division in Matsushita. North American Philips purchased Magnavox in 1974, while taking over GTE-Sylvania's consumer operations, consisting of the Philco and Sylvania brands, in 1981, Thus, the color TV business has been one in which large foreign multinationals have absorbed smaller and financially weaker U.S. companies. This is not to say that the U.S. operations of foreign firms have fared much better; they do not seem to have been any more profitable than American-owned TV manufacturers, perhaps less so (table 11 averages profit data for companies with plants in the United States whether American- or foreign-owned).

What are the implications of these changes? On the one hand, foreign takeovers point to the fact that some U.S. companies, for whatever reasons, have simply been unable to maintain their competitiveness. It seems likely that even purely domestic competition would, sooner or later, have led to a series of failures among the smaller American color TV manufacturers, From the point of view of the consumer, that foreign enterprises purchased and modernized these plants has probably yielded a more competitive industry; certainly the concentration has not changed appreciably (the 15 TV manufacturers at present compare with 16 a decade ago), On the other hand, many of the higher skilled jobs remain overseas, along with management control.

The distribution network for TVs has mirrored broader trends in the structure of American retailing rather than changing in any fundamental way as a consequence of foreign competition. Furniture and department stores have become less important as outlets, while sales have increased through appliance and discount retailers, along with chains like Sears and J. C. Penney. These shifts have multiple causes: heightened price competition; changing consumer preferences leading to much greater sales of small, easily portable sets (table 9); improvements in reliability, a consequence of solid-state chassis designs (chs. 3 and 6) lessening the need for after-sales service and repair. The opening of the distribution structure has added to price competition in the TV market.

Imports and Offshore Assembly in Color Television

International trade flows in color TV show two more or less concurrent trends: imports of complete sets into the United States by foreign firms, with subassemblies coming later, accompanied by re-imports from U.S.-owned subsidiaries following offshore assembly.

As table 12 demonstrates, by 1976 one-third of the U.S. color TV market was being supplied by shipments from the Far East. American producers had seen—some had experienced—ear-

Table 12.—Color TV Imports Into the United States

	Number of color TVs imported by origin (thousands)				Imports from all sources as a percentage of U.S. consumption
Year	Japan	Taiwan	Korea	Total[a]	
1967	315	–	—	318	6.7%
1969	879	22	—	912	15.7
1971	1,191	85	–	1,281	18.9
1973	1,059	325	2	1,399	15,8
1975	1,044	143	22	1,215	17.9
1976	2,530	235	47	2,834	33.0
1977	1,975	318	92	2,476	27.0
1978	1,434	624	437	2,775	26.4
1979	513	368	314	1,369	13.6
1980	435	303	293	1,288	11.7
1981	727	514	393	1,946	15.6

[a] Includes imports from countries not listed individually

SOURCES *1967, 1969 —Television Receivers and Certain Parts Thereof* (Washington, D C : U S Tariff Commission Publication 438, November 1971), p A-82.

1971, 1973— *Television Receivers, Color and Monochrome, Assembled or Not Assembled, Finished or Not Finished, and Subassemblies* Thereof (Washington, D C U S International Trade Commission Publication 808, March 1977), pp. A-W, A-99.

1975-79—Color Television Receivers and Subassemblies Thereof (Washington, D C U S International Trade Commission Publication 1088, May 1980), p D-6.

1980—Television Receiving Sets From Japan (Washington, D C U S. International Trade Commission Publication 1153, June 1981), p H-21

1981-information from Department of Commerce lier incursions in portable radios and monochrome TVs; as early as 1970, half the black-and-white sets sold in the United States were imports. The sentiment in the U.S. industry was that if import trends in color TV continued this far more lucrative market would also be taken over.

It makes little difference now whether or not such perceptions were accurate: increasing import penetration was the proximate cause for negotiation of the 1977 OMA with Japan. But what table 12 also shows is that no sooner did imports from Japan drop—in 1978—than imports from South Korea and Taiwan jumped, Although taking a slightly smaller fraction of the market, the number of imported color TVs actually grew in 1978. Only in 1979, when quotas with Taiwan and Korea took effect, did the import share come down.

This period, the late 1970's, coincided with the beginning of large-scale Japanese production here; color TV output in the United States by Japanese-owned firms went from 1.2 million sets in 1977 to 3,2 million in 1980—mostly final assembly operations which substituted imports of components for imports of complete sets. As table 13 shows, not only have subassemblies gone from half of all color TV-related imports by value to more than three-quarters, but *the total value of color TV imports including sub assemblies increased, despite the OMAs,* (Imports of incomplete TVs—as well as certain types of subassemblies —were restricted by the quotas, and remained small, but other subassemblies were uncontrolled.)

Table 13.—U.S. Imports of Complete Color TVs Compared to Incomplete TVs and Subassemblies

	Value of imports (millions of dollars)		
	1976-"	1978	1980
Complete color TV receivers .	$ 520	$ 577	$ 311
Incomplete receivers and subassemblies[a] . . .	527	748	1,112
	$1,049	$1,335	$1,427

[a] More than 98 percent subassemblies mostly circuit boards and picture tubes Incomplete sets are valued at only a few million dollars annually

SOURCE *Television Receiving Sets From Japan* (Washington, D C U S International Trade Commission Publication 1153 June 1981) pp H 20 H 22 H-23

The second major effect on the import side of the ledger has been the rising quantity of what are known as 807 imports. There are certain conditions to be satisfied—described in chapter n-but in essence item 807.00 of the U.S. Tariff Schedules allows an American company to export components for further processing abroad, then re-import them while paying duties only on the value added in the offshore facility, Absent this provision, tariffs would be assessed on the total value of re-imported goods. Labor cost savings have been the primary reason for moves offshore, with item 807 making the choice more attractive. In most cases, final assembly has remained here. All the major U.S. color television manufacturers have taken advantage of item 807 in their efforts to keep labor costs down, with Zenith being the last to moves

Table 14—which includes black-and-white TVs, although these are small compared to 807 imports of color sets—shows that offshore assembly and re-importation account for a substantial fraction of imports. In 1980, 44 percent by value of all U.S. imports of TVs and subassemblies entered under the provisions of item 807,00. (This does not mean that 44 percent of the value was added overseas, but that 44 percent of imports had *some* value added in other countries after originating here, In 1980, foreign value added came to about 11 percent of the total value of all imports,) As table 14 indicates, Mexico accounts for the majority of 807 imports, with Taiwan in second place. Mexico is unique in being almost exclusively an offshore assembly site for U.S. firms, which operate factories close to the border. The concurrent trends of foreign investment in U.S. plants and American investment in offshore produc-

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[5] Zenith's decision to transfer much of its production to Mexico and Taiwan, entailing layoffs to more than 5,000 U.S, workers, came at the end of 1977—"Situation Report: color Television, " Department of Commerce, May 1978, p. 4. The company evidently judged both the risks and costs of moving offshore to be less than for automation of its domestic production facilities. App. B discusses the costs and benefits of offshore manufacturing from an economic perspective.

Item 806.30 of the U.S. Tariff Schedules permits re-importing with duties charged only on foreign value added under a

Table 14.—Imports of Color and Monochrome TVs, Plus Subassemblies, Under Item 807.00 of the U.S. Tariff Schedules[a]

	Value of imports (millions of dollars)		
Source	1976	1978	1980
Japan:			
Total imports from Japan[b]	$ 666	$ 627	$ 435
807 imports[b]	0.6	3.6	5.7
Taiwan:			
Total imports from Taiwan	287	416	*354*
807 imports	150	184	*169*
South Korea:			
Total imports from Korea	36	137	164
807 imports	0.5	—	1.5
Mexico:			
Total imports from Mexico	261	348	536
807 imports	257	347	513
Singapore:			
Total imports from Singapore	25	77	185
807 imports	5	17	64
Other countries:			
Total imports	29	81	94
807 imports	15	60	26
All sources of imports:			
Total imports	1,304	1,687	1,770
807 imports	428	611	780
807 as percent of total	32.80/o	36.20/o	44.1 %

[a] **Breakdowns** for color and black.and.white sets covering subassemblies (and incomplete sets) are not available; however, the vast majority of 807 imports are color **subassemblies—mostly circuit** boards.

[b] **Total** import figures consist of the value of all imports entering from the source country; *807* imports consist of the total value of imports entering under item **807.00** from the source country, not the duty-free value, which is only a fraction of this Greater detail is available in the report cited below.

SOURCE” Television Receiving ***Sets From Japan*** (Washington, D.C.U.S International Trade Commission Publication 1153, June 1981), p. H-30

somewhat different set of conditions than for item 807.00. For practical purposes, 806.30 imports of televisions are negligible.

The table below lists several offshore plants operated by American firms, indicating the kinds of products that are shipped to the United States—mostly components and subassemblies for color sets; some black-and-white TVs are made overseas, but few complete color sets. North American Philips has also established overseas facilities.

Offshore Manufacturing Plants of Major U.S. TV **Manufacturers**[a]

Company	Location	Year established	Products
General Electric	Singapore	1988	TV parts and subassemblies
RCA.	Taiwan	1969	TVs, subassemblies, parts
	Mexico	1969	Subassemblies
Zenith	Taiwan	1971	Complete monochrome TVs; circuit boards, parts, subassemblies for color TVs
	Mexico	1978	Circuit boards, parts, subassemblies, chassis

[a] **Because** of the fluidity of offshore manufacturing activities, the information ‘" this table is not necessarily complete or current.

SOURCES Annual reports, R. W Moxon, “Offshore Production in the **Less**-Developed Countries by American Electronics Companies, ” DBA thesis, Harvard University, 1973

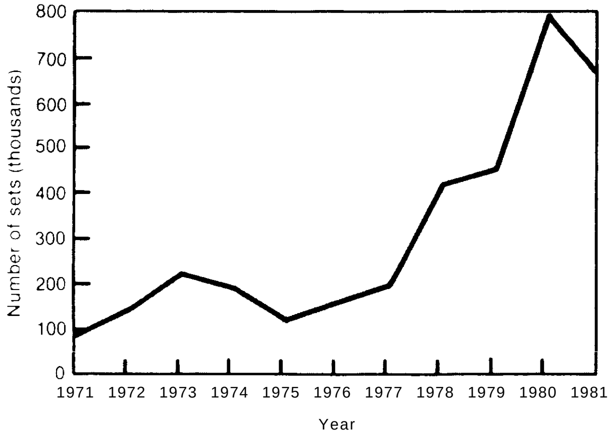
tion have caused the rapid shift in composition of U.S. color TV imports toward components and subassemblies illustrated in table 13.

U.S. consumer electronics manufacturers have been able to reduce production costs through offshore assembly. To the extent that their ability to remain competitive has depended on transferring some operations abroad, American workers have lost job opportunities. On the other hand, a total collapse of color TV production in the United States would have cost more jobs—a point explored in greater depth in chapter 9 as well as appendix B.

Exports

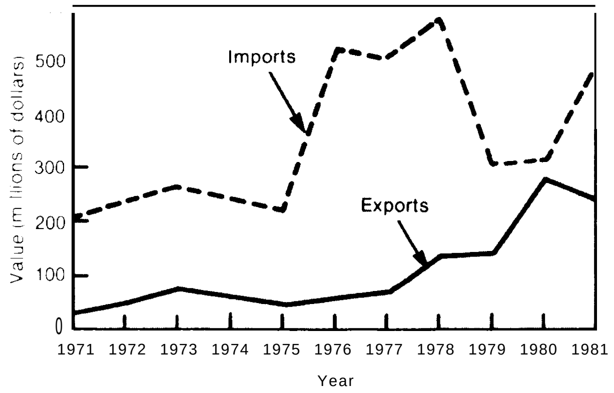
Despite the large negative U.S. trade balance in consumer electronics—which, depending on year and the definitional bounds employed, has been in the range of $3% billion to $6 billion annually—and the continuing pressure generated by imports, the U.S. industry has managed to export growing numbers of color TVS. Figure 20 shows the export trend in numbers of color sets, while figure 21 compares imports

Figure 20.— U.S. Exports of Color TV Receivers



SOURCES *1971*· 79— *Color Television Receivers and Subassemblies Thereof* (Washington D C U S International Trade Commission Publica tion 1068 May 1980), p A 25
1980, 1981 — *Electronics Foreign Trade Five Year Summary 19771981* (Washington, D C Electronic Industries Association, March 1982), pp. 38, 50

Figure 21 .—U.S. Exports and Imports of Color TV Receivers (complete sets only)



SOURCE *Consumer Electronics Annual Review* (Washington D C Electronic Industries Association. 1982), p 37

and exports of complete TVs in terms of value. Two-thirds of U.S. color TV exports have recently gone to Latin American countries, in **a** number of which color broadcasting has only recently begun.[6]

The Japanese Consumer Electronics Industry

The market for consumer electronics in Japan is now second only to that in the United States, with 1982 sales of $10.9 billion, about half the level here.[7] This was certainly not always the case; in 1965, when U.S. output was approaching 3 million color TVs, Japan produced less than 100,000. How did the Japanese consumer electronics industry grow in size and competitiveness so that it could ship more than a million color sets to the United States by 1971 (table 12)–at which time Matsushita was already the largest consumer electronics producer in the world?

Early Development

In fact, the United States had a good deal to do with the development and expansion of Japan's consumer electronics industry.’ After World War II, the Japanese economy was in shambles. The government could not stimulate developments in electronics through defense spending, but had clearly decided by the end of 1953—when television broadcasting began in Japan—to promote consumer electronics as a road to overall strengthening of the industry. In November of that year, the Ministry of International Trade and Industry (MITI) announced a policy aimed at increasing production capacity for TVs. One step was to restrict imports. The government also encouraged acquisitions of foreign technology, most of which came from American firms.

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[6] 1981 U.S. industrial *Outlook* (Washington, D. C.: Department of Commerce, January 1981), p. 441. The remainder are sold mostly in Canada. No information is available on the fraction of exports originating with the U.S. operations of foreign-owned firms.

[7] *Electronics*, Jan, 13, 1983, pp. 136, 154. While other sources—defining consumer electronics more or less inclusively–give different magnitudes, the relative sizes of the U.S. and Japanese markets remain about the same. The figures cited later in this paragraph come from *The U.S. Consumer Electronics Industry* (Washington, D. C.: Department of Commerce, September 1975), pp. 20 and 24, and "International Technological Competitiveness: Television Receivers and Semiconductors, draft report CRA 425 prepared by Charles River Associates, Inc. for the National Science Foundation under NSF grant No. PRA 78-20301, July 1979, p. 2-19.

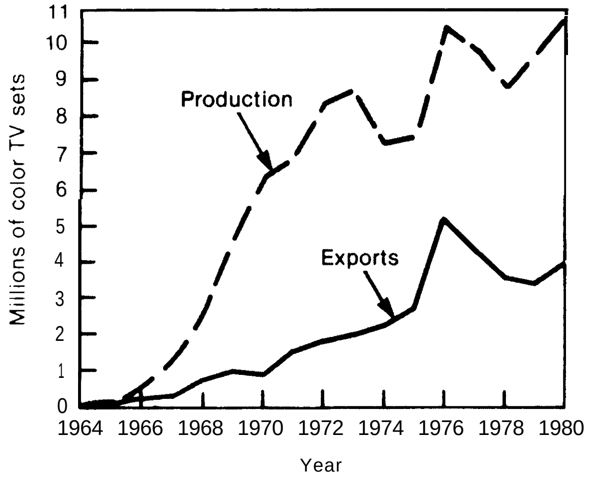
[8] Much of the material that follows is drawn from "Sources of Japan's International Competitiveness in the Consumer Electronics Industry: An Examination of Selected Issues, " prepared for OTA by Developing World Industry and Technology, Inc. under contract No. 033-1010. o.

U.S. servicemen stationed in Japan after World War II and during the Korean War proved an attractive market for Japanese consumer electronics manufacturers. Both fledgling companies like Sony and larger firms with prewar roots like Matsushita swiftly expanded their outputs of radios and audio tape recorders. Sometimes U.S. products brought to Japan by servicemen were reverse-engineered. By the mid-1950's, production was growing at very high rates; Japan's output of TVs doubled from 613,000 sets in 1957 to 1.2 million the next year, reaching 2.8 million in 1959.[9]

High-volume production of color sets began in 1964, spurred by the televising of the Tokyo Olympics. Exports followed, as shown in figure 22, with a large though variable fraction—in some years as much as half—of Japan's color TV production shipped abroad. During the 1960's, almost all these exports were destined for the United States, many to be sold by private brand retailers such as Sears; by the turn of the decade, Japan was producing as many color TVs as were made here. More recently, Japanese firms have also shipped large numbers of TVs to Western Europe and other parts of the world; in 1977, 95 percent of Japan's color TV exports reached the United States but 3 years later half were shipped to other Asian nations, Canada, and Western Europe—another consequence, at least in part, of the OMA limiting Japan's access to the U.S. market.

Within Japan, consumer electronics firms have competed strongly among themselves. Although the larger, more diversified enterprises—well-known companies like Matsushita (which markets in the United States under Panasonic, Quasar, and National brand names), Hitachi, and Sony—have had secure positions for many years, smaller firms have come—and mostly gone—depending on economic conditions and technological or market opportunities. The number of companies making radios in Japan dropped from 80 in 1948 to 18 in 1950. The more than 30 entrants in the TV market in the early 1950's were likewise quickly winnowed down by competitive forces; after a decade, virtually all of Japan's output of TVs was accounted for by the top 10 manufacturers.[10] At present, the Japanese TV industry is dominated by a few large vertically integrated firms which make many of their own components. Some of these firms also manufacture broad ranges of other electrical and electronic products—e.g., semiconductors, computers. Matsushita, the largest in terms of consumer electronics sales, has held around 30 percent of the Japanese color TV market in recent years.

Figure 22.—Japanese Production and Exports of Color TV Receivers



SOURCES *Exports-1964.67-Japan Economic Yearbook, 1968,* p 171
1968.70–Japan Economic Yearbook, 1971, p 208
7971.75–Japan Economic Yearbook, 1976/77, p 133
1976—Japan Economic Journal, February 15, 1977, p 8
Production—7962.70-Japan Economic Yearbook, 1971, p 289
1971.75–Japan Economic Yearbook, 1976/77, p 215
7976–Japan Economic Journal, February 15, 1977, p 8
***Exports and production—1977.79–Japan** Economic Yearbook 1980/81, p* 125
*Exports **and product/on—1980—Japan** Electronics Almanac **1982***
(Tokyo Dempa Publications, Inc , 1982) p 129

Japan's consumer electronics firms based many of their product developments on technologies developed first in the United States. From 1960 through 1967 alone, Japanese com-

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[9] "Fifty Years of Japanese Broadcasting, " Japan Broadcasting Corp., Radio and TV Culture Research Institute, 1977, p. 227.

[10] *Gijutsu Donyo no Genjo to Kongo no Mondai (Technological* Imports and Future Problems] (Tokyo: Ministry of International Trade and Industry, 1963), pp. 723-725. The number of color TV manufacturers in Japan has continued to decrease, from 22 in 1963, to 15 in 1972, to 11 in 1978—"Sources of Competitiveness in the Japanese Color Television and Video Tape Recorder Industry, " Developing World Industry and Technology, Inc., for the Department of Labor, Oct. 16, 1978, p. 100.

panies negotiated nearly 200 licensing agreements with RCA.[11] Until the 1970's, most of the flow of TV technology into Japan contributed to incremental improvements in existing products and processes. At the same time, Japanese companies actively sought more advanced technologies, realizing that imitation and refinement could only take them so far. Sony, for example, took out a license from Western Electric covering transistor technology in 1954; 10 years later, Toshiba was negotiating to purchase video tape recorder technology from Ampex.

Government Supports

While the aid given consumer electronics by Japan's Government–through policies encouraging exporting as well as protection from outside competition—has helped the industry, Japanese industrial policy, here as elsewhere, has been more notable for careful targeting of critical areas than for the overall magnitude of assistance. The success stories of individual firms reveal a host of factors contributing to growth, only one of which is government support. Continuing attention to manufacturing technologies, reduced costs through economies of scale and rapidly increasing productivity, innovative product designs and marketing strategies, home-grown R&D—all have made contributions.

MITI's role—discussed more extensively in chapter 10—is not restricted to supporting the industry. Faced with the 1977 OMA, it was MITI that allocated export quotas among Japanese TV manufacturers. Earlier the agency not only set price levels for exports to Western Europe, aiming to alleviate protectionist pressures, but in 1974 negotiated a quota on shipments.[12] In the wake of the increasing difficulty Japanese TV manufacturers faced in exporting, the ministry established a Plant Export Policy Committee intended to guide and encourage overseas investment. It is no surprise that when Japanese consumer electronics firms have been accused of price-fixing and other unfair trade practices, the allegations have often focused on MITI as coordinator.[13]

Industrial Structure

The three-tiered structure that characterizes many Japanese industries—large end-product manufacturers supplied by an array of small firms, many of them affiliates, the third tier consisting of even smaller suppliers and subcontractors—is found in consumer electronics as in the Japanese electronics industry at large. The structure differs from that of other countries mostly in that second- and third-tier firms tend to be more closely linked to end-product manufacturers, the links ranging from longstanding buyer-seller relationships to partial ownership. According to many Western observers, relationships between vendor and vendee—which tend to be arms-length in the United States, typified by hard bargaining over price—are more cooperative and supportive in Japan. Moreover, the second- and third-tier firms act as "shock absorbers" over the course of the business cycle, being the first to hire or fire and thus adding to the flexibility of the system. * Japanese firms are said to gain a variety of advantages compared to American companies, even where the latter, on the usual quantitative measures of vertical integration, exhibit a greater degree of internal production and value added. Of course, just as in the United States—where Zenith's component production is smaller than RCA's—Japan's consumer electronics producers differ significant-

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[11] See "Sources of Japan's International Competitiveness in the Consumer Electronics Industry: An Examination of Selected Issues, " op. cit., app. D, for a list. RCA established a small engineering laboratory in Tokyo as early as 1954, primarily to assist its licensees.

[12] *Television Digest*, June 27, 1977, p. 7.

[13] See, for example, J. Nevin, "American-Built Consumer Electronics: Can the Species Be Saved?" Appliance *Manufacturer*, February 1977, p. 74. At the time, Nevin was president of Zenith,

*Discussion of ties among purchasers, suppliers, and affiliates in Japan suffers from an unfortunate lack of empirical analysis; as a result, it is difficult to evaluate these arrangements, particularly from the viewpoint of the economy as a whole rather than the corporations which have developed them. On employment stability and layoffs in Japanese companies, see ch. 8.

ly in effective levels of integration. Matsushita makes perhaps 90 percent of its own TV components; worldwide, only Philips, the Dutch multinational, comes close to this figure.[14]

Names like Sony, Pioneer, and Toshiba have now become well known in the United States, indeed throughout the world. Many of these corporations are not only integrated in consumer electronics but highly diversified. Mitsubishi makes cars, steel, and ships as well as a wide range of consumer products. Yamaha builds pianos and motorcycles along with stereo equipment, Companies like Matsushita and Hitachi are leaders in home appliances; the latter, frequently compared to GE, gets about 20 percent of its sales in consumer goods ranging from TVs and stereos to washing machines. Hitachi is also a major producer of computers and semiconductors, as well as heavy machinery, both electrical and nonelectrical.[15] Even at Sony, revenues from TVs account for only about a third of sales, with another third from other consumer electronics products.[16] In part because of their diversified businesses, Japanese consumer electronics manufacturers—more so than most of their American counterparts—had begun to design and manufacture their own semiconductors by the 1960's; even today, half of Japan's output of microelectronics devices goes into consumer products, versus only 15 to 20 percent in the United States.

As early as 1971, 5 of the 10 largest consumer electronics producers in the world were Japanese, led by Matsushita and including Hitachi, Toshiba, Sony, and Mitsubishi. The Japanese consumer electronics industry was already considerably larger than the American, with more than twice as many employees and—although productivity had not yet reached the U.S. level—a much higher rate of growth in output per man-hour.[17] The larger Japanese consumer electronics firms have by now become true multinationals; not only do 7 of Japan's 11 color TV manufacturers operate plants in the United States, Japanese companies manufacture TVs in countries such as West Germany, Spain, and the United Kingdom, along with developing nations in Asia and South America. Matsushita has approximately 40 manufacturing plants outside Japan, mostly in developing countries. Sanyo and Matsushita are the leaders in foreign investment, with each accounting for about $1.5 billion in overseas production during 1980, much of this in other Asian nations.[18]

Japan's dominance of consumer electronics—now global though facing increased challenges from other Asian countries—extends well beyond TVs; Japanese corporations account for about 60 percent of world production of audio equipment, as well as virtually all VCRs. Philips is the only non-Asian company with its own technology for consumer VCRs—a product which, after a very long gestation period in the R&D laboratories of several Japanese companies, notably Sony and Matsushita (see ch. 5), was initially slow to find a a market. Now that sales are booming, Japanese firms are reaping the dividends, building virtually all their VCRs at home and exporting about 80 percent of them.[19] In this new generation of consumer products, Japan has taken a leadership position—although their designs were originally based on American technology, they have been through several generations of

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[14] "Sources of Competitiveness in the Japanese Color Television and Video Tape Recorder Industry, " op. cit., p. 148.

[15] N. Pearlstine, "That Old Nobushi Spirit, " *Forbes,* July 23, 1979, p. 42.

[16] "Sources of Competitiveness in the Japanese Color Television and Video Tape Recorder Industry, op. cit., p. 143; "Sony Heads Back to Broadcast Market, " *Electronics,* Mar. 27, 1980, p. 98.

[17] *The U.S. Consumer Electronics Industry,* op. cit., Pp. 24, 26. From 1972 to 1976, employment in TV manufacturing in Japan declined by almost half although output grew substantially—"Colour Television: Japan's Global Strategy Adapts to New Realities, Part II, " *Multinational Business, No.* 4, 1978, p. 18,

[18] J. Marcom, Jr., "Japanese Consumer Electronics Firms See Room To Expand Plants in Southeast Asia, " *Asian Wall Street Journal Weekly,* Mar. 1, 1982. Total production outside Japan in 1980 for the five largest Japanese consumer electronics firms came to about $4,3 billion.

[19] "Stagnant Export Industries Outlined, " *Japan Report,* Joint publications Research Service JPRS 1./10639, July 7, 1982, p. 56. Japan's estimated 1982 production of VCRs was 12.2 million units, with 9.7 million scheduled to be shipped abroad. Two Korean firms also build VCRs.

independent development already—rather than following behind American or European firms as had been the case with TV receivers.

Consumer Electronics in Western Europe

Table 15 compares relative sizes, as of 1978, of color TV manufacturers with headquarters in various parts of the world, While production levels will have changed, it is unlikely that positions have altered greatly except in the case of Philips—which, with the acquisition of GTE-Sylvania's TV operations by Magnavox in 1980, has probably moved into first place. Note that among the lower volume producers of TVs lumped under the "other" category are a number of large, diversified concerns with relatively small consumer electronics operations—e.g., General Electric.

The 13 color TV producers listed in table 15 include 5 Japanese companies, 3 American (of which only 2 now remain), and 5 European (counting ITT in this category)-–the latter all rather small except for Philips. The Dutch-based multinational has been a dominant force in European consumer electronics markets for years, but in color TV as in electronics as a whole the European industry includes many small-scale producers; more than 30 in the case of TVs. This dispersion of production capacity mirrors the relatively isolated markets that continue to characterize Western Europe a quarter-century after the establishment of the European Economic Community (EEC).

Table 15.—Worldwide Production of Color TV Receivers by Firm, 1978

Company	Headquarters	Annual production (millions of color TVs)
Matsushita, ...	Japan	3.60 (12.50/o)
Philips [a].	Netherlands	3.50 (12.1 %)
RCA	United States	2.00 (6.90/o)
Zenith	United States	1.97 (6.8%)
Sanyo	Japan	1.95 (6.8°/0)
Sony	Japan	1.70 (5.9%)
Toshiba	Japan	1.50 (5.20/o)
Grundig	West Germany	1.40 (4.80/o)
Hitachi	Japan	1,25 (4.3°/0)
GTE-Sylvania [a]. . .	United States .	1.20 (4.2%)
AEG-Telefunken . .	West Germany	0.98 (3.4%)
Thomson-Brandt .	France	0.94 (3.3%)
ITT [b].	United States	0.78 (2.7%)
Other		7.10 (24.60/o)
		28.9 million

[a] Figures for Philips Include Magnavox but not GTE Sylvan la, whose U S TV facilities were purchased by Magnavox in 1981 Saba, a German TV producer was sold by GTE to Thomson Brandt the same year

[b] ITT is an American based conglomerate that produces televisions in Europe but not the United States

SOURCE *Financial Times* Nov 18 1980

As a whole, the European consumer electronics market is nonetheless large. Table 16 gives approximate 1982 sales by major product category for the United States, Japan, and Europe. European consumers buy more TVs and VCRs than Americans, and almost as much audio equipment (radios, stereos, etc.).[20] Only in the "other" category of table 16 is the U.S. market much larger—a reflection of affluence and appetite for products like electronic toys and games; Americans bought more than 10 times as many toys and games as Europeans last year,

In contrast to the color TV markets of the United States and Japan, where most sales are replacements or additional sets, only about 60 percent of Western European households have color sets. In some countries—even France—the penetration is far less. While these large and still-expanding markets have attracted non-European firms, importers have faced an uphill battle; local producers are shielded by an array of trade barriers, with broadcasting standards the strongest,

Technologies for receiving European broadcast signals—particularly the PAL (Phased Alternating Line) system used everywhere except in France—are covered by a wide array of patents. Initially, the owner of the PAL patents, the West German firm AEG-Telefunken, refused licenses to all Japanese companies, Eventually licenses were granted allowing imports of smaller screen models only, or local production by Japanese manufacturers.[21] In ad-

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[20] West Germany is the largest country market, absorbing 2.6 million color TVs in 1979. Sales in Italy during 1979—where color broadcasting began only 3 years earlier—totaled 1.9 million sets, while consumers in the United Kingdom bought 1.8 million and in France 1.5 million The 1979 figure for the United States was about 10 million, slightly below total European sales of 10.5 million, See *Financial Times*, Nov 18, 1980, p. 18.

[21] In the United Kingdom, for example, sets with screen sizes over 20 inches cannot be imported from Japan. " Sectoral Study

Table 16.—Consumer Electronics Markets in the United States, Europe, and Japan

	1982 sales (billions of dollars)					
	Color TV	Monochrome TV	Video cassette recorders	Audio equipment	Other	Total
United States	$4.4	$0.5	$1.3	$5.7	$9.5	$21.4
Europe	5.0	0.4	2.4	5.2	1.5	*14.5*
Japan	2.6	0.02	1.8	*3.6*	*2.9*	10.9

SOURCES: *Electronics,* Jan. 13, 1963, pp 136, 146, 154; Mar. 10, 1963, p. 8.

dition to the protective effect of broadcast standards and patent licenses, tariffs into the EEC are relatively high—14 percent for color TVs—while value-added taxes can be as much or more. Some European countries have, from time to time, also adopted import quotas.

Just as they did in the United States, Japanese color TV manufacturers have established European production facilities to circumvent market restrictions, Five Japanese firms assemble color sets in Britain either through joint ventures or wholly owned subsidiaries, with much of this output being exported to other EEC countries.[22] Sony was the first to build TVs in the United Kingdom, just as it led the way into the United States; its British plant opened in 1968. While most of the foreign investment in the EEC has flowed to Britain, Japanese firms have holdings in countries like Italy and Spain as well—the latter particularly attractive because wage levels are comparatively low.

The first of more than 75 PAL patents lapsed in 1981; all will expire during the current decade. With considerable anxiety, Europe's color TV manufacturers are awaiting stiffer Japanese competition in the lucrative large screen market. For some—i.e., Telefunken, which entered bankruptcy in August 1982 after a period of poor financial performance extending over nearly 10 years—even the protection available in the past has not been enough.[23]

The fragmented character of the industry and market in Europe has created competitive problems for consumer electronics firms that cannot generate the revenues to support ongoing R&D and investments in up-to-date manufacturing facilities. Besides Philips, the principal exception has been the French company Thomson-Brandt, the consumer arm of the Thomson group, Both Philips and Thomson have recently moved to increase the scale of their European operations, aiming to position themselves for competition with the Japanese. Philips has solidified its ties with the West German firm Grundig—of which it purchased a 25-percent share in 1979—in part through joint efforts to improve the Philips VCR system.[24] Thomson-Brandt—although losing money in recent years—invested more than $150 million between 1978 and 1980 in acquisitions of West German consumer electronics firms.[25] The company's aim—which the French Government actively supported even before Thomson was nationalized under Mitterrand—has been

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No. 2: Transfer of Technology in the Consumer Electronics Industry-The Television Sector," Organization for Economic Co-operation and Development, Paris, Sept. 14, 1979, p. 16. Korean firms have been denied PAL licenses of any type.

Color broadcasting in the United States, Japan, and South America is based on the NTSC (National Television System Committee) system, developed here and approved in 1953 by the Federal Communications Commission after several years of controversy—" In the Wake of the Transistor," *Electronics,* Apr. 17, 1980, pp. 281, 284. France has its own SECAM (Sequential and Memory) system, also used in Eastern Europe.

[22] The companies are Sony, Matsushita, Toshiba, Mitsubishi, and Hitachi—"Sources of Japan's International Competitiveness in the Consumer Electronics Industry: An Examination of Selected Issues, " op. cit., pp. 124-125.

[23] See, for example, "Germany's Telefunken Insolvent: Huge Concern Discloses Debt of $1.84 Billion, " *New York Times,* Aug. 10, 1982, p. D1. The company had not paid dividends since 1974.

[24] "Philips: An Electronics Giant Rearms To Fight Japan, " *Business Week* Mar. 30, 1981, p. 86. A major difference between Philips' strategy and that of Japanese color TV manufacturers like Toshiba or Matsushita has been the siting of foreign manufacturing facilities. Almost all of Philips' operations are in industrialized countries, mostly in Europe (North American Philips is legally independent although closely tied to the Dutch firm]. In contrast, Japanese companies have moved aggressively into developing country markets.

[25] J. Tagliabue, "Europeans Battle Japanese TV Tubes, " New *York Times,* Feb. 10, 1982, p. D4.

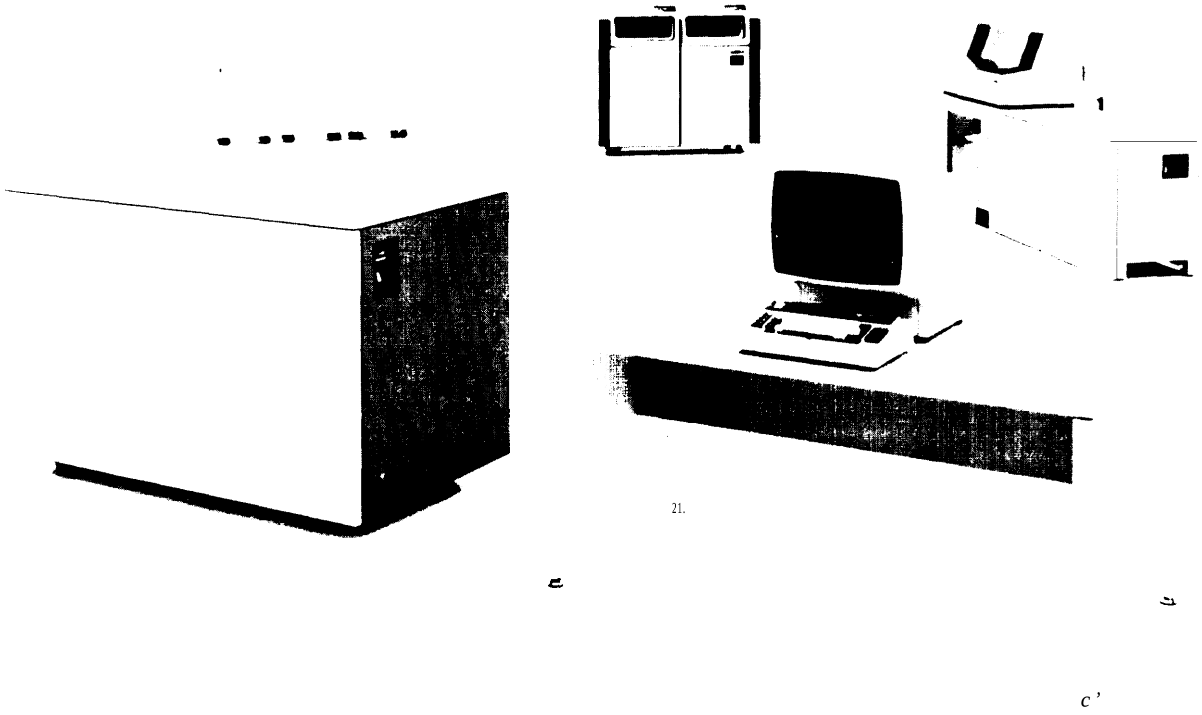

Photo credit: IBM

Small general-purpose computer system

to expand from its base in France to other parts of Europe.

In common with major Japanese producers, the larger European electronics manufacturers tend to be diversified. Philips makes computers and semiconductors, as does the largest of the West German entrants, Siemens—although Siemens has only a small consumer electronics business. Table 17 illustrates something of this diversification. The table ranks firms by sales in electronics—worldwide sales for European companies, sales only in Europe for American producers. Note first that U.S. firms have about 30 percent of the total European electronics market—mostly in computers, semiconductors, and other nonconsumer products. No *European country can claim a share of total European electronics sales approaching that of the United States.*[26] Second, although Japan's electronics manufacturers are perceived as rapidly increasing threats, as yet no Japanese firm has European sales in the top 20. Finally, the the low profit levels of the European companies in the table offer a striking contrast to American corporations like IBM or Xerox. The predominance of computer firms in table 17 demonstrates the size and importance of the information processing market in industrial-

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[26] G. de Jonquieres, "U.S. Dominates Europe's Electronics Markets," *Financial Times*, July 9, 1982, p. 7. Twenty-eight of the hundred largest firms ranked by electronics sales (defined as in table 17) are American. Sales for the 28 American companies came to $31.5 billion, with West German companies following at $19.2 billion; the top 100 firms had sales totaling $100 billion. Figures for the United Kingdom and France came to $12.3 billion and $11.3 billion, respectively. Japanese companies did $3.7 billion of business in Europe. (The totals are annualized for slightly different periods within the calendar years 1980 and 1981.)

Table 17.—Electronics Firms Ranked by European Sales[a]

Company	Headquarters	Electronics sales (billions of dollars)	Electronics as a percent of total company sales	Pre-tax profits as a percent of sales
Philips .,	Netherlands	$11.1	600/0	1 .9 "/0
IBM	United States	9.4	99	22.5
Siemens	West Germany	8.7	49	5.0
ITT	United States	8.6	50	6.7
Thomson	France	6.5	75	3.1
GEC[b]	United Kingdom	3.8	47	13.7
AEG-Telefunken	West Germany	2.9	36	(1.9)[c]
Ericsson	Sweden	2.0	70	7.7
CGE	France	1.9	18	6.3
Xerox	United States	1.9	80	16.5
Olivetti	Italy	1.7	68	6.8
Plessey	United Kingdom	1.7	85	10.0
ICE	United Kingdom	1.7	100	3.5
Grundig	West Germany .	1.5	100	(5.4)[c]
CII-Honeywell Bull	France	1.5	100	3.4
Thorn-EMI	United Kingdom	1.5	27	4.2
Bosch	West Germany	1.4	21	6.0
Hewlett-Packard.	United States	1.1	100	16.9
Racal	United Kingdom	1.1	90	13.6
Honeywell	United States	1.1	100	8.2

[a] The figures and rankings are for electronics sales only, but include electronic products of all types. For European firms, worldwide sales are listed; for American companies, only sales within Europe—whether through local production or imports. Sales figures are on an annualized basis but cover slightly different time periods between January 1980 and June 1981.

[b] The British General Electric Co. (GEC) is not related to the American firm of the same name.

[c] Loss.

SOURCE: G. de Jonquieres, "U S. Dominates Europe's Electronics Markets," *Financial Times,* July 9, 1982, p 7 Based on "Mackintosh European Electronic Companies File, 1981-82 "

ized economies. Not only do IBM, Hewlett-Packard, and Honeywell get much of their European revenues from computer sales, but several European companies in the table—ICL, CII-Honeywell Bull—are primarily computer manufacturers. Siemens and Olivetti are more diversified, but also among the larger European suppliers of data processing equipment.

Consumer Electronics in Other Parts of the World

A number of developing Asian economies have already established themselves as significant competitors in the global market for electronic products: Taiwan, South Korea, Hong Kong, and Singapore all have rapidly growing industries. The capabilities of each differ, as do the roles their governments have played. Generally, manufacturers in these countries are still concentrating on consumer electronics (see ch. 10, table 79), although clearly intending to move toward more advanced products, including semiconductors and computers; in essence, they are following the Japanese model. Only Taiwan and Korea have locally owned TV industries of any size. Hong Kong and Singapore have been effective competitors in calculators, electronic watches, and toys and games; Hong Kong's $2.6 billion in electronics exports during 1980 were split approximately 70:30 between consumer products and components.[27]

Japanese firms have invested extensively in TV production facilities in other Far Eastern nations, as have American manufacturers and a few European companies (Thomson-Brandt has a color TV plant in Singapore). RCA transferred some of its color production to Taiwan as early as 1969. By the time Rockwell's Admiral division left the business at the end of 1978, all of its TV production had been moved to Taiwan; the facilities were sold to a Hong Kong-based conglomerate.[28] Although U.S. companies have not invested in Korean consumer electronics plants, Matsushita began

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[27] R. Neff, "Hong Kong Prepares To Change, " *Electronics,* July 14, 1982, p. 124.

[28] *Television Receiving Sets From Japan* (Washington, D. C.: U.S. International Trade Commission Publication 1153, June 1981), p. A-21.

to ship color TVs from Korea to the United States in the mid-1970's.[29] By the end of the decade, Japanese electronics firms relied on subsidiaries or subcontractors in other Asian nations for two-thirds of their production of radios, 40 percent of their black-and-white TVs, and more than a quarter of their audio tape recorders.[30] In turn, Japan supplied electronics manufacturers in the rest of Asia with about 70 percent of their ICs and other high-technology components.

Wage Rates and Investment

Chief among the attractions of Asian nations as locales for foreign investment have been low wages, Savings in labor costs have drawn both Japanese and American firms making consumer electronics and semiconductor devices, As the economies of these countries develop, wage rates go up; table 18 illustrates the narrowing gap between Japan and other Asian nations over the period 1975-80, Labor costs in all the countries listed except the Philippines have increased with respect to Japan, but the rise in several of the more advanced economies—Korea, Hong Kong, Singapore—has been particularly steep. All three have been preferred investment sites for Japanese electronics firms, several of whom have responded to wage increases by returning some production to Japan, making extensive use of automated equipment.[31] In comparison to the higher wage countries listed in table 18, the electronics industries in Indonesia and Sri Lanka remain in an early stage of development.

Table 18.—Wage Rates for "Skilled" Labor in Asian Countries Compared to Japan

	1975	1980
Japan	100	100
Hong Kong	29	38
South Korea	22	51
Malaysia	20	29
Taiwan	15	21
Singapore	15	32
Philippines	14	12
Thailand	13	17
Indonesia	9	12
Sri Lanka	2	3

SOURCE *Denshi Sangyo no Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku* (Survey Report on Trends in the Internationalization of the Electronics Industry and Their Influence, Part II on East and Southeast Asia) (Tokyo Nihon Denshi Kikai Kogyokai (Electronic Industries Association of Japan), March 1981), p. 5

As the patterns outlined above might suggest, foreign investments have made substantial contributions to the development of host country electronics industries.[32] Foreign-owned plants train people who can then staff indigenous companies, as well as nurturing the infrastructure—suppliers, transport facilities, financial institutions, government agencies—needed to support a local industry. Moreover, as the economies of these countries expand, their own electronics markets grow. At present, consumers in Taiwan probably buy more consumer electronic products than those in any Asian country except Japan, with South Korea close behind. Demand should continue to grow rapidly in both Taiwan and Korea; color TV broadcasting–which began at the end of 1980 in South Korea—will be a major spur.

During the 1960's, most of the developing Asian economies pursued policies aimed at attracting outside capital. Several countries later restricted direct investment, but in response to slow economic growth during the latter part of the 1970's often moved back toward selective encouragement. Foreign-owned electronics plants in Asia have typically been built for export rather than local sales; table 19 illustrates the heavy dependence of these countries on exports as well as foreign capital.

“’International Technological Competitiveness: Television Receivers and Semiconductors, op. cit., p. 2-23.

[30] *Denshi Sangyo* no *Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku* (Survey Report on Trends in the Internationalization of the Electronics Industry and Their Influence, Part II on East and Southeast Asia) (Tokyo: Nihon Denshi Kikai Kogyokai (Electronic Industries Association of Japan), March 1981].

[31] J. Marcom, Jr., "Japanese Electronic Firms Cut Reliance On Offshore Plants, " *Asian Wall Street Journal Weekly,* Aug. 17, 1981, p. 1.

[32] For a case study that describes how technology transfers associated with offshore assembly in Korea helped build the foundation for a domestic industry, see J. N. Behrman and H. W. Wallender (eds.), *Transfers of Manufacturing Technology Within Multinational Enterprises* (Cambridge, Mass.: Ballinger, 1976], ch. 10 on "Motorola -Korea.'

Table 19.—Foreign Capital, Production, and Exports in Asian Electronic Industries, 1979

	Foreign investment as a percentage of total investment in electronics	Total electronics production (millions of dollars)	Exports as a percentage of total electronics production
South Korea	25%	$3,300	70%
Taiwan	45	3,200	80
Hong Kong	-10	2,000	90
Singapore	80+	1,850	90
Malaysia	90+	990	75
Indonesia	high	540	Not available
Philippines	very high	320	90
Thailand	very high	110	10

SOURCE *Denshi Sangyo no Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku* (Survey Report on Trends in the Internationalization of the Electronics Industry and Their Influence, Part II on East and Southeast Asia) (Tokyo: Nihon Denshi Kikai Kogyokai (Electronic Industries Association of Japan), March 1981), p. 7.

By ***1978,*** before the OMA, Korea's shipments of color TVs to the United States exceeded 400,000 sets (table 12)—a graphic illustration of expanding scale and rising competitiveness in the country's consumer electronics industry, which, in contrast to that in Taiwan, owed little to U.S. capital (although Japanese investment had been substantial). Following in the footsteps of Japanese and Taiwanese color TV manufacturers, the Korean Gold Star firm has now established U.S. production facilities. Gold Star—a member of the Lucky Group, a large conglomerate—began operations in Alabama during 1982 (table 10), Taiwan's exports of color sets to the United States had, before the OMAs, been even greater than those of Korea. Many of these shipments came from plants operated by RCA and Zenith, who own a considerable fraction of Taiwan's production capacity and who were also restricted by the 1979-82 OMA. Tatung, the country's largest electronics manufacturer, opened the first Taiwanese-owned assembly plant in the United States in 1980, with Sampo beginning production in Atlanta the following year.[33] Such investments are a clear indication that consumer electronics firms in the rapidly industrializing nations will continue their efforts to penetrate U.S. markets.

China has been a major exception to otherwise common trends in the developing Asian economies (also see ch. 10, which compares industrial policies in these countries). The People's Republic has negotiated a number of joint ventures with foreign concerns, most of whom have viewed it as potential market more than potential competitor. Sony, for instance, has announced an agreement with China's National Electric Technology Import Corp. to provide technology and manufacturing equipment for producing VCRs in Beijing.[34] The People's Republic has already become a significant market for consumer electronics products originating elsewhere in Asia; Japanese firms have dominated shipments of black-and-white TVs, with South Korea and Taiwan leading in exports of tape recorders and radios, respectively.[35] American and European firms are also competing for electronics sales in China, though seldom in consumer products.

The Example of South Korea[36]

As the paragraphs above indicate, and as table 19 also shows, South Korea—along with Taiwan—is a leader among developing Asian electronics industries. Government has given

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[33] T. Furukawa, "See Taiwan Elect. Growth, " *Electronic News,* Dec. 7, 1981, p. W. About half Taiwan's total exports of electronics have been coming to the United States. On Gold Star, see E. Lachica, "Korea's Gold Star Seeks To Make a Name for Itself in the U.S. Television Market, " *Asian Wall Street Journal Weekly,* July 5, 1982, p. 8.

[34] N. Hashimoto, "Sony, China To Try A New Approach to Joint Ventures," *Asian Wall Street Journal Weekly,* Jan. 19, 1981, p. 6.

[35] "Chugoku ni Dairyo Yushutsu, " (Large-Volume Exports to China) *Nihon Keizai Shimbun,* Jan. 12, 1981.

[36] The information that follows is drawn largely from *Denshi Sangyo no Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku* (Survey Report on Trends in the Internationalization of the Electronics Industry and Their Influence, Part II on East and Southeast Asia), op. cit.

local manufacturers considerable assistance since Korea made its first transistor radios in 1950, with the commitment to expansion in electronics strengthening in recent years. During the 1970's, Korea's production of consumer electronics grew at nearly 50 percent per year—table 20. The fraction of total manufacturing output accounted for by electronics swelled, with exports of consumer electronics increasing at nearly 65 percent annually, During the 1980's, production and exports of data processing and telecommunications equipment are expected to grow faster than consumer goods output, components other than microelectronics to decrease (see table 78, ch. 10).

Table 20.—South Korea's Electronics Production

	Output (millions of dollars)			Average annual growth rate (1971-80)
	1971	1976	1980	
Consume; . ., ...	$ 33	$ 551	$1,148	48.30/,
Industrial[a] ., . . .	19	126	364	38.8
Components	86	745	1,341	35.7
	$138	$1,422	$2,853	40.0
Electronics as a percentage of all manufacturing .	1.40/0	5.60/o	8.5%	

[a] Includes computers and telecommunications equipment

SOURCE *Denshi Sangyo no Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku* (Survey Report on Trends in the Internationalization of the Electronics Industry and Their Influence, Part II on East and Southeast Asia) (Tokyo Nihon Denshi Kikai Kogyokai (Electronic industries Association of Japan), March 1981), p 103.

As table 20 indicates, components—many of them produced by the small firms that predominate in Korean industry—are a staple of the nation's output; of roughly 750 Korean electronics firms in 1978, well over half were capitalized at less than $500,000, and about 500 were parts suppliers. [37] As a result, the country is largely self-sufficient in the components needed for production of both color and monochrome TVs, as well as many other consumer products. The chief weakness of the components sector—a weakness shared with other developing economies—has been ICs. Nevertheless, Korean firms have managed to outstrip their rivals elsewhere in Asia, always excepting Japan, in technology and production capacity for microelectronic devices. [38] While most of the semiconductors now made in Korea are discrete devices and small-scale integrated circuits, the Hyundai Group—a large conglomerate—has announced plans for substantial investments in advanced devices, aiming at production of 64K RAMs and other advanced products within a few years.

Semiconductors

Technical advances in electronics, as in many other industries, flow in good measure from synergistic relationships among end-product manufacturers and suppliers—here, suppliers of the primary building blocks for electronic systems, semiconductors. IC designs represent direct responses by companies in the merchant industry to perceived needs at the user level. In their turn, semiconductor firms depend on suppliers who design and build the specialized equipment needed for producing ICs—equipment ranging from electron-beam mask-makers and optical wafer-steppers to annealing furnaces (ch. 3). A separate section below is devoted to the equipment industry because of its role in providing the tools that semiconductor manufacturers need to maintain their own technological competitiveness.

American dominance of world semiconductor markets continued through the 1970's without significant challenge, least of all in ICs. Virtually all the major innovations in microelectronics have come from the United States; most foreign producers depended to considerable extent on licensing agreements with American firms. U.S. companies have also supplied world markets directly, through exports or local pro-

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[37] Ibid., p. 107.

[38] A. Spaeth, "Korea's Electronics Industry Making Rapid Gains in Shift to High-Technology Products, " *Asian Wall Street Journal Weekly, Dec.* 20, 1982, p. 1; R. Neff, "Bold Koreans Push Into Leading-Edge ICs, " *Electronics,* June 16, 1983, p. 98.

duction by subsidiaries, Including captive production and overseas operations, U.S.-owned firms accounted for nearly two-thirds of total world semiconductor output in 1981.[39] Only near the end of the last decade did the situation begin to change, as Japanese enterprises made rapid strides in IC design and production.

If the 1970's represented the zenith, American dominance seems bound to wane during the present decade. There are many signs. First and perhaps foremost is the determination by other governments to contest the U.S. lead in technology (ch. 10). While the results of government-sponsored R&D efforts have been mixed—and no doubt will remain so—such programs, many of which are of substantial if not overwhelming magnitude, demonstrate the importance other nations attach to an independent capability in microelectronics. The many efforts by foreign enterprises to tap the U.S. technology reservoir through investments in American firms are another sign. Still more tangible evidence that the current decade will not duplicate the 1970's comes, not surprisingly, from Japan. Partly as a consequence of government-subsidized research efforts, as many as six Japanese companies have demonstrated their ability to compete successfully in the design and production of sophisticated ICs—most notably, memory chips such as dynamic RAMs. Although the range of products in which the Japanese are strong is fairly narrow, they are quickly broadening their product lines. For U.S. manufacturers, the competitive situation in the 1980's differs substantially from that to which they had grown accustomed.

The Semiconductor Industry in the United States

Growth continues to be a major descriptor of the U.S. semiconductor industry. Output in the United States, including exports and production consumed internally, has gone from about $600 million in 1960 to $9.5 billion in ***1982;*** the average annual increase, nearly 14 percent, has been well above the 9 percent (in current dollars) average for the gross national product.[40] Output in 1983 is projected to reach $11.3 billion.

Demand in the rest of the world has also expanded at high rates. Table 21 compares sales in the major markets—the United States, Western Europe, and Japan—for 1974 and 1982. Sales more than tripled in the United States and Japan, with increases for ICs compared to discrete semiconductors especially striking, Over the same period, European semiconductor sales increased by only 75 percent. The Japanese market is now half the size of that in the United States.

Structure

Something over a hundred American firms make semiconductors, with about 60 percent of the industry's output coming from the four largest manufacturers: IBM and Western Elec-

Table 21 .—Semiconductor Sales in the United States, Western Europe, and Japan

	Sales (billions of dollars)	
	1974	1982
United States		
Discrete semiconductors . . .	$0.88	$1.3
Integrated circuits	1.2	6.3
	$2.1	$7.6
Western Europe		
Discrete semiconductors . . .	$0.77	$0.77
Integrated circuits	0.52	1.5
	$1.3	$2.3
Japan		
Discrete semiconductors . . .	$0.55	$1.2
Integrated circuits.	0.59	2.4
	$1.1	$3.6

SOURCES: ***1974—Electronics***, Jan. 8, 1976, pp. 92, 93, 105
1982- Electronics, Jan 13, 1983, pp. 126, 142, 150; Mar, 10, 1983, p 8

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[39] ***Status 1982;*** *A* ***Report*** *on the Integrated Circuit* ***Industry*** (Scottsdale, **Ariz**.: Integrated Circuit Engineering Corp., 1982), p. 5.

[40] **Domestic** shipments were $571 million in 1960—A *Report on the U.S. Semiconductor Industry* (Washington, D. C,: Department of Commerce, September 1979), p. 39. The 1982 and 1983 figures are from 1983 U.S. *Industrial* ***Outlook*** (Washington, D. C.: Department of Commerce, January 1983), p. 29-7. Other definitions of the industry's products and boundaries will, as for consumer electronics, result in different figures. The gross national product (GNP) growth rate is based on table B-1, p. 233 of the *Economic Report of the President* (Washington, D. C.: Government Printing Office, February 1982). GNP in real terms has, of course, grown much more slowly,

tric, which produce only for internal consumption, plus Texas Instruments (TI) and Motorola, which sell most of their production on the open market. Some 80 percent of U.S. output comes from the 20 largest manufacturers, a percentage that would be higher if ICs alone were considered.[41]

Major U.S. merchant companies—those that sell on the open market—are listed by sales level in table 22. Note that 3 of the 10 have been purchased—in 2 cases by foreign interests—since 1977; thus, strictly speaking, the table no longer represents U.S. companies only, The ups and downs of sales figures for various companies over the period ***1978-82*** show that positions are likely to continue to change; indeed, Motorola nearly caught TI in ***1981/1982,*** managing small increases despite the recession while the latter company's sales dropped nearly ***20*** percent.

Market Trends

Table **23** shows sales and projections by device type in the domestic market (exports are not included), while figure **23** illustrates end uses for ICs. Sales growth between ***1982*** and ***1986*** is projected at 20 percent per year. While such estimates often miss the mark—1982 sales

Table 22.—Merchant Semiconductor Sales of Ten Largest U.S. Suppliers

	Worldwide semiconductor sales (millions of dollars)				Approximate 1982 market share
	1974	1978	1980	1982	
Texas Instruments	$634	$921	$1,580	$1,300	8.8 ”/0
Motorola	481	680	1,120	1,219	8.3
National Semiconductor	210	376	800	673	*4.6*
Intel	115	300	575	578	*3.9*
Fairchild Camera and Instrument acquired by Schlumberger in 1979).	323	358	566	412	2.8
Signetics (acquired by Philips in 1977)	121	214	384	340	2.3
Advanced Micro Devices	26	132	282	329	2.2
General Instrument	63	129	244	313	2.2
RCA	NA	NA	NA	291	2.0
Mostek (acquired by United Technologies in *1980)*	*60*	*134*	*360*	*220*	*1.5*

NA = Not available

SOURCE Dataquest

Table 23.—U.S. Semiconductor Sales by Type

	Sales volume (millions of dollars)			
	1975	1980	1982	1986a
Discrete semiconductors	$ 665	$1,255	$1,322	$ 1,720
Integrated circuits:				
Standard logic families	364	1,313	1,183	*1,920*
Microprocessors/microcomputers	68	641	1,053	*2,820*
Memory	257	1,862	2,113	*5,450*
Linear circuits	192	676	868	1,700
Consumer products ICs.	—[b]	393	497	820
Custom ICs	—[b]	—[b]	426	1,410
Other ICs	57	304	137	310
	938	5,190	***6.277***	14.430
Total semiconductors	$1,603	$6,445	$7,599	$16,150

[a]Projected.
[b]Included under “Other ICs “

SOURCES ***1975****—Electronics*, Jan. 8, 1976, pp 92, 93.
1980*—Electronics*, Jan 13, 1962, pp 124, 125
1982,1986*—Electronics*, Jan 13, 1963, pp 128, 129, Mar 10, 1983, p 8

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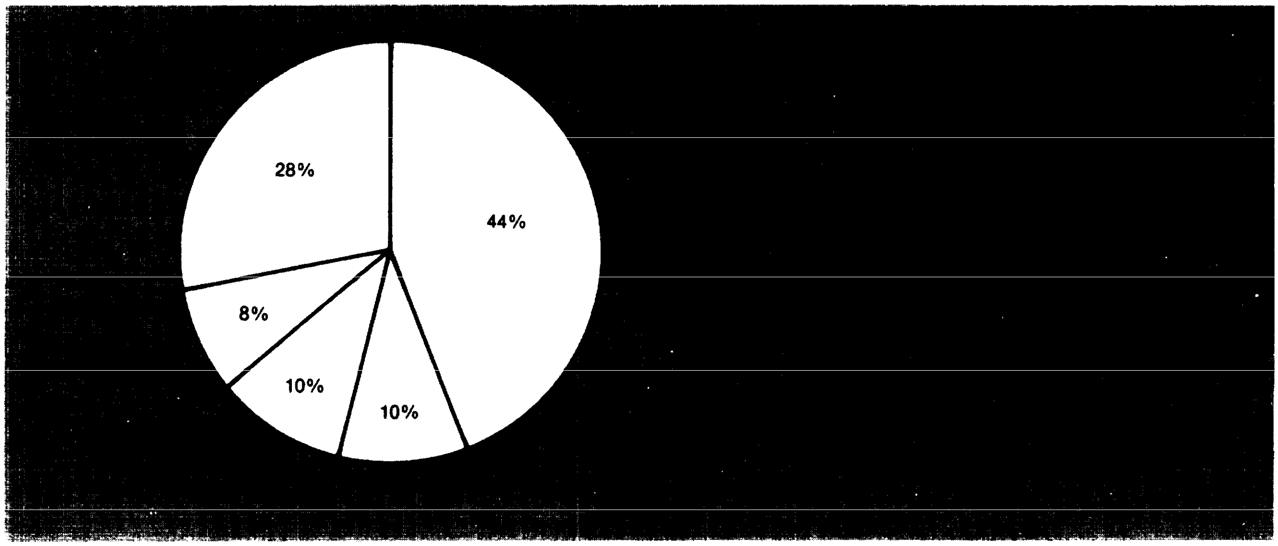
[41] *Summary of Trade and Tariff Information: Semiconductors* (U.S. International Trade Commission Publication 841, Control No. 6-5-22, July 1982), p. 8.

Figure 23.—End Uses of Integrated Circuits Sold Worldwide in the Merchant Market, 1980



SOURCE *Status '80 A Report on the Integrated Circuit Industry* (Scottsdale, Ariz : Integrated Circuit Engineering Corp , 1980), p. 34

proved disappointing when the economy failed to recover as expected—the longer term demand trend is bound to be steeply upward. Growth will be fastest for ICs, with discrete semiconductors—e.g., transistors—declining in relative importance as ICs continue to replace them. Within the IC category, microprocessors and microcomputers are in turn taking over some of the applications formerly performed by standard logic circuitry (ch. 3). Note the rapid increases in demand for microprocessors and single-chip microcomputers and the steep rise anticipated for custom circuits. Because table 23 is based on value rather than units, it may understate demand for memory circuits in comparative terms. Memory chips were the opening wedge for Japanese marketing efforts in the United States; price competition—expected to continue—means that dollar sales gain may be be depressed even as unit sales skyrocket.

Where in 1960 about half of U.S. semiconductor production was sold to the military, 1982 military sales were at a level of $900 million to $1 billion — a bit more than 10 percent of the total; if only ICs are considered, defense production accounts for around 7 percent of demand.[42]

Merchant and Captive Producers

U.S. semiconductor manufacture is marked by two types of companies: 1) the so-called *captive producers* who make semiconductors to be incorporated in their own end products, which may range from consumer items to computers and defense systems, and 2) *merchant manufacturers* who sell a major part of their output to other firms. Some captives—IBM, Western Electric—consume all their production internally, while other integrated producers—RCA, NCR—sell a fraction of their output on the open market and use the rest themselves. Most companies that depend on micro-

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[42] L. Wailer, "Cadence Slow for Military Sales, " *Electronics,* Aug. 25, 1982, p. 75; *An Assessment of the Impact of the Department of Defense Very-High-Speed Integrated Circuit Program* (Washington, D. C.: National Materials Advisory Board Report NMAB-382, National Research Council, January 1982), p. 6. The two largest defense suppliers, Texas Instruments and Motorola, had 1980 military sales of about $110 million and $90 million, respectively—6.8 percent and 7.4 percent of their total semiconductor output. These figures are for direct sales; semiconductor products embodied in standard systems such as computers would add to the totals.

electronic devices buy a portion of their needs from merchant firms even if they operate captive facilities. While a number of the larger merchant producers also make end products, and consume some of their semiconductor output internally, the fraction tends to be small compared with outside sales—typically in the 10-percent range (table 24; note that this table lists production rather than sales, thus the figures differ somewhat from those in table 22).

The only recent and authoritative data on production by U.S. captives covers ICs only. Collected by the U.S. International Trade Commission (ITC), the data shows the percentage of domestic IC output accounted for by captives to have ranged between 40 and 50 percent during the period 1974-78.[43] Table 25 contains another set of estimates, these based on *worldwide* production of firms with headquarters in the United States (and elsewhere); the captive percentages here are lower than those found by the ITC's surveys in part because U.S. merchant firms have extensive overseas operations while captive production remains more heavily concentrated in the United States.

Table 25 also illustrates the extent to which American companies have captured world markets for ICs (in this table, production by foreign subsidiaries of U.S. firms is attributed to the United States). Although the U.S. position has been challenged by Japanese manufacturers in some segments of the market, American companies still produce more than two-thirds of the world's ICs.

All estimates indicate that captive production accounts for a substantial fraction of U.S. semiconductor output; not only is captive production large, according to table 25 it is increasing. For a variety of reasons, this trend is expected to continue; one projection shows captive IC production rising from about one-third of the worldwide output of U.S.-based firms in 1982 to 40 percent by 1985 and 50 percent at the close of the decade.[44] While such estimates are always problematical, they are based on forces that have been at work in the industry for a number of years—in many cases the same forces that have led enterprises like GE and United Technologies to purchase merchant semiconductor firms. Manufacturers of

Table 24.—internal Consumption of Several U.S. Semiconductor Producers, 1978

	Semiconductor production (millions of dollars)	
	Total	Internal consumption
Texas Instruments	$1,192	$112 (9.4%)
IBM	750a	750 (100%)
Motorola	582	31 (5.3°/0)
Fairchild Camera and Instrument	389	37 (9.5°/0)
National Semiconductor. . .	364	37 (105)
Intel	298	30[a] (10%)
Western Electric	200[a]	200 (loo%)

[a] Estimated

SOURCE Dataquest.

Table 25.—World Integrated Circuit Output by Headquarters Location of Producing Firms

	1978		1982a	
	Production (millions of dollars)	Share of world output	Product ion (millions of dollars)	Share of world output
United States.	$4,582	*68.3%*	*$9,700*	*69.5%*
Merchant	3,238		*6,450*	
Captive	1,344		*3,250*	
Captive percentage.	29.30/o		*33.50/0*	
Western Europe	453	*6.7*	*620*	*4.4*
Japan	1,195	17.8	3,440	24.7
Rest of the world[b]	482	7.2	190	1.4
	$6.712		$13.950	

[a] Estimated

[b] Includes the Soviet Union and Eastern Europe for 1978 but not 1982

SOURCES ***1978****—Status* '130 *A Report on the Integrated Circuit Industry* (Scottsdale, Ariz. " Integrated Circuit Engineering Corp , 1980), p 4
1982*—Status 1982: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz Integrated Circuit Engineering Corp , 1982), p 5

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[43] *Competitive Factors influencing World Trade in* Integrated *Circuits* (Washington, D.C.: U.S. International Trade Commission Publication 1013, November 1979), pp. 82, 84. The captive percentages were:

1974	1975	1976	1977	1978
44.0%	47.9%	*49.80/o*	*44.10/o*	*40.*.0%

[44] *Status* 1982: *A Report on the Integrated CircuitIndustry,* op. cit., p. 48.

products incorporating semiconductors—computers, automobiles, industrial machinery—see benefits in an internal capability for design and production. Large consumers of ICs, such as computer manufacturers (table 26), look for cost savings. But even if the firm supplies only a small fraction of its own needs—as in fact most captives do—experience with state-of-the-art devices is an advantage in the development of end products. Many companies want to be able to produce their own custom ICs; among the secondary benefits is protection of proprietary circuit designs—easier if production is in-house. In their pursuit of such goals, a number of captive facilities have earned places among the technological leaders of the U.S. industry.

The figures in table 26—restricted to firms that build exclusively for internal consumption except for NCR, which ventured into the merchant market in a small way in 1981—should be regarded as no more than rough indications; other estimates differ. The general trends are not in question, however; most captive operations—the exception is IBM—remain modest in size, manufacturing specialized devices. Computer firms predominate in table 26. A good deal of their production consists of small lots—i.e., 1,000 to 10,000—of custom chips for which outside sources are scarce or unavailable.[45] Honeywell's Solid State Electronics Division, for instance—which produces largely for the firm's line of industrial control systems, rather than its general-purpose computers—expects to be making 1,500 different chip designs by 1985. NCR and Burroughs use much of their output in peripherals such as terminals, where the cost advantages are greater than in processors. IBM, unlike other computer firms, makes most of its own memory circuits; the company is the largest producer of semiconductors in the world. At the same time, IBM has probably become the biggest single customer for merchant devices, purchasing substantial quantities of memory chips from Japanese as well as American vendors. One motive for the company's recent acquisition of a substantial interest in Intel was to help protect a major supplier from possible takeovers.

International Operations of U.S. Firms

Most American semiconductor producers are multinationals. Foreign investments began in the late 1950's; a little over a decade later, the overseas production facilities of U.S. semiconductor manufacturers numbered more than a hundred.[46] Overseas plants typically serve one of two purposes. First, many U.S. firms

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[45] See L. Marion, "Mainframe Builders Making More ICs," *Electronics,* May 22, 1980, p. 106; W. I. Iversen, "Captive Semiconductor Facilities Are Gearing Up To Compete Against Established Merchant Suppliers," *Electronics,* May 19, 1982, p. 133. All of the mainframe manufacturers profiled in the first of these articles already had, or were planning to install, the capacity for producing at least 20 percent of their own semiconductor needs.

[46] *A Report on the U.S. Semiconductor Industry,* op. cit., p. 38.

Table 26.—Estimated Production Levels for Captive Manufacturers of Integrated Circuits

	1982 IC production (millions of dollars)	Captive production as percentage of all ICs consumed	Circuit types emphasized in captive operations
IBM (worldwide)	$2,080	80 ”/0	Bipolar and MOS logic and memory
Western Electric	385	NA	Microprocessors, memory
General Motors (Delco)	185	NA	Bipolar
Hewlett-Packard	160	NA	Wide range of MOS and bipolar
Honeywell [a]	90	10-20	Mostly bipolar logic
NCR	70	40	MOS microprocessors, memory
Digital Equipment Corp. (DEC)	60	NA	Bipolar
Burroughs	40	NA	MOS logic and memory
Data General	30	High	MOS and bipolar; many standard parts
Tektronix	25	NA	Bipolar linear

NA - Not available

[a] Honeywell also owns the merchant firm Synertek, the production of which has been excluded,

SOURCES *Output figures, products—Status 1982: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz. Integrated Circuit Engineering Corp , 1982), pp 52-56
Percentage consumption, products—L Marion, "Mainframe Builders Making More ICs," *Electronics,* May 22, 1980, p 106.

own *offshore* facilities to which labor-intensive production operations—particularly wire bonding and assembly—have been transferred. Second, many companies manufacture semiconductors in industrialized countries to better serve the market or in response to foreign government pressures for local production. Subsidiaries of the second type are often called point-of-sale plants. The larger U.S. merchant firms have made foreign investments of both sorts. Most offshore plants are in newly industrializing countries: Malaysia, Singapore, Taiwan, Mexico, the Philippines, Like color TVs, semiconductors are major U.S. import items under items 806.30 and 807.00 of the Tariff Schedules. The great majority of point-of-sale plants, in contrast, are in Europe—where U.S. merchant companies hold about half the market, These plants are concentrated in the United Kingdom and West Germany. Point-of-sale manufacturing also takes place in Australia, Japan, and Brazil. TI, for instance, builds such products as 64K RAMs in Japan, shipping some back to the United States; the company owns as many as 40 overseas plants in 19 countries,

Captives also produce overseas. While IBM has not invested in offshore plants that send semiconductors back to the United States, the company makes ICs in West Germany and France to supply its European subsidiaries. NCR produces semiconductors in Mexico, Hong Kong, the United Kingdom, and West Germany; Rockwell—which splits its production between merchant sales and captive consumption —has plants in Mexico, Taiwan, the Philippines, and Malaysia.[47] Wide dispersion in both production and sales has been a hallmark of the semiconductor industry for many years.

Exports and Imports

As figure 24 shows, U.S. imports and exports of semiconductors have risen steeply over the years. Much of this trade consists of intracorporate transfers—American companies shipping wafers offshore to be returned later in semifinished or finished form. If ICs only are

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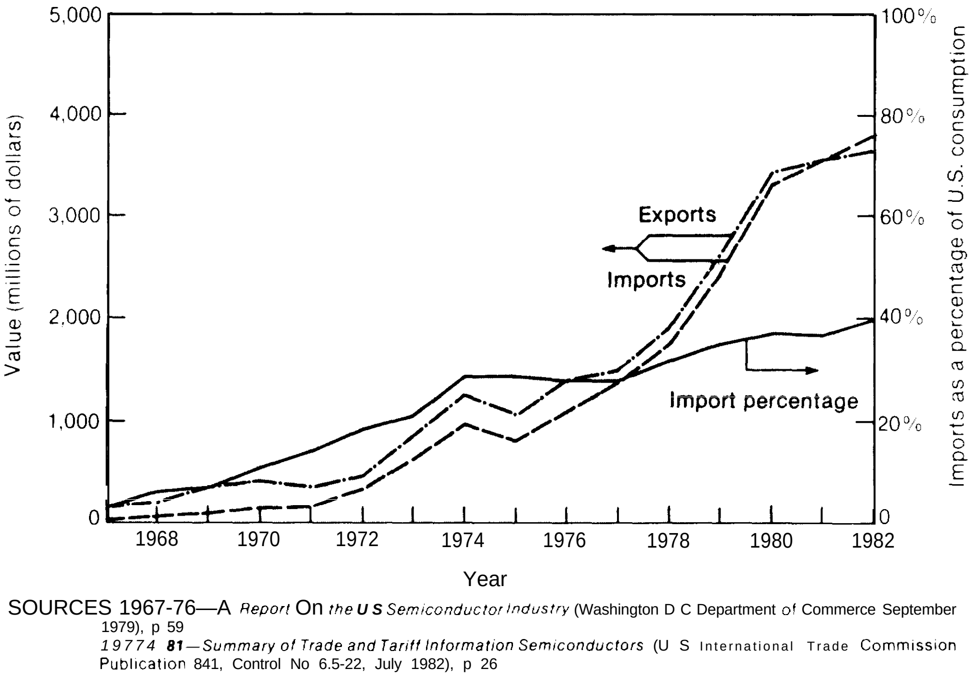
[47] See *Japan Fact Book'79* (Tokyo: Dempa Publications, Inc., 1979), p. 96, for one of the more complete surveys of semiconductor plants owned by U.S. as well as Japanese firms.

Figure 24.—U.S. Imports and Exports of Semiconductor Products



SOURCES 1967-76—A *Report* On *the* ***U S*** *Semiconductor Industry* (Washington D C Department of Commerce September 1979), p 59
19774 ***81***—*Summary of Trade and Tariff Information Semiconductors* (U S International Trade Commission Publication 841, Control No 6.5-22, July 1982), p 26
1982– *1983* U S *Industrial Outlook* (Washington, D C Department of Commerce January 1983), p 29-6

considered, U.S. imports have exceeded exports since 1978, and by slowly increasing margins.[48] For all semiconductor products, as figure 24 indicates, the trade balance has now begun to follow that for ICs onto the negative side of the ledger; still, shipments by American-owned firms continue to predominate among *both* imports and exports. According to table ***27,*** about **80** percent of all U.S. imports of semiconductor products in recent years have been re-imports after offshore assembly by U.S. producers—which enter under items **806.30** and **807.00** of the Tariff Schedules (virtually all **807).** At the same time, imports from Japan have grown swiftly as a share of total imports. The increase in percentage of domestic value added between 1977 and 1981 stems mostly from the increasing capital intensity—hence increasing share of costs—for the front-end wafer fabrication carried out in the United States.

Table 28 classifies imports for the years 1977 and 1981 by source, showing more clearly the increase in shipments from Japan as compared with other Asian nations. A small fraction of the imports from Japan originate with American-owned companies such as TI, but most come from Japanese manufacturers. Virtually all imports from the other countries listed are 806/807 shipments of U.S.-based multinationals. This table emphasizes the continuing importance of offshore assembly.

Table 28.—Origin by Country of U.S. Imports of Semiconductor Products[a]

Country of origin	Import shipments by value and percentage of total imports (millions of dollars) 1977	1981
Japan	$ 87 (6%)	$ 398 (11 °/0)
Malaysia	286 (21 %)	880 (250/o)
Singapore ...	257 (19°/0)	593 (17%)
Philippines	72 (5°/0)	471 (13%)
South Korea	224 (17°/0)	238 (7°/0)
Mexico	78 (6°/0)	149 (4%)
Taiwan	93 (7%)	131 (4%)
All other	260 (19°/0)	723 (20°/0)
	$1,357	$3,584

[a] Includes discrete semiconductors and integrated circuits, partially completed as well as finished products,

SOURCE" Summary *of Trade arrd Tariff /n formation: Semiconductors* (U.S. International Trade Commission Publication 841, Control No. 6-5-22, July 1982), p. 28.

A similar picture emerges on the export side: nearly three-quarters of U.S. semiconductor exports consist of semifinished products—mostly wafers—shipped to offshore plants.[49] Among industrialized countries, major destinations for U.S. shipments—semifinished as well as completed devices—include Canada and West Germany, the latter serving as a convenient entry point into the European Community; U.S. ship-

Table 27.—Sources of U.S. Imports of Semiconductor Products[a]

Year	Total value of imports (millions of dollars)	Distribution of imports by source: 806/807 imports[b]	Distribution of value added for 806/807 imports[c]: Foreign	Domestic	Imports from Japan	Imports from all other countries
1970	$ 157	88.30/o	43.60/o	56.40/o	NA	—
1975	803	76.9	52.7	47.3	N A[d]	—
1977	1,360	81.5	44.9	55.1	6.40/o	12.1 %
1981	3,584	78.3	32.7	67.3	11.1	10.6

NA = Not available.

[a] Includes discrete semiconductors and integrated circuits, partially completed as well as finished products

[b] Based on total value of all Imports entering under items 806.30 and 807.00 of the Tariff Schedules of the United States

[c] Foreign value added percentages are based on the dutiable value of the 806/807 imports, domestic value added the duty-free value.

‘In 1975, 4.4 percent of integrated circuits (only) originated in Japan.

SOURCES" ***1970,*** 1975–A ***Report on the*** *U.S.* ***Semiconductor*** *Industry* (Washington, D.C.: Department of Commerce, September 1979), P 62
1977,1981—*Summary of Trade and Tariff Information: Semiconductors* (U S. International Trade Commission Publication 841, Control No 6.5-22, July 1982), p 15.

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[48] *Summary of Trade and Tariff Information: Semiconductors,* op. cit., p. 27.

[49] In 1981, 73 percent of U.S. exports of semiconductor products went to offshore assembly sites in developing countries—*Summary of Trade and Tariff Information: Semiconductors,* op. cit., pp. 16, 29, The destinations and relative magnitudes of these exports correlate closely with the import figures in table 28. Data on exports to the European Community, mentioned later in the paragraph, come from Bureau of Industrial Economics printouts, Department of Commerce.

ments of semiconductor products to West Germany in 1980 come to about $264 million, 42 percent of total U.S. semiconductor exports to the EC. Point-of-sale production in Europe by American-owned firms is probably somewhat greater than exports from the United States, although precise figures are not available.

Pricing and Profits

American semiconductor firms have invested in offshore production facilities in part because of price battles waged among themselves. Learning curve pricing has been common, with manufacturers anticipating future cost savings when setting prices for new products. Such practices quickly pass production efficiencies along to purchasers; as pointed out in the previous chapter, costs per bit for random access memories—a convenient measure—have fallen steadily over the years.

If price competition in semiconductors has been good for purchasers, it has sometimes cut into the industry's profitability. Merchant sales tend to be quite cyclical; when customers adjust their inventories in response to the business cycle, fluctuations at the supplier level are magnified. In some years, semiconductor industry profits have been higher than for U.S. manufacturing as whole, in other years lower; over the longer term, the semiconductor industry has done about as well as other manufacturing sectors. This variability also shows up when profitability is compared to costs for acquiring investment capital. In 1979, profitability was well above costs of capital, in 1975 —a recession year—substantially below.[50] Larger companies such as TI and Motorola have often managed better than average profits, reflecting at least in part their diversification; when the semiconductor market slumped in 1981, TIs' Geophysical Services subsidiary provided excellent returns, helping the company's net profits.

Employment

Given the extensive offshore assembly activities of U.S. merchant firms—which concentrate on the labor-intensive steps in the production process—it is no surprise that domestic employment in semiconductor manufacturing has not expanded *as* rapidly as unit sales. From 1972 to 1982, the average annual rate of growth in employment was 7.2 percent (ch. 9, especially figs, 56(B) and 60), Over this same period, the rate of growth of output was twice as high (15 percent). Domestic semiconductor manufacturing has shown a steady increase in the proportion of white-collar workers, many of them technical professionals, with commensurate increases in overhead costs as a proportion of direct labor costs.

Semiconductor Manufacturing in Japan

Structure

The independent merchant suppliers that have been such a vital force in the U.S. semiconductor industry have few analogs in other parts of the world; while Japan's Government has made sporadic attempts to stimulate entrepreneurial risk-taking, in the world semiconductor industry only the British-owned Inmos represents a serious attempt at emulation of the American model. Thus it is no surprise to find the major Japanese producers—table 29—to be relatively large, diversified firms that make microelectronics devices for both internal consumption and outside sales—more like RCA than Intel.

The top five semiconductor manufacturers in Japan account for almost three-quarters of the country's production, the next five virtually all the rest. The industry is somewhat more concentrated than that in the United States, with a near absence of small, specialized suppliers. As table ***29*** indicates, many though not all of the principal Japanese competitors in microelectronics are the same companies that U.S. manufacturers face in consumer markets or in computers—Hitachi, Fujitsu, Toshiba. Nippon Electric Co. (NEC), the largest pro-

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[50] "U.S. and Japanese Semiconductor Industries: A Financial Comparison, " Chase Financial Policy for the Semiconductor Industry Association, June 9, 1980, p. 5.8.

Table 29.—Total Sales and Semiconductor Share for Major Japanese Producers

	Sales (millions of dollars)				Semiconductor as percentage of total (1981)	Percentage of semiconductors used internally (1982)[b]
	Total	Semiconductor[a]				
	1981	1978	1981	1982		
Nippon Electric Co. (NEC)	$4,850	$520	$960	$990	19.8%	24%
Hitachi	15,500	465	825	800	5.3	19
Toshiba	9,540	400	770	740	8.1	8
Fujitsu	3,210	125	415	480	12.9	24[c]
Matsushita	15,700	225	475	410	3.0	13[c]
Mitsubishi	6,060	145	320	320	5.3	11
Sanyo	4,470	120	215	185	4.8	32
Sharp	2,810	NA	125	140	4.3	27
Oki	986	NA	95	125	9.8	44

NA = Not available.
[a] Merchant sales only.
[b] Estimated from value of merchant sales and value of fiscal year (beginning in April) semiconductor production.
[c] 1981

SOURCES: ***Merchant semiconductor sales***—Dataquest.
Total semiconductor production—"One Trillion Yen Semiconductor Industry Forecast for FY 1981," *Japan Economic Journal,* June 16,1981, p. 9; "Semiconductor Manufacturers' Strategy In FY-82 Discussed, " *Japan* Report, Joint Publications Research Service JPRS U11012, Dec. 16, 1902, p 93 Yen conversions at 220 per dollar for 19S1, 249 for 1982.
Total sales—"The 500 Largest Industrial Corporations Outside the U.S., " *Fortune,* Aug. 23, 1982, p. 207

ducer of semiconductors in Japan, stands out because of the high fraction of its business accounted for by microelectronics, yet this fraction is only one-fifth; most Japanese producers get substantially smaller proportions of their revenues from semiconductors.

None of the nine firms listed in table 29 consumes as much as half its output internally. Sony, the biggest Japanese manufacturer producing solely for internal consumption, has recently been operating at a level of about $100 million annually—placing them roughly tenth in total semiconductor output. Thus, the distinction between merchant and captive producers is less relevant for Japan; major Japanese computer and/or systems firms both make and sell semiconductors. (Nippon Telegraph and Telephone—which, like AT&T, has a large and widely respected R&D effort in microelectronics—does no manufacturing itself.)

Figure 25 compares semiconductor production in Japan to that in the United States. While it was only in 1981 that Japan's output reached a level half that here, over the 1980-81 period Fujitsu's production increased by one-third, Matsushita's by one-half, Oki's even more.[51] As figure 25 indicates, total production in Japan was up by one-third during a period when U.S. output declined slightly, although remaining flat over the 1981-82 period (comparisons of production level reflect differing demand levels related to economic conditions in the two countries, along with exchange rate fluctuations). While Texas Instruments and Motorola remain the two largest merchant manufacturers in the world, NEC was the third largest by 1980, Hitachi sixth. Given the growth rates of the recent past, other Japanese firms seem likely to follow NEC into the top ranks of the world's producers, No wonder American semiconductor firms are worried.

To support the production increases of recent years, Japanese manufacturers have made heavy capital investments. Japan's microelectronics industry reportedly invested nearly $900 million on plant and equipment in 1981, after spending $750 million the previous year.[52] Meanwhile, U.S. producers—remembering the consequences of their spending cuts in 1974 and 1975—have maintained their own capital expenditures at somewhat over $1 billion annually.[53] Because the Japanese industry remains

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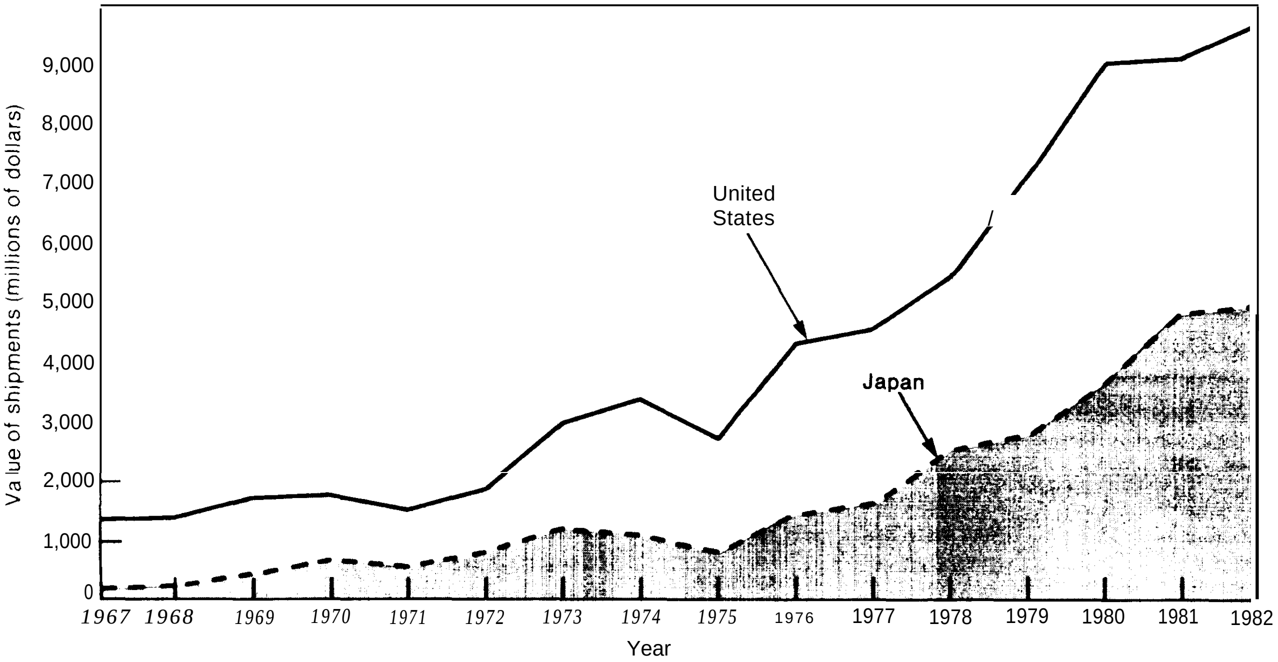
[51] "One Trillion Yen Semiconductor Industry Forecast for FY 1981, " *Japan Economic Journal,* June 16, 1981, p. 9. Here and at several other places in the chapter, financial or production data for Japanese firms is given on a fiscal year basis, beginning in April of the year noted.

[52] Ibid.

[53] *1982 U.S. Industrial Outlook,* op. cit., p. 238. Japan's exports of semiconductors to the United States benefited from continued investments in new production capacity during the 1974-75 sales slump. When the market recovered, Japanese suppliers of 16K RAMs were able to take advantage of capacity shortages in the United States to enter the American market in a major way.

Figure 25.—Semiconductor Production in Japan and the United States



SOURCES *United States— 1967-76— Report on the* U S *Semiconductor Industry* (Washington, D C Department of Commerce, September 1979), p 39
7977-80— Summary of Trade *and Tariff /n formation Semiconductors* (Washington, D C U S International Trade Commission Publication 641 Control No 6-5-22, July 1982), p 26
1981,1982*—1983 U S Industrial Outlook* (Washington, D C Department of Commerce, January 1983), p 29-7
Japan*— 1967-80-Japan Fact Book '80* (Tokyo Dempa Publications, Inc , 1980), p 188; *Japan Electronics Almanac 1982* (Tokyo Dempa Publications, Inc 1982), pp 149, 178
1981, 1982- *In-Stat Electronics Report,* Feb. 21, 1983, p 5.
Yen conversions from *Economic Report of the President* (Washington, D C U S. Government Printing Office, February 1983), p 275

a good bit smaller than that in the United States, capital spending as a percentage of sales has been considerably higher (see fig. 51, ch. 7),

Early Development

For many years, Japanese expansion in microelectronics was fueled by demand from consumer products manufacturers. In the late 1950's, as much as two-thirds of Japan's total output of transistors went into radios. [54] Even for the period 1974-78, nearly 40 percent of all ICs produced in Japan were purchased by the consumer sector.[55]

Given this dependence on consumer products, it is no surprise that, as in the United States, the early manufacturers of semiconductors in Japan included many firms that also made vacuum tubes. But while few of the American vacuum tube producers were able to carve out a major place in the semiconductor market, the large Japanese firms all negotiated this transition successfully, They were joined by only a few newer companies, although one of these—Sony—was the first Japanese firm to mass-produce semiconductors, The structure of the Japanese industry thus evolved quite differently from that here, as table 30 makes evident.

Most of the technology embodied in Japan's output of semiconductors, as for consumer electronics, was at first based on developments originating in the United States, As of 1974, Bell Laboratories had licensed a greater number of semiconductor patents in Japan than in

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[54] J. E. Tilton, *International Diffusion of Technology: The Case of Semiconductors* (Washington, D, C.: The Brookings Institution, 1971), p. 157.

[55] *Competitive* Factors *influencing World Trade in Integrated Circuits,* op. cit., p. 117. The percentage would no doubt be higher if all semiconductors were included. Furthermore, an additional 30 percent of Japan's IC output was sold through distributors, much of this presumably ending up in consumer goods,

Table 30.-Major Producers of Semiconductor In the United States and Japan at the End of the 1950's

	Share of domestic semiconductor market
United States (1960)	
Vacuum tube manufacturers	35%
GE	8
RCA	7
Raytheon	4
Philco	4
Westinghouse	4
Others	4
Semiconductor Entrants[a]	60%
Texas Instruments	20
Transition	9
Hughes	5
Motorola	5
Fairchild Camera and instrument	5
Others	16
Western Electric (captive)	5%
	100%
Japan (1959)	
Vacuum tube manufacturers	79%
Toshiba	26
Matsushita	16
Hitachi	15
Nippon Electric Co. (NEC)	15
Mitsubishi	2
Others	5
New entrants[a]	19%
Sony	11
Sanyo	2
Others	6
imports	2%
	100%

[a] Defined as all firms that had not manufactured vacuum tubes. Fujitsu was formed in 1968 from a merger of apair of firms, one falling in each category; the sharesof each have been included under "Others."

SOURCE: J. E. Tilton, *International Diffusion of Technology: The Case of Semiconductors* (Washington, D.C.: The Brookings institution, 1971), pp 66, 144.

all of Europe.[56] Much the same is true for patents owned by other American companies; nearly half of Fairchild's semiconductor patent licenses have gone to Japanese firms. Over the latter part of the 1960's, royalty payments by Japanese manufacturers to U.S. holders of semiconductor patents averaged $10 million annually.

The Government Role

If the industrial policy of Japan's Government was a secondary influence on consumer electronics, this has certainly not been the case for semiconductors. Here, MITI and the rest of the Japanese bureaucracy took a direct hand—particularly when it came time to move into ICs. Although the repertory of measures was much the same as for the consumer sector—restrictions on imports and foreign investment, promotion of exports, R&D assistance—the relatively comprehensive MITI "vision" developed for the 1970's placed IC technology at the center of an ambitious plan aimed at strengthening the entire electronics industry and building competitiveness in computers and communications (see chs. 5 and 10).

MITI's efforts to keep out foreign semiconductor firms were largely successful; although a number of American companies were allowed to join in minority partnerships or create sales arms, only TI managed to establish a wholly owned manufacturing subsidiary, Liberalization did not come until the 1970's; Motorola has built its presence through a joint manufacturing venture, while several other U.S. semiconductor firms have recently moved to start production in Japan—more than two decades after such investments in Europe,

In concert with restrictions on investment, a variety of protectionist measures limited export shipments by American firms. The shares of the Japanese semiconductor market held by U.S. manufacturers thus remain far below those in other industrialized countries, In 1982, U.S. exports of ICs to Japan totaled no more than $135 million (fig. 26), only 4 percent of Japan's own output. In 1981, TI—the chief American supplier within Japan—had sales through local production and export shipments which came to about $120 million; if included in table 29, TI-Japan would barely place in the top 10 among those selling in the Japanese market.[57]

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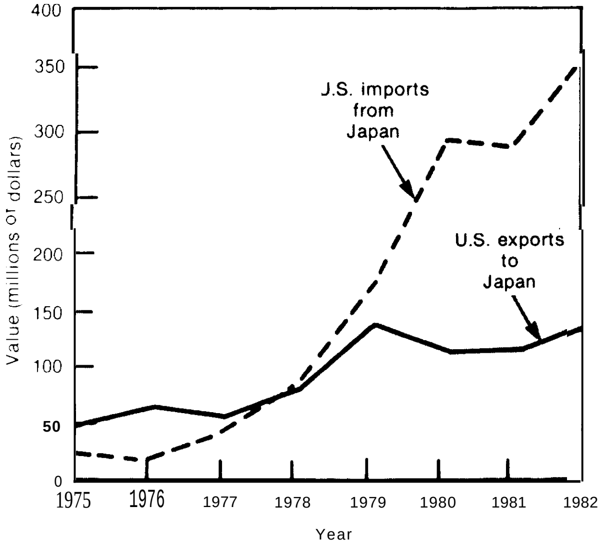
[56] W. F. Finan, "The Exchange of Semiconductor Technology Between Japan and the United States," First *U.S.-Japan Technological Exchange Symposium,* Washington, D.C., Oct. 21,1981. Also see, in general, Tilton, op. cit.

[57] The statistics collected by the United States and Japan for semiconductor trade between the two countries differ in some years by more than 50 percent; Japan typically reports shipments *from* the United States to be higher than U.S. sources show, shipments *to* the United States lower. Some of the reasons are discussed in *A Report on the U.S. Semiconductor Industry,* op. cit., p. 96.

TI's sales in Japan are the largest of any American supplier, though reportedly limited by the original agreement with MITI to a market share no greater than 10 percent. Approximate 1981 sales in Japan by U.S. firms were: TI, $120 million; Motorola, $35 million; Fairchild, $31 million; Intel, $30 million–S. Lohr, "A Piece of Japan's Chip Market," New *York Times,* Feb. 1, 1982, p. D1 (the estimates are those of the Bank of America's Asia Division),

Figure 26.— U.S.-Japan Trade in Integrated Circuits



SOURCE 1983 U .S *Industrial Outlook* (Washington D C Department of Commerce, January 1983) p 29-5 1982 figures estimated

International Trade

As Japanese production grew, exports and imports rose roughly in parallel—table 31—until the latter part of the 1970's, when the balance swung decisively toward exports. Most of Japan's imports are ICs. In recent years, the majority have originated in the United States and Europe; shipments from IBM's European plants to IBM-Japan account for a sizable percentage.[58] As figure 26 shows, U.S. exports of ICs to Japan have not changed much since 1979. Japanese manufacturers export roughly comparable volumes of ICs and discrete devices; these have gone largely to the United States and the developing Asian economies, with shipments to Western Europe rising quickly over the past few years.[59]

Table 31.—Japan's Semiconductor Trade

	Shipments (millions of dollars)	
Year	Imports	Exports
1960	$ 1.6	$ 8.0
1965	7.9	21,0
1970	92.1	27.9
1975	172	128
1977	293	310
1978	382	486
1979	559	757
1980	611	1,090
1981[a]	670	1,100

[a] Annualized from first 6 months

SOURCES' ***1960, 1965***—J E Tilton, *International Diffusion of Technology" The Case of Semiconductors* (Washington, D C The Brookings Institution, 1971), p 45
1970, 1975—R H Silin, *The Japanese Semiconductor Industry* (Hong Kong: Bank of American Asia Ltd , May 1960), p 115
1977—Japan Fact Book '80 (Tokyo Dempa Publications, Inc 1960), pp. 212, 216.
197841—Japan Electronics Almanac 1982 (Tokyo Dempa Publications, Inc , 1962), p. 28.
Yen conversions—*Economic Report of the President* (Washington, D C Government Printing Office, February 1982, p 345.

Although Japanese semiconductor manufacturers have established production facilities in Asia and Europe, their investments total much less than those of American firms–nor do they compare with Japan's overseas investments in consumer electronics. In value terms, less than 5 percent of semiconductor production by Japanese-owned firms took place outside Japan as of the end of the 1970's; this percentage will no doubt rise as Japanese manufacturers continue to invest in point-of-sale operations in the United States and Europe.[60]

The Semiconductor Industry in Europe

While Western Europe has been largely self-sufficient in consumer electronics, this was never true in semiconductors (or computers); consistently, at least 5 of the top 10 firms in European semiconductor sales have been American-owned.[61] Plants sited in Europe account for about a quarter of world semiconductor production, but well over half of European output flows from subsidiaries of American corporations. Moreover, European-owned

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[58] *Japan Fact Book* '80, op. cit., p. 193. Where as late as 1970, 90 percent of Japan's IC imports came from the United States, more recently the figure has been about 60 percent—*Japan Fact Book* '79 (Tokyo: Dempa Publications, Inc., 1979), p. 99.

[59] During 1980, Japan's exports of integrated circuits by value were distributed as follows:

United States	39.5°/0
Hong Kong, Taiwan, Korea, Singapore, and the Philippines	33,5°/0
Western Europe (mostly West Germany)	19,10/.
Rest of the world	7.9%

See *Japan Electronics Almanac 1982*, op. cit., pp. 181, 184.

[60] R. H. Silin, *The Japanese Semiconductor Industry: An Overview* (Hong Kong: Bank of American Asia Ltd., January 1979), p. 137.

[61] On the earlier years of the European industry, see Tilton, op. cit., especially ch. 5.

firms are especially weak in ICs. In 1981, they accounted for about 7½ percent of world output of all types of semiconductors but only 4½ percent of IC production; 8 years earlier, in 1973, European companies supplied 18 percent of the world's semiconductors, about the same as the Japanese at that time.[62] As this demonstrates (see also table 25), Europe's semiconductor manufacturers have declined in importance compared to firms in the United States and Japan, despite efforts by European governments to shore up domestic industries. Indeed, *on a global basis, most of the gains by Japan can be viewed as coming at the expense of European producers.*

Table 32 shows that the primary European entrants are diversified companies; like those in Japan, they get relatively small fractions of revenue from microelectronics. (The sales declines between 1980 and 1982 reflect depressed business conditions.) Most of the firms listed in the table consume some of their production internally, selling the rest on the open market; only SGS-Ates and the three new ventures at the bottom of the list are primarily suppliers of microelectronics. As might be expected, each company's semiconductor line has been shaped to considerable extent by its end products. Philips is strong in linear circuits for consumer electronics, Ferranti in devices for military systems and communications, Siemens in digital ICs for computers and industrial products.

The dilemma of the European manufacturers is exemplified by companies like Siemens and Philips. Both have excellent fundamental technology in microelectronics, but—as table 33 illustrates—have not managed to convert their technical skills into positions of market leadership outside Europe. Sales in other parts of the world by European firms generally come in specialized devices rather than mass-market products; before Inmos began production in 1982, Siemens was the only European-owned company making 64K RAMs.

Table 33 also demonstrates the importance of the European market for several of the larger American producers. While the data are for 1978, the picture has not changed that much over the years: American merchant manufacturers do greater volumes of business in Europe

Table 32.—Total Sales and Semiconductor Share for European Manufacturers

		Sales (millions of dollars)			
		Total	Semiconductor		Semiconductor fraction, 1980
Company	Headquarters	1980	1980	1982	
Philips.	Netherlands	$18,403	$558	$494	3.0 ”/0
Siemens	West Germany	17,950	420	328	2.30/o
Thomson-CSF	France	3,901	190	184	4.80/o
SGS-Ates	Italy	119	100	158	High[b]
AEG-Telefunken.	West Germany	6,756	196	150	2.90/o
Plessey	United Kingdom	1,638	49	NA	3.0 ”/0
Ferranti	United Kingdom	498	48	82	9.60/o
Inmos	United Kingdom	—	—	26	High
Matra-Harris	France	—	—	14	
Eurotechnique	France	—	—	12	
Other.			79		
			$1,690		

NA = Not available
[a] Merchant sales only.
[b] 1980 semiconductor sales estimated, SGS-Ates does almost ail Its business in Component%

SOURCES: ***1980 semiconductor sales***—E. Williams, "Electronic Components," *Financial Times,* Apr 5, 1962, sec. III, p. I Original source, Dataquest. The SGS-Ates estimate Is from '(Management, American-Style, at Italy's Microchip Manufacturer," *World* Business *Weekly,* Aug. 31, 1961, p. 22.
1982 semiconductor sales—Dataquest; SGS-Ates—"SGS-Ates Expects Move Into Black, " Electronics Apr 21, 1983, p 76
Total sales—"The 500 Largest Corporations Outside the US.," *Fortune,* Aug. 10, 1981, p. 207; "The 100 Largest Foreign Companies, " Forbes, July 6, 1981, p. 96; R. Whiteside (cd.), Major *Companies of Europe 1982* (London' Graham & Totman Ltd , 1982), "International Corporate Scoreboard, " *Business Week,* July 19, 1982, p 85.

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[62] The 1981 figures are from Status 1982: *A Report onthe ink+grated Circuit Industry,* op. cit., p. 5; those for 1973 from G. Dosi, *Technical Change and Survival: Europe Semiconductor Industry* (Sussex, United Kingdom: Sussex European Research Centre, 1981), p. 62.

Table 33.—Merchant Semiconductor Sales by Region for Selected Manufacturers, 1978

	Approximate world market share	Proportion of company sales by geographic region			
		United States	Europe	Japan	Rest of world
Texas Instruments . .	11%	55%	31%	10%	4%
Motorola	8	62	25	5	8
Nippon Electric Co. (NEC).	7	24	4	77	11
Philips[a].	7	24	63	4	9
National	5	65	19	5	11
Fairchild	5	63	18	3	15
Hitachi	5	6	2	80	12
Toshiba.	5	6	4	70	20
Intel ., ...	4	59	27	3	11
Siemens	3	12	78	0	10

[a]Includes Signetics

SOURCE G Dosi, *Technical Change and Survival Europe's Semiconductor Industry* (Sussex, United Kingdom Sussex European Research Centre, 1981), p 65 Original source, Nomura Research Institute.

than the Europeans do elsewhere; U.S. firms also have much higher sales in Europe than in Japan, a reflection of the effectiveness of Japanese barriers to trade and investment.

As one remedy to the gradual decline painted above, several European manufacturers have actively pursued American technology. One of the companies listed in table 33—Fairchild—was purchased by the French concern Schlumberger in 1979. Philips had acquired Signetics several years earlier. Siemens owns 20 percent of Advanced Micro Devices. Two of the small firms included in table 32–Matra-Harris and Eurotechnique, both French—originated as joint ventures with American partners holding minority interests. For the French, a major goal was technology acquisition; from the standpoint of the U.S. participants, joint ventures may give better entry into European markets—particularly that of France itself, where the telecommunications sector has been especially well protected.

European firms are also negotiating joint ventures with Japanese concerns. Despite persistent efforts to strengthen Europe's technological capability in microelectronics on an EC-wide basis (ch. 10), European companies seem to find it easier to cooperate with American or Japanese firms than with each other. One reason may be that the Americans and Japanese are viewed as having more to offer.

Semiconductor Manufacture Elsewhere

While semiconductors are made in many parts of the world by U, S- and Japanese-owned firms, only a few developing economies have much indigenous production—and then usually in discrete devices rather than ICs. Firms outside the advanced industrial countries (excluding the Soviet Union and Eastern Europe) accounted for only 0.3 percent of world production in 1981, with most of this in the developing Asian nations, Of these, Korea probably has the strongest technical capability in ICs, but Taiwan, Malaysia, Hong Kong, and Singapore are all attempting to improve their positions, Chip production under local ownership began in Taiwan in 1982, with the first products intended for consumer applications.[63] A pair of locally owned companies in Hong Kong have begun producing ICs; while some of the output will go into watches and other consumer products, one of these manufacturers is already making LSI memory chips.[64] The developing Asian nations clearly hope to follow Japan in moving from consumer products into ICs and systems.

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[63] R. Neff, "Buzzword in Taiwan is 'Information, '' *Electronics,* Apr. 21, 1982, p. 96. The 0.3 percent figure given above is from Dataquest.

[64] A. Spaeth, "Two Firms Begin Making Hong Kong's First Chips, " *Asian Wall Street]ournal Weekly,* April 5, 1982, p. 20.

Semiconductor Manufacturing Equipment

Advances in IC design move in parallel with advances in processing equipment; indeed, IC designs depend heavily on the capability of the available manufacturing equipment. A number of large-volume semiconductor manufacturers, both here and in Japan, develop some of their own production equipment—including such companies as TI, Western Electric, IBM, and Matsushita. While the Japanese evidently expect to build more of their own equipment in the future, semiconductor manufacturers in all parts of the world, Japan included, have relied heavily on independent equipment suppliers—most of them relatively small American companies. These firms design and fabricate wire bonders, annealing furnaces, ion bombardment apparatus, lithographic equipment, plasma etchers, automated test equipment, and other specialized capital goods. The U.S. semiconductor industry, particularly the smaller independent firms, has drawn strength from the concentration of equipment firms here—about 275 companies, most with annual sales in the range of $5 million and below.[65]

Table 34 lists the 10 leading suppliers of semiconductor manufacturing equipment on the basis of world sales. The industry includes only a few large enterprises, with sales levels dropping rapidly past the top five; nonetheless, the total approaches $2 billion yearly, to which expendable such as chemicals and silicon add perhaps $3 billion more. The larger companies in table 34 tend to concentrate on lithographic equipment and automated circuit testers, relatively expensive items. Something over half the total sales of the industry consists of front-end wafer fabrication equipment, with about half of this for lithography.[66] A number of the equipment firms in table 34—e.g., Varian, Kulicke & Sofa—have entrepreneurial roots similar to the merchant semiconductor manufacturers they do business with. Others, such as Fairchild Test Systems or Canon, are divisions of much larger corporations.

While the lithographic equipment made by Censor—a firm based in Liechtenstein—is well known, and companies like Philips and Siemens can and do build a good deal of their own production machinery, on the whole Europe's

Table 34.—Semiconductor Equipment Manufacturers Ranked by Worldwide Sales

		Sales[a] (millions of dollars)		
	Headquarters	1979	1981	Major products
Perkin-Elmer	**United States**	**$106.0**	$186.0	Lithographic equipment
GCA	United States	55.7	142.0	Lithographic equipment
Applied Materials	United States	74.6	104.0	Epitaxial reactors, sputterers, plasma etchers
Fairchild Test Systems	United States[b]	111.0	83.1	IC testers
Teradyne	United States	53.5	79.2	IC testers
Varian	United States	60.9	75.0	Ion implanters, sputterers
Eaton	United States	64.1	64.1	Lithographic and test equipment
Takeda Riken	Japan	26.3	55.3	IC testers
Canon	Japan	16,7	47.6	Lithographic equipment
Kulicke & Sofa	United States	36.3	37.5	Wire bonders
Others		NA	∼1,000	
			$1,800-$1,900	

NA - Not available.
[a] Open-market sales of semiconductor manufacturing equipment only.
[b] Part of Fairchild camera and Instrument, which is now owned by the French concern Schlumberger.

SOURCE: "Gear Makers Sea Essentially Flat Year," *Electronic* News, Mar. 8, 1982, Supplement p. 4. Original source, VLSI Research, Inc. Other sources give considerably different estimates for several of these firms, a number of which are privately held and do not report sales.

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[65] *An Assessment of the Impact of the Department of Defense Very-High-Speed Integrated Circuit Program,* op. cit., p. 133.

[66] L. Wailer, "Advanced Gear Leads Production Sales, *Electronics,* Mar. 10, 1982, p. 46. Back-end testing and assembly equipment accounts for most of the remainder. Other definitions of the equipment industry yield sales estimates spanning a considerable range.

equipment industry is weak. The situation is quite different in Japan, Aided over the latter part of the 1970's by the MITI-sponsored VLSI joint R&D project, discussed in more detail elsewhere, Japan is becoming increasingly self-sufficient in processing equipment. The VLSI project concentrated most of its resources on fabrication technology; because the participants were large, integrated manufacturers, the result was to strengthen the internal capabilities of these companies rather than build an independent equipment industry as exists in the United States, While Japan's semiconductor producers continue to buy about half their equipment from American suppliers, the U.S. share of Japan's equipment market has been declining.[67] To counteract this erosion, many American suppliers have been investing within Japan, following the lead of U.S. semiconductor firms. The equipment market in Japan reached about $600 million in 1981; sales have been growing considerably faster than in the United States because of the high capital spending rates of Japanese semiconductor manufacturers.[68] Companies like Canon are also beginning to make inroads into the U.S. equipment market.

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[67] R. Neff, " U.S.IC Gear Makers Build in Japan, *Electronics,* July 14, 1981, p. 89.

[68] "Semiconductor Equipment Makers Cutting Into American Share," *Japan Economic Journal,* Dec. *1, 1981,* p. 10.

The Computer Industry

For many years the world's producers of data processing equipment seemed to consist of IBM plus a dozen or so much smaller competitors. This picture has changed for several reasons: continued expansion by independent manufacturers of peripherals; rapid growth in sales of smaller systems; the emergence of software as a separate industry. No longer is the typical computer a general-purpose mainframe; now there is no such thing as a typical computer. Processors are becoming more specialized, computing power dispersed to the locations where needed. This evolution does not imply that mainframes have diminished in importance, simply that they no longer account for the vast majority of the output of computer manufacturers. The following description of the data processing equipment industry focuses on processors themselves, with limited attention to peripherals; no attempt is made to cover the software industry, the dimensions of which are largely unmapped.

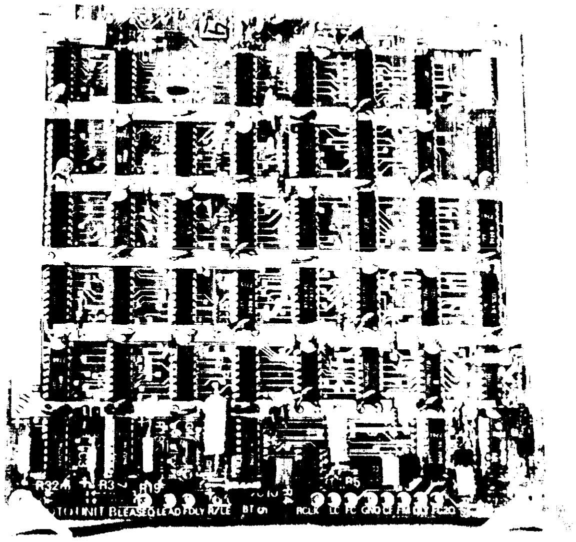


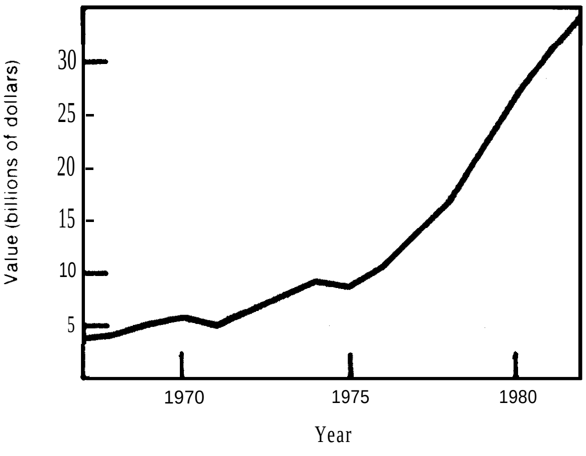
Photo credit *Compugraphic Corp*

Printed circuit board for computerized typesetter

The Computer Industry in the United States

No matter how its boundaries are defined, the value of U.S. production of computers far outstrips that of consumer electronics or semiconductors. Growing predominately from and far surpassing the manufacture of business machines, computer production in the United States–including peripherals–approached $35 billion in 1982 (fig. 27).[69] As for microelectronics, the expansion of the computer industry has been phenomenal; the annual growth rate over the past 10 years has averaged 18 percent. Some parts of the market have grown for periods of several years at 30 to 50 percent annually; while mainframe sales were up by nearly 7 percent in 1982, minicomputer sales increased twice as fast; microcomputer sales grew more than 60 percent.[70] Table 35 gives more detail on U.S. sales for 1975 and 1982; the projections for 1986 indicate that the total market may increase by nearly 10 times over the 1975 figure. Small computers and separately purchased software will lead the expansion.

Figure 27.—U.S. Production of Computer Equipment (SIC 3573)



SOURCE 1972, 1975, 1977, 1960, 1963 editions, *U.S. Industrial Outlook,* Department of Commerce. 1981 and 1982 shipments estimated.

Table 35.—Sales of Computers and Equipment in the United States

	Sales (billions of dollars)		
	1975	1982	1986[a]
Hardware			
Processors			
Desktop, small business, personal	$0.08	$6.05	$25.4
Minicomputers, other small systems	0.78	7.76	16.0
Mainframes	5.40	13.0	18.7
	$6.26	$26.8	$60.1
Memory, mass storage	2.95	4.14	8.9
Other peripherals	3.62	13.2	26.9
Total hardware	$12.8	$44.1	$95.9
Software	***NA***	***3.11***	16.8
Total	$12.8	$47.2	$113

NA = Not available.
[a]Projected.

SOURCES: ***1975—Electronics,*** Jan. 8, 1976, p. 94.
1982,1986—Electronics, Jan. 13, 1963, pp. 132, 133.

Structure

In large measure because IBM is so much bigger than its competitors—with sales nearly eight times those of its nearest rival, the minicomputer specialist Digital Equipment Corp. (DEC)—the U.S. computer industry is highly concentrated by the usual measures; the four largest domestic firms account for three-quarters of sales.[71] Once past the leader, the industry is populated by a relatively large number of firms that do not differ so greatly in size—table 36. The table ranks U.S. computer manufacturers by worldwide sales—an appropriate basis given the global outlook shared by firms in this industry.

Table 36 makes the long-term preeminence of IBM quite evident, but it is the shifts in position beneath that are truly striking. DEC, which more than any other company started the minicomputer industry-largely by virtue of the pioneering PDP-8 of the mid-1960's (ch. 3)—was a tiny company 15 years ago. By 1979, its sales

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[69] As defined by Standard Industrial Classification 3573, 1982 estimated shipments (including exports) came to $34. I billion—1983 *U.S. Industrial Outlook,* op. cit., p. 27-5. Other definitions of the industry's boundaries—e.g., that adopted by *Electronics* magazine and referred to in several places below—result in much larger sales figures. *Electronics'* total for 1982 —including imports but not exports by American manufacturers–is $52.1 billion (Jan. 13, 1983, p. 132). Neither of these two figures includes data processing services, itself a major industry; in 1981, the worldwide revenues of U.S. computer services firms exceeded $20 billion—1983 *U.S. Industrial Outlook,* p. 27-4. When the full range of data processing activities are aggregated, figures in the range of $70 billion thus result.

[70] P. Archbold, "The Datamation 100: Welcome to the Club, " *Datamation,* June 1983, p. 87.

[71] *Summary of Trade and Tariff Information: Computers, Calculators, and Data Processing Machines* (Washington, D. C.: U.S. International Trade Commission Publication 841, Control No. 6-4-13, September 1981), p. 6. IBM's place in the industry can be judged by noting that its 1982 U.S. sales of computers and related products—a little over half the company's worldwide sales—came to $18.9 billion, 40 percent of the total U.S. computer market in that year (the IBM sales figure is from "The Datamation 100: Welcome to the Club," op. cit., the total U.S. market figure from table 35. Most of IBM's sales are in computers, but it does have other business activities.

Table 36.—U.S. Computer Manufacturers Ranked by 1982 Worldwide Sales

	Computer-related sales (millions of dollars) 1975	Computer-related sales (millions of dollars) 1982	Return on equity (1982)[a]	Major products
IBM	$11,116	$31,500	23.4%	Mainframes and minicomputers; peripherals; office automation
Digital Equipment Corp. (DEC)	534	4,019	14.3	Minicomputers and peripherals
Burroughs	1,447	3,848	5.7	Mainframes and minicomputers
Control Data Corp. (CDC)	1,218	3,301	11.1	Mainframes and peripherals
NCR	960	3,173	12.4	Mainframes and peripherals
Sperry (Univac)	1,295	2,800	9.2	Mainframes and peripherals
Hewlett-Packard	250	2,165	16.3	Mini and microcomputers; peripherals
Honeywell	1,324	1,685	13.2	Mainframes and minicomputers
Wang	50	1,322	20.6	Minicomputers; office automation
Xerox	80	1,300	18.0[b]	Peripherals; office automation

[a] All lines of business
[b] 1981

SOURCES 1975—0 Rothenbuecher, "The Top 50 Companies in the Data Processing Industry," *Datamation*, June 1976, p 48
1982—P Archibold, "The Datamation 100 Welcome to the Club, " *Datamation*, June 1983, p. 87.

ranked sixth, and in 1981 DEC surpassed the mainframe companies between it and IBM to become the second largest computer manufacturer in the world. Wang Laboratories—known for its small business systems and word processors—entered the top 10 in 1981. The computer industry no longer consists of IBM plus the five smaller mainframe-oriented companies –CDC, NCR, Burroughs, Sperry-Univac, Honeywell. Yet it is not so many years since American firms could be contrasted to the rest of the world as the "big eight''—the six mentioned plus GE and RCA. The latter two have dropped out of the computer business; even so, while producing computers their sales volumes were greater than virtually any foreign manufacturer.

Aggregated data on the profitability of the U.S. computer industry tends to be dominated by IBM's figures, which–as table 36 indicates—have usually been well above the average, The computer industry has been less affected by the business cycle than most; nearly all the firms listed in table 36 did reasonably well in 1982 despite a depressed economy. In general, the industry has been more profitable than U.S. manufacturing as a whole. *

Evolution and Structural Change

Many of the early entrants in the computer industry began as business machine manufacturers. While IBM trailed such firms as Remington Rand and Underwood into data processing, its share of the market rose steadily; dating computer manufacturing from 1951, by the end of the industry's first decade more than 70 percent by value of all systems installed in the United States had been built by IBM.[72] This percentage held roughly constant through the 1960's, only beginning to fall as minicomputer sales surged; while IBM has retained its posi-

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* Comparing the industry composite figures for "Office Equipment, Computers" With the "All-Industry Composite" as tabulated by *Business Week* in their yearly corporate scoreboard issues (each March) gives the following picture:

Return on Equity (Profits as a Percentage of Value of Common Stock)

	Computer composite	*All-industry composite*
1974	16.9%	14.0%
1976	17.9	14.0
1978	20.4	15.1
1980	19.2	15.3
1981	15,2	14.0
1982	15.9	11.0

Again note that the computer figures are heavily weighted by IBM's profits, and that the firms Business Week includes in this category do not necessarily coincide with the "computer industry" as defined elsewhere.

[72] *Gaps in Technology: Electronic Computers* (Paris: Organization for Economic Cooperation and Development, 1969), p. 39. The percentage by number of machines was somewhat less, IBM's position benefited greatly from success in marketing to the Department of Defense; in the mid-1960's, nearly half the company's U.S. sales were to the Federal Government, a much larger fraction than any of its rivals managed. At the end of the 1960's, perhaps three-quarters by value of all computers in the world were IBM machines (pp. 8, 139).

tion in mainframes, still holding around 70 percent of the domestic market for large systems, its share of minicomputer sales in the United States is only about 20 percent.[73]

Virtually any business or other organization is now a potential computer purchaser; with the appearance of machines in the $1,000 and under price range, so are households. As costs come down, sales rise; the mid-1960's, which brought the minicomputer, proved a watershed for the industry. Many of the older mainframe companies had trouble competing successfully in markets for small systems—indeed still do. New entrants emerged building small, inexpensive systems suitable for dedicated applications as well as general-purpose data processing. While most of the companies that had been competing in the mainframe market introduced smaller machines—later if not sooner—newcomers such as DEC and Data General, the latter spun off from DEC in 1968, emerged as the leaders.

Table 37 lists major producers of minicomputers. (The distinctions between mainframes and minis are arbitrary; this listing simply follows one definition, as noted in the table.) Although IBM sells more small systems than any other company, its advantage does not compare with the margin it holds in mainframes, and indeed might disappear under a more restrictive definition of "minicomputer." Only a few other entrants from the early days of mainframes are major factors in this part of the market. The table is restricted to American firms, but would differ little if foreign manufacturers were included. U.S. companies dominate world minicomputer markets more completely than for either mainframes or desktop machines; only the West German firm Nixdorf is among the world's 10 largest minicomputer manufacturers (although its U.S. sales were but $150 million in 1981, the company has a substantial presence in Europe).

Table 37.–Major U.S. Manufacturers Ranked by 1982 Worldwide Minicomputer Sales[a]

	Minicomputer sales (millions of dollars)		Return on equity, 1982[c]
	1975[b]	1982	
IBM	$450	$3,000	23.40/o
Digital Equipment Corp. (DEC)	160	1,680	14.2
Burroughs	290	800	5.7
Data General	35	604	5.8
Hewlett-Packard	70	588	16.3
Wang	15	585	20.6
prime	NA	351	31.1
Honeywell	80	330	13.2
Gould	NA	325	10.60/0
Texas Instruments	25	320	8.9

NA = Not available.

[a] This table uses *Datamation's* definition of the minicomputer market; all such definitions are arbitrary and others might give a different ranking.

[b] Approximate.

[c] All lines of business

SOURCES: 1975—0. Rothenbuecher, "The Top 50 Companies in the Data Processing Industry," *Datamation,* June 1976, p 48.
1982-P. Archbold, "The Datamation 100: Welcome to the Club," *Datamation,* June 1963, p 67.

Just as the minicomputer opened vast new markets through lower costs—made possible largely by ICs–so the microcomputer has followed, again extending sales to new groups of customers. And just as the growth of minicomputer sales saw new firms challenging the established leaders, so microcomputer systems have been pioneered by companies like Commodore, Apple, and Tandy (makers of Radio Shack computers); now it is DEC and Hewlett-Packard that find themselves in a reactive position. Table 38 shows how fast microcomputer sales have been expanding—although they are still small in value compared even to minicomputers—and the extent to which new entrants have taken leading positions; even so, IBM is already in second place.

Change is taking place at the other end of the market as well, with plug-compatible manufacturers (PCMs) continuing to enlarge their positions. Building mainframe processors and peripherals that are compatible with IBM systems, these companies strive to offer superior price/performance combinations; perhaps one-third of the disk drives used with IBM processors, for instance, are now supplied by other firms.[74] CDC, one of the first to make plug-compatible peripherals, sells processors that run on IBM software as well, while Amdahl continues

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[73] G. Anders, "Lawsuit's End May Spur IBM To Acquire Firms, Expand in Satellite, Office Markets, " *Wall Street Journal,* Jan. 11, 1982, p. 29.

[74] " IBM's Coming Disk-Drive Surge, " *Business Week* June 11, 1979, p. 116.

Table 38.—Major U.S. Manufacturers Ranked by 1982 Worldwide Microcomputer Sales

	Microcomputer sales (millions of dollars)		Return on equity, 1982[a]
	1979	1982	
Apple	$ 75	$664	28.0°/0
IBM	—	500	23.4
Tandy (Radio Shack)	150	466	32.3
Commodore	55	368	52.9
Hewlett-Packard	NA	235	16,3
Texas Instruments	—	233	8.9
Digital Equipment Corp. (DEC)	–	200	14.3

NA = Not available
[a]All lines of business

SOURCES *1979*—"The Datamation 100, " *Datamation*, June 1980, p 87
1982—P Archbold, "The Datamation 100 Welcome to the Club, " *Datamation*, June 1983, p 87

to be the leading American PCM firm, with about half of all such installations.[75] The PCM share of the U.S. market for mainframe processors has risen over the last 5 years to perhaps 20 percent. Yet another indication of IBM's strength is that most of the gains of the PCMs appear to have come from sales won in competition with mainframe manufacturers other than IBM.[76]

The PCM portion of the industry is characterized by particularly strong international ties. A number of foreign firms, including several leading Japanese manufacturers, supply IBM-compatible equipment. Amdahl is 28 percent owned by Fujitsu, with which it shares technology. National Advanced Systems, which stopped making its own machines early in 1983, markets large computers built by Hitachi.[77] Several European firms also market Japanese-built PCMs.

International Trade and Investment

As in microelectronics, U.S. computer manufacturers have been heavily oriented toward the world marketplace, which they have supplied through exports and foreign investment, Offshore assembly to reduce labor costs has been far less central to competitive dynamics than in the semiconductor industry, but price competition in microcomputers and other small systems will probably cause more U.S. firms to transfer labor-intensive operations offshore in the future. Point-of-sale investments—primarily in Europe—have been the rule for the major U.S. firms, while—as figure 28 shows—exports from the United States have exceeded imports by wide margins. Nearly half the export shipments go to Western Europe, with Japan and Canada also getting substantial fractions.[78]

Although imports of computers and equipment exceeded $2 billion in 1982, much of this consists of re-imports by U.S. firms following offshore assembly, Detailed figures are not available, but the percentage of computer imports entering under item 807,00 of the Tariff Schedules has been in the range of 40 percent over the past few years.[79] Most of these re-imports come from U.S.-owned plants in Canada; parts and subassemblies also enter from the Far East and Mexico. Of imports originating with non-U. S. firms, Japan is the leading source. In 1980, Japanese manufacturers shipped computers and equipment worth less than $200 million to this country. By 1982, imports from Japan had more than tripled, with Japan's share of U.S. computer imports rising from about 16 percent to nearly one-third.[80] Many of these

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[75]’ Moving Away From Mainframes: The Large Computer Makers' Strategy for Survival, " *Business Week* Feb. 15, 1982, p. 78; "In Focus: 1982 CPU Market Survey, " *Datamation,* May 1982, p. 44. Amdahl's 1982 mainframe sales were $312 million. The next largest PCM supplier, National Advanced Systems—a division of National Semiconductor—has about 18 percent of U.S. PCM installations. The core of National's base stems from Itel Corp. 's plug-compatible business, which was acquired by National when the failing company reorganized in 1979.

[76] G. Bylinsky, "The Game Has Changed in Big Computers, " *Fortune*, Jan. 25, 1982, p. 82

[77] "Unit of National Semiconductor Ends Computer Product ion, *Wall Street Journal*, *Feb. 1, 1983, p. 41.*

‘Bin 1980, us. exports of computers and equipment, which totaled $7.54 billion, were distributed as follows:

Western Europe	44,50/0
Canada	10.0
Japan	7.9
Others.	37.6

See *Summary of Trade and Tariff Information: Computers, Calculators, and Data Processing Machines,* op. cit., p. 23.

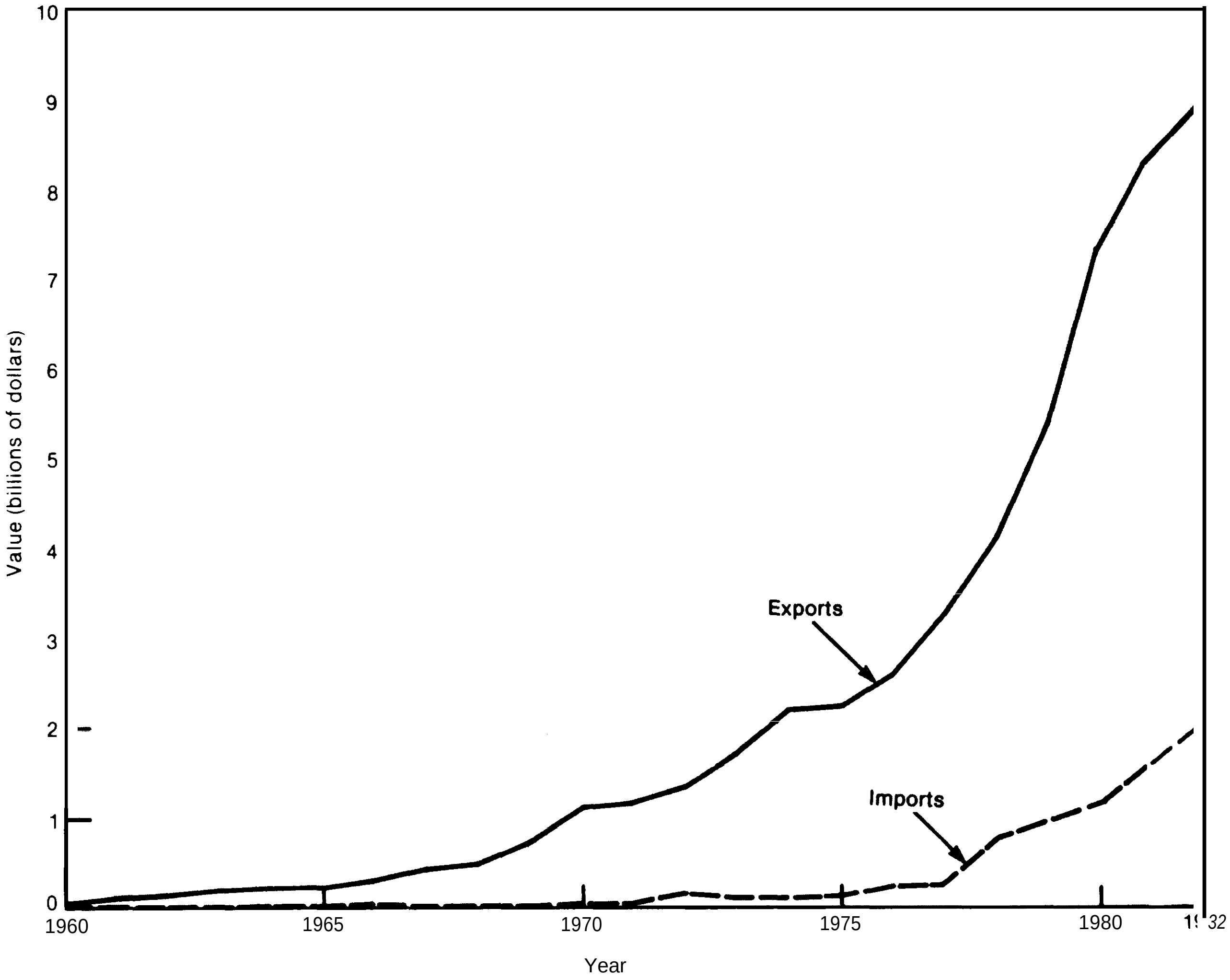
[79] Imports under 806.30 are negligible. The U.S. International Trade Commission aggregates 807,00 imports of computer equipment with those for calculators. Dividing 807 imports for computers plus calculators by total imports for computers gives:

	1976	*1977*	*1978*	*1979*	*1980*
Ratio of 807 to total	410/o	360/0	37%	420/o	47%

Since *807* imports of calculators are small in value, these percentages overstate the fraction of 807 computer imports only slightly. See *Summary of Trade and Tariff Information: Computers, Calculators, and Data Processing Machines,* op. cit., pp. 11, 20.

‘I bid., p. 20; 1983 U.S. *industrial Outlook*, op. cit., p. 27-4.

Figure 28.—U.S. Exports and Imports of Computers and Equipment



SOURCES 796066-Gaps in Technology Electronic Computers (Paris Organization for Economic Cooperations' and Development, 1989), P.50
1967-81— 1972, 1977, 1980, 1982 editions, U S *Industrial Outlook*, Department of Commerce
1982— Department of Commerce, Bureau of Industrial Economics

shipments have been plug-compatible mainframes distributed by American companies, but Japan has also begun to push into personal and desktop systems as well as peripherals.

No recent estimates of foreign investments by U.S. computer manufacturers are available, but it is clear that these have been large. Many American computer firms do a quarter to half their business overseas, with production facilities as well as sales and distribution affiliates located in countries around the world. Domestic jobs–see chapter 9–total more than 400,000, while American-owned computer firms probably employ several hundred thousand people in other countries.

Computer Industries in the Rest of the World

Computers are sold all over the world; as table 39 indicates, installations outside the industrialized nations lag in value—because most are small—but number about the same as in Europe. However, manufacturing—leaving aside desktop machines—is largely the province of companies with headquarters in ad-

Table 39.—Worldwide Computer Installations

	Number of systems and value of computers and equipment					
	1960		1970		1983[b]	
	Number	Value	Number	Value	Number	Value
United States	5,500	$ 8.8 billion	65,000	$ 92.6 billion	400,000	$300 billion
Japan	400	0.5	6,000	7.5	70,000	50
Western Europe	1,500	2.6	21,000	40.5	225,000	220
Rest of world	1,600	0.8	18,000	9.6	205,000	130
Total	9,000	$12.7 billion	110,000	$150.2 billion	900,000	$704 billion

[a] Excludes desktop and other very small systems
[b] Projected

SOURCES "Japan Takes Aim at IBM's World, " *World Business Weekly,* Apr 20, 1981, p 30 Original source, Diebold Europe

vanced industrial economies; the global industry consists basically of the several hundred U.S. firms—more making peripherals than processors—plus their counterparts in Japan, Britain, France, and West Germany. While subsidiaries of Japanese and Western manufacturers can be found in developing countries like Mexico, Brazil, and Taiwan, it will probably be some years before the industrializing Asian nations produce anything other than small and simple systems. Still, countries like South Korea and Taiwan have ambitious plans for entering data processing markets, Sales of computers in Taiwan are growing at about 40 percent annually, and the country is already home to many small software-oriented businesses, as well as a number of firms making microprocessor-based systems.[81] Much the same is true in Korea, where firms that have been making computer terminals are beginning to introduce microcomputers .[82]

In Japan, computer manufacture started late compared to Western Europe and the United States, Whereas American and European firms began during the 1950's more or less on a par in data processing technology—if not in market potential—Japan followed about a decade behind, Table 39 illustrates the gap in terms of installations. Now Japan has the second largest computer industry in the world, although still far behind the United States; sales in Japan are also second only to the United States. As table 40 shows, the Japanese computer market was two-thirds as big as the entire Western European market by 1982. Within Europe, West Germany absorbs the most computers, with the United Kingdom and France following,

Of the major Japanese-owned manufacturers —the same six firms that are the chief competitors in microelectronics—only three (Fujitsu, Nippon Electric, Hitachi) have annual sales of data processing equipment exceeding $500 million (table 41). In 1981 worldwide sales, the largest non-U, S. manufacturer—Fujitsu— ranked between Sperry-Univac and Hewlett-Packard, seventh largest, with barely half the

Table 40.—World Computer Markets

	Sales (billions of dollars)	
	1975	1982
United States[a]	$12.8	$47.2[b]
Japan		
Microcomputers and minicomputers	$0.17	3.19
Mainframes	1.89	2.63
Memory, storage	0.44	1,60
Other peripherals	0.53	3,61
	$3.03	$11.0
Western Europe		
Microcomputers and minicomputers	$0.37	$ 4.54
Mainframes	2,79	8.00
Memory, storage	1.40	—[c]
Other peripherals	1.24	3.5a
	$5.80	$16.1

[a] See table 35 for U S sales by category
[b] Includes software
[c] Included under 'Other peripherals

SOURCES *1975—Electronics* Jan 8, 1976 pp 94 106
1982—Electronics Jan 13, 1983 pp 146, 154 table 35

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[81] "Buzzword in Taiwan is 'Information' " op. cit.; A Spaeth, "Upstart Taiwan Electronics Firms Are Making 'Their Mark by Design," *Asian Wall Street Journal Weekly,* Dec. 13, 1982, p. 7.

[82] "Korea's Electronics Industry Making Rapid Gains in Shift to High-Technology Products, " op. cit.; A Spaeth, "Asian 'NICs' Rely on Cheap Brainpower To Plan output of More Advanced Goods," *Wall Street Journal,* Jan. 5, 1983, p. 25.

Table 41.—Non-U.S. Computer Manufacturers Ranked by 1981 Sales[a]

Company	Headquarters	Computer-related sales, 1981[b] (millions of dollars)
IBM	**United** *States*	*$26,340*
Digital Equipment Corp. (DEC)	*United States*	*3,587*
Fujitsu	Japan	1,950
ICL	United Kingdom	1,513
Olivetti	Italy	1,436
CII-Honeywell Bull	France	1,353
Nippon Electric Co. (N EC)	Japan	1,330
Siemens	West Germany	1,330
Hitachi	Japan	1,290
Wang	*United States*	*1,009*
Nixdorf	West Germany	856
Data General	*United States*	*764*
Toshiba	Japan	430
Apple	*United States*	*401*
Oki	Japan	400
Mitsubishi	Japan	330

[a]Selected American firms included for comparison only, see tables 38 through 38 for complete US rankings by sales.
[b]Fiscal years for Japanese firms plus ICL and Siemens

SOURCES *U.S.* ***firms***—P Archbold, "The Datamation Top 100,'' *Datamation*, June 1982, p. 115
Japanese Wins— "Status of Top Computer, OA Semiconductor Companies Studied, " ***Japan Report,*** Joint Publications Research Service JPRS U10319, Feb 11, 1982, p 17 Original source, *Computopia*. (Yen conversions at 220 per dollar),
European fhrrs-''Reviewing Europe's Top 25, " *Datamation*, November 1982, p. 124 Original source, Logica

computer sales of DEC. As table 41 shows, the European firms of any size number but five: ICL in Great Britain, Siemens and Nixdorf in West Germany, Olivetti in Italy, and CII-Honeywell Bull in France.

Europe

Almost from the beginning, American computer firms have been more viable competitors in European markets than local manufacturers.[83] The largest European entrants now have data processing equipment sales not too much greater than Wang's; national industries in Europe have passed through periodic cycles of financial problems, mergers, and government subsidies. ICL lost $245 million in 1981; the firm has had to depend on loan guarantees from the British Government.[84] In West Germany, IBM's market share—about 60 percent—is three times that of Siemens' money-losing data processing division.[85] In Europe as a whole, IBM has more than half of all computer sales by value—90 percent supplied by IBM's European plants—and American firms take about two-thirds of the total market.[86] The U.S. share of computer sales in Europe has, nonetheless, been declining slowly during the past few years.

The only internationally competitive European computer firm to recently emerge has been Nixdorf—a West German manufacturer of small systems intended primarily for business applications. The company has a global outlook; it currently gets less than half its sales in West Germany, nearly 20 percent in the United States.[87] Nixdorf is perhaps the closest to an entrepreneurial firm in the American style that the European electronics industry has seen. The company has actively sought out the best technologies available—e.g., in microelectronics—from both U.S. and Japanese suppliers, and cultivates close ties with customers in its efforts to anticipate user needs, Both atti-

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[83] See *Gaps in Technology: Electronic Computers,* op. cit. Also *The American Computer Industry in Its International Competitive Environment* (Washington, D. C.: Department of Commerce, November 1976).

[84] S. Love, "New Talent Spurs Britain's ICI.," *Wall Street Journal,* Mar. 1, 1982, p. 27.

[85] E. DiMaria, "European Makers Move to End Red Ink, " *Electronic News, Nov.* 16, 1981, see, II, p. 23.

[86] "European Computers: Pie in the Sky?" *Economist,* Sept. 9, 1978, p. 30; "Reviewing Europe's Top 25, " *Datamation,* November 1982, p. 124.

[87] J. Tagliabue, "Nixdorf's Rise From a Cellar, " New York *Times,* Feb. 18, 1981, p. D1. The company was started with capitalization of $6,000 in the early 1950's.

tudes have been atypical among European computer manufacturers.

Nixdorf is likely to benefit from the continuing expansion of markets for smaller systems—a trend as evident in Europe as here. Still, most of this growth will probably continue to be taken by American-owned companies. Symptomatic of the difficulties of European suppliers is the case of Philips—a firm that would seem to have as much ability as any in Europe to compete in computer manufacturing. Since the collapse of the Unidata consortium—a joint effort of Philips, Siemens, and CII during the 1970's—Philips has concentrated most of its efforts on small systems. But in contrast to Nixdorf, the Dutch multinational has had little success; at the end of 1981, Philips' share of European small business installations was only 3½ percent by value, as compared to Nixdorf's 10½ percent.[88]

The Japanese are also headed for a greater presence in the European market, but thus far most of their computer sales in the EC have come through ties with local firms. Not only do Siemens and ICL market Fujitsu's large mainframes, but Hitachi processors are sold by Olivetti and BASF.[89] The French remain committed to CII-Honeywell Bull—now nationalized, although Honeywell retains a 20 percent interest—as champion of the domestic market, and presumably the European market as well. However, the chances seem small that the Mitterrand Government will have more success than its predecessors in promoting CII-Honeywell Bull.

In only two countries in the world do American firms have less than half the installed base—a vital predictor of future trends because customers tend to become locked into a manufacturer's product line, largely through their software inventories. The two are the United Kingdom, where government procurement and other policy tools have heavily favored British-built computers, and Japan, where the government has used a variety of measures over many years to protect and support the domestic industry.

Japan

Britain's policies may have kept ICL in business, but the firm is hardly thriving. Japan has had more success; the government played a central role in the development of the country's computer industry, with many of the subsidies given semiconductor manufacturers based on the desire to help build a strong computer sector.[90]

Japanese computer manufacturers have not yet had the export success of the nation's consumer electronics firms, but they have outstripped their rivals in Europe on most indicators of competitive ability if not always in total sales (table 41). In contrast to Europe, the dynamic is upward; Japan's computer firms appear to be the only real threats to American leadership in information processing, Originally, the Japanese were heavily dependent on U.S. technology; now they have excellent capabilities of their own, particularly in hardware. Though still lagging in software, this is a current emphasis of R&D; as discussed in the next chapter, Japanese manufacturers hope to break free of their reliance on IBM software and plug-compatible systems.

Figure 29 shows how rapidly Japan's output of computers has increased; production volumes were quite low as late as 1970. Now exports have also begun to rise steeply, doubling from 1980 to 1981 and increasing by another 50 percent in 1982. Still, even at the 1982 level–about $1.7 billion—Japan's exports of computers are less than 20 percent those of the United States. Moreover, as figure 30 points out, IBM-Japan is by far the leading exporter; in 1981, this American-owned firm accounted

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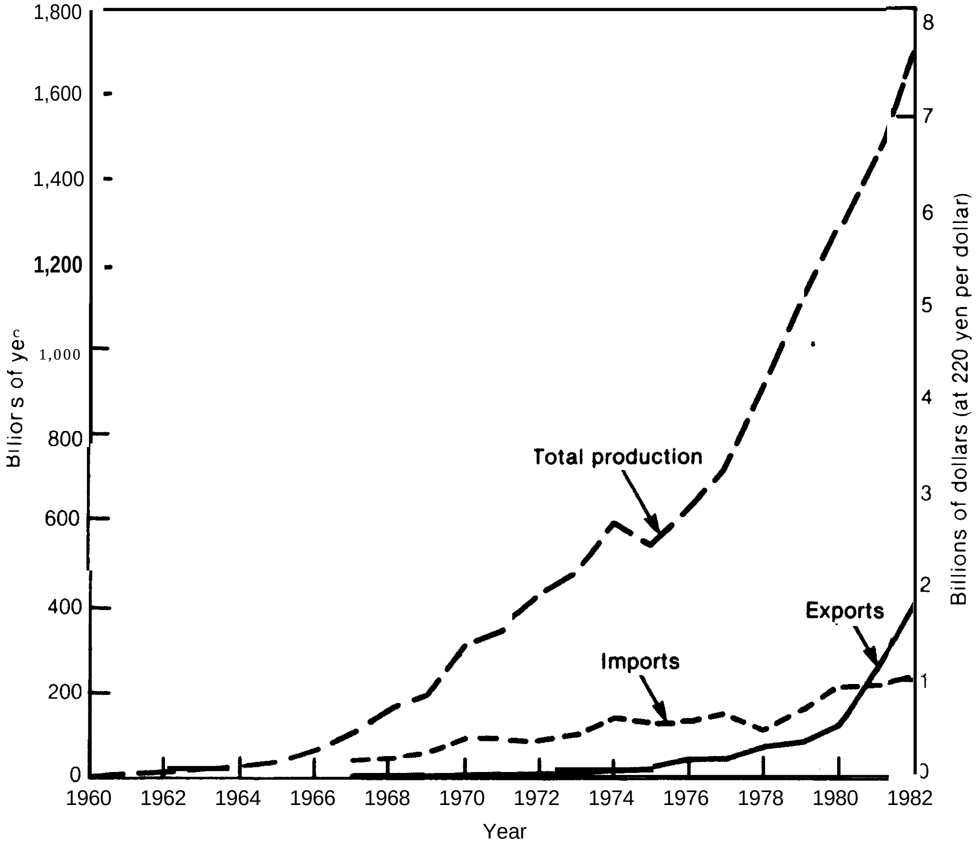
[88] "Small Business Systems, " *Financial Times,* June 8, 1982, sec. III, p. V. Philips' installed base in these systems ranks ninth by value, Nixdorf's third. IBM and Olivetti were first and second; 5 of the top 10 firms in this survey were American-owned,

[89] G. de Jonquieres, "ICL Launches Japanese Computer, " *Financial Times,* May 7, 1982, p. 7.

[90] See the appendix on "The Development of the Japanese Computer Industry" in E. J. Kaplan, *Japan; The Government-Business Relationship* (Washington, D. C,: Department of Commerce, February 1972], pp. 77-1o1, Also J. Gresser, *High Technology and Japanese Industrial Policy: A Strategy for U. S. Policymakers,* Subcommittee on Trade, Committee on Ways and Means, House of Representatives, Oct. 1, 1980.

Figure 29.—Japanese Production, Imports, and Exports of Computers and Equipment, Including Production and Exports of U.S.-Owned Subsidiaries



SOURCES 1985-78-Japan *Fact Book '80* (Tokyo Dempa Publications, Inc , 1980), pp 173, 174
1978.80–Japan *Electronics Almanac 1982* (Tokyo Dempa Publications Inc 1982), pp 58, 59
1981, 1982— Bureau of Industrial Economics, Department of Commerce

for some 40 percent of Japan's total exports of computers and equipment.

The major Japanese computer manufacturers come from the familiar group of diversified electronics companies. The three largest in terms of data processing equipment sales are Fujitsu, NEC, and Hitachi (table 41). While perhaps 50 firms make small business systems, there are no minicomputer specialists as such in Japan.[91] Like Siemens but unlike most other European and American computer firms, the principal Japanese suppliers get relatively small fractions of their revenues from computers and peripherals—table 42. Fujitsu is something of an exception, as is Oki, but both are still considerably more diversified than the typical U.S. manufacturer of data processing equipment.

As they did in Europe, American computer firms moved early into the Japanese market, but in Japan their penetration was limited by MITI's efforts to protect and nurture a domestic industry. In 1960, imports captured 70 percent of Japanese computer sales, a situation unacceptable to the government; IBM was able to use its patent leverage to establish a wholly owned manufacturing subsidiary, but other production by American firms was restricted to minority interests in joint ventures.[92] Sperry-

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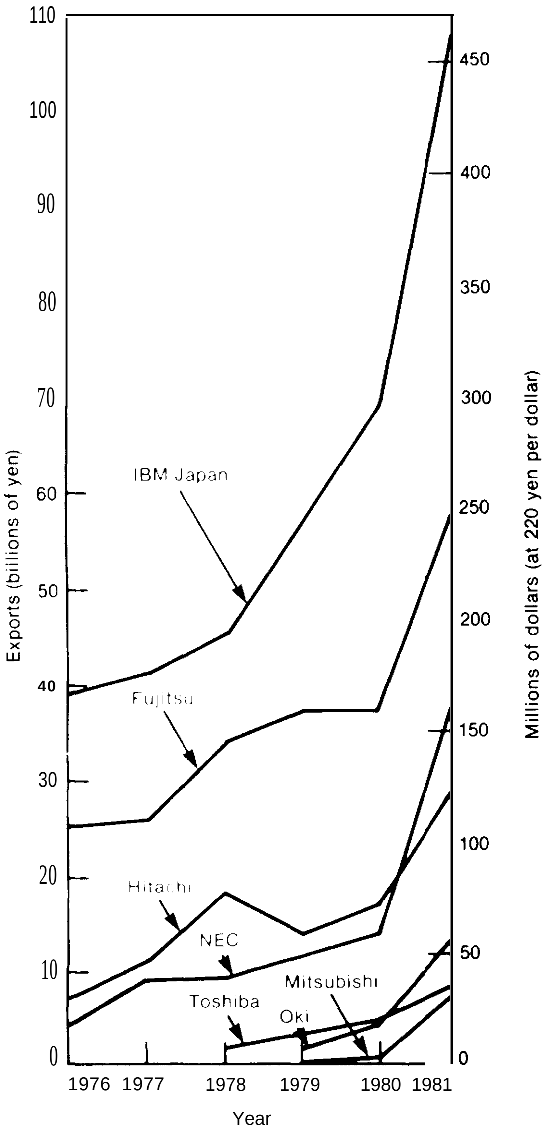
[91] "Competing At Home Prepares Japanese Vendors for Export, " *Electronics*, Mar. 27, 1980, p. 120.

[92] "The Development of the Japanese Computer Industry, " op. cit. IBM-Japan was established in 1960. On other U.S. ventures, see "Can the U.S. Recapture Its Japanese Market?" *Business*

Figure 30.— Japanese Computer and Equipment Exports by “Firm



SOURCE Top Ten Computer Companies' Business Performance in FY 1981 Analyzed, *Japan Report*, Joint Publications Research Service JPRS L 11414 June 29, 1983 p 109 Original source, *Computopia*

Univac, which also had a relatively strong patent position, managed to maintain a place in Japan through a jointly owned sales company, Nippon-Univac, plus a minority interest which it still holds in Oki-Univac, a manufacturing enterprise. NCR owns 70 percent of a Japanese venture that is largely a marketing arm for imported systems. Japanese operations by other American computer firms have been small in scale, most established quite recently. Through such efforts, U.S. companies have managed to retain perhaps 45 percent of computer sales in Japan, including both local production and imports; IBM-Japan accounts for most of this.

Indeed, until 1979 IBM-Japan had a market share greater than any other firm, outstripping all the Japanese-owned manufacturers. Since then, Fujitsu’s sales have exceeded IBM’s—figure 31. IBM still has the largest installed base in value terms—about 28 percent—with Fujitsu ahead in total number of systems, Part of the reason for IBM-Japan’s lagging rate of sales growth compared with Fujitsu, Hitachi, and NEC—all of which, as figure 31 shows, have seen their sales expand rapidly—lies with IBM-Japan)s relatively weak position in smaller systems.

Another factor working to the advantage of locally owned companies has been the Japan Electronic Computer Co. (JECC), a leasing organization supported by loans from the Japan Development Bank. JECC was organized more than 20 years ago under MITI auspices to aid the domestic industry; it purchases systems and leases them to users so that computer manufacturers need not tie up large sums of capital in lease bases. American-owned suppliers have not been allowed to participate. JECC has given smaller Japanese manufacturers like Fujitsu and NEC much more financial flexibility than they would otherwise have had. The leasing program is still seen by both government and the manufacturers as a necessary support for the industry; only Hitachi, with its vast resources, is no longer heavily dependent on sales to JECC.[93] As this implies, the computer operations of Japanese firms have not been very profitable, Although line-of-business figures are not generally available, continued support via JECC—plus the reported inability of firms that received loans and other subsidies

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Week, Aug. 25, 1980, p. 73, and “U.S.-Japanese Computer Companies Joint Venture Reported, ” *Japan Report*, Joint Publications Research Service JPRS 1./10701, July 30, 1982, p. 16.

[93] M. Inaba, “Say JECC Aid Is Still Vital to Japanese CPU Firms, ” *Electronic News*, June 22, 1981, p. 22.

in the early 1970's to pay them back—indicate that a number of Japanese companies may still be losing money in their data processing divisions.[94]

W"Domestic Computer Makers Unable To Return Subsidies," *Japan Report,* Joint Publications Research Service LI1oO4O, Oct. 8, 1981, p. 10. An industry analyst at Nomura Securities has speculated that only Fujitsu and Hitachi are earning profits in computer manufacturing, but that NEC and Mitsubishi maybe breaking even—"Competing at Home Prepares Japanese Vendors for Export," op. cit.

Table 42.—Total and Computer-Related Sales for Japanese Manufacturers

	Sales (millions of dollars					
	1970		1977		1981	
	Total	Computer[a]	Total	Computer	Total	Computer
Fujitsu	$423	$230 (55°/0)	$1,450	$1,030 (70.80/o)	$3,209	$1,950 (60.8"/.)
Nippon Electric Co. (N EC)	691	210 (30°/0)	2,010	510 (25.60/o)	4,854	1,330 (27.40/o)
Hitachi	2,191	330 (15°/0)	5,190	600 (1 1.5°/0)	15,519	1,290 (8.30/o)
Toshiba	1,666	130 (8°/0)	3,950	220 (5.60/o)	9,536	430 (4.5%)
Oki	—	NA	480	170 (34.7%)	986	400 (40.60/o)
Mitsubishi	1,102	55 (5%)	2,960	140 (4.80/o)	6,058	330 (5.4%)

NA = Not available
[a]Estimated.

SOURCES. *1970*— E J Kaplan, *Japan The Government-Business Relationship* (Washington, D.C Department of Commerce, February 1972), p 101
1977—"Status of Top Computer, OA Semiconductor Companies Studied, " *Japan Report,* Joint Publications Research Service JPRS IJ10319, Feb 11, 1982, pp 17, 24; original source, *Computopia,* yen conversions at 288 per dollar
IfXl I-Tables 29 and 41

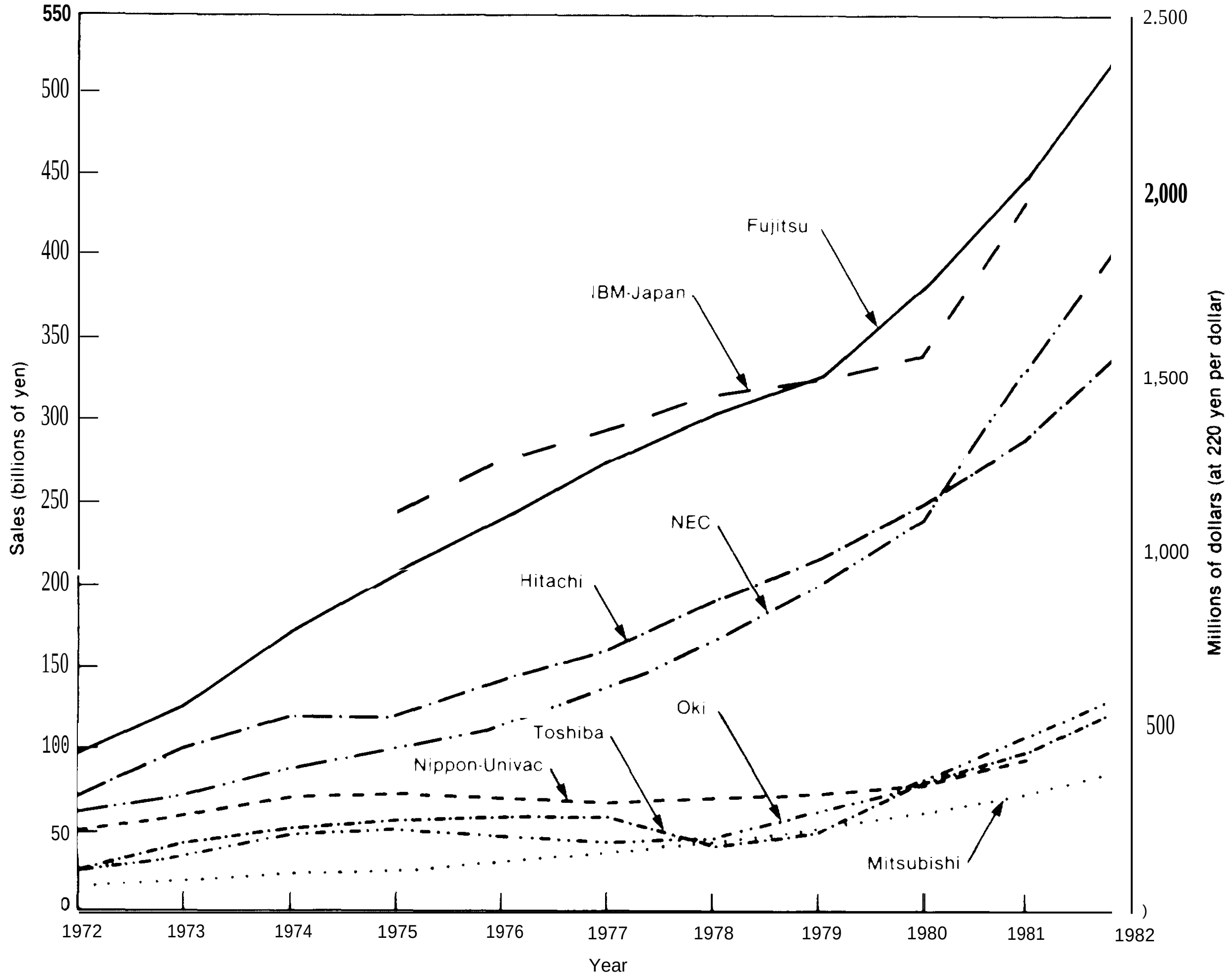
Summary and Conclusions

Industrial structures and patterns of international trade are continuing to shift, though at different rates, in the three sectors of the electronics industry under discussion. In consumer products, U.S. manufacturing has been reconstituted with considerable foreign ownership. The transformation came somewhat later in color TV than in black-and-white TV or consumer audio products, where imports have been dominant for a decade or more, with domestic production at relatively low levels. As a result of unrelenting import competition for color television sales during the 1970's, weaker American manufacturers left the industry—mostly replaced with assembly plants owned by Asian firms. North American Philips, the quasi-independent subsidiary of the Dutch multinational, has also increased its holdings. The size of the color TV market and the protective measures adopted by the Federal Government have helped keep some manufacturing here, although—depending on the firm—as much as half the value may be added overseas, Zenith and RCA have retained their traditional market shares, as has GE, but these companies all perform substantial portions of their manufacturing offshore.

On a world basis, the Japanese have far outstripped other countries in consumer electronics. They have a major share of all markets outside the industrial economies, and have been making steady inroads into Western Europe, where most of the local firms have been small and markets fragmented. Philips, the primary exception to the general weakness of European consumer electronics manufacturers, has mounted a forceful effort to maintain its position. The only company outside Asia to make consumer VCRs, Philips' determination to persist with this line of products, as well as its expansion in the United States, signifies its commitment to a continuing presence in consumer electronics.

Suppliers with headquarters in the developing Asian economies of Taiwan, South Korea,

Figure 31.—Japanese Computer Sales, Including Exports, By Firm



SOURCES 1972-80 *Fujitsu and the Computer Industry in Japan* (Tokyo Fujitsu Ltd June 1982) p 11 Original source Computopia *Japanese owned firms*, 1981, 1982 Computer Companies Mid Term Business Reports Announced Japan *Report* Joint Publications Research Service JPRS L 11100 Jan 28 1983 p 73 (1982 estimated) *IBM Japan and Nippon Univac, 1981* U Weil Evaluating the Japanese Challenge *Datamation* January 1983 p 133

Hong Kong, and Singapore are following in the footsteps of the Japanese multinationals. Already producing large volumes of components—as well as radios and other audio equipment, watches, and calculators—firms in these countries are strengthening their technological capabilities as a prelude to expanding into new product lines. With infrastructures owing much to the investments of American and Japanese manufacturers moving offshore in search of lower labor costs, several have already proved able competitors in color TV.

The situation is quite different in microelectronics. Here the European industry has never been able to develop a strong independent capability. American investments overseas accelerated through the 1960's; U.S. firms built both offshore plants in developing countries and point-of-sale subsidiaries to serve the European market, While U.S.-owned manufacturers continue to supply nearly two-thirds of the world's semiconductors, a pair of major changes are underway: first, vertical integration is increasing; second, the Japanese are rapidly increasing their competitiveness in world markets.

Captive semiconductor production by integrated manufacturers like Western Electric or IBM is not a new phenomenon, but the number of captive facilities in the United States is on the rise. While merchant semiconductor firms like Motorola or National Semiconductor have been expanding rapidly, captive production has been increasing even faster. The motives for vertical integration are several. Large consumers of semiconductors can help control their costs by manufacturing internally. Others seek a custom design and production capability, assured supplies of low-volume specialty circuits, or simply to keep up with the state of the art, In a few cases, diversification may have been the primary motive for acquisitions of merchant semiconductor firms by larger corporations. While the number of high-volume independent merchant suppliers has diminished as companies like Mostek, Fairchild, and Intersil have been purchased, a new wave of startups—beginning in 1980—may help replenish their ranks, given growth rates comparable to those in earlier periods.

In essence, then, the U.S. semiconductor industry consists of two kinds of manufacturers: merchant firms that sell in the open market, and captives. That some of the merchant manufacturers have now been acquired by other companies has not yet changed these patterns significantly; the formerly independent merchant firms still produce largely for open market sales. Captives, in contrast, rarely sell outside the parent organization. Industrial structures in Japan and Europe lack this relatively clear distinction. Most foreign production takes place in divisions of large, diversified corporations; semiconductors seldom account for even one-third of revenues, often much less. Typically, such companies use a substantial fraction of their microelectronics output in their own end products.

In Japan, the major producers of semiconductors–including Toshiba, Fujitsu, NEC, and Mitsubishi—also make consumer goods or computers or both. These firms specialize to some extent—Fujitsu in computers, NEC in communications equipment and microelectronics, Toshiba in consumer products—but all have multiple lines of business, some extending well beyond the bounds of the electronics industry, Japanese manufacturers are now expanding aggressively into Europe, setting up point-of-sale plants as American firms have been doing for years. While none of the developing countries are as yet factors in IC production, several are making determined efforts to expand from discrete semiconductors into more advanced devices.

The computer industry, which consumes more than 40 percent of world output of ICs, has changed radically over the past two decades. *There is hardly an identifiable computer industry any longer.* As more and more computing power can be packed into a microprocessor or single-chip microcomputer, semiconductor firms like Intel are pointing their R&D efforts toward "systems on a chip. " Others—e.g., National Semiconductor—have entered the market for large computer systems; National's computer division sells IBM-compatible mainframes made by Hitachi.

More broadly, distributed intelligence and the ever-expanding demand for smaller systems are transforming the industry. Lower costs open new markets—typically supplementing existing applications rather than supplanting them. Symptomatic of the changes in the global computer industry is the emergence of DEC—a pioneer in minicomputers and still a specialist in small systems—as the second largest computer firm in the world. In 1981, DEC moved past two mainframe-oriented companies, NCR and CDC, into second place in worldwide sales behind IBM. While IBM is still an order of magnitude ahead of its competitors, too much should not be made of this position; after all, U.S. Steel once held two-thirds of *its* market.

Nevertheless, the world computer industry can still be pictured as IBM on the one hand and everyone else on the other, The difference is that the others are much more numerous and diverse than 15 or 20 years ago, Not only are minicomputer firms like DEC more prominent, but microcomputer manufacturers such as Apple and Tandy now have some of the highest growth rates in the industry. In Europe too—where, as in semiconductors, subsidiaries of American firms have dominated production—the most competitive locally owned manufacturer is Nixdorf, which makes small systems. The other European computer firms—Siemens, ICL, CII-Honeywell Bull—have been growing more dependent on foreign technology, with only the last-named trying to break out of this mold.

Japan's computer industry has been marked by a comparatively strong American presence. While U.S. computer makers have not been able to penetrate Japanese markets as extensively as European, they have had much more success in Japan than American consumer electronics firms; the share of computer sales accounted for by U.S.-owned suppliers—about 45 percent, mostly due to IBM-Japan—is also far greater than the U.S. share of the Japanese semiconductor market. Still, IBM has lately lost first position in Japanese sales to Fujitsu, As this indicates, a ***major difference between Japan computer industry and Europe is that Japanese firms are getting stronger,*** while European suppliers are not. Japan's computer manufacturers have excellent hardware technology, and arc increasing their production and exports at high rates, In this they have been greatly helped by the size and new-found technical ability of the Japanese semiconductor industry. Japan's computer industry is the only potentially serious challenger to the United States now visible. While the Japanese tend to be weak in software and in minicomputers, the country's major producers—aided by government-supported R&D efforts such as the fifth-generation computer project—appear on their way to becoming formidable competitors in the global computer market,

CHAPTER 5

Competitiveness in the International Electronics Industry

Contents

List of Tables

List of Figures

CHAPTER 5

Competitiveness in the International Electronics Industry

Overview

According to numerous American business and political leaders, other nations are overtaking the United States in trade competitiveness. Growing import penetration in such industries as automobiles, steel, and electronics—including high-technology products like computer memory chips-has led to discouraging commentaries and a variety of diagnoses. But from their statements, international competitiveness clearly means different things to different people. Some see the United States losing competitiveness as a nation relative to economic rivals like Japan or West Germany; to such observers, the declining U.S. share of global trade in manufactured products—from 25 percent in 1960 to 18 percent in 1980—is prima facie evidence that the Nation is losing competitive vigor. On the other hand, OTA in its past work has evaluated competitiveness on a sector-by-sector basis—believing this to be more meaningful than attempts to generalize about the economy as a whole,

That multiple views on international competitiveness coexist would be of little moment if similar policy remedies followed. But they do not. Viewing competitiveness from an aggregate perspective directs attention toward policies affecting the economy as a whole, and perhaps toward measures intended to promote exports. Policies aimed at improving overall productivity, encouraging capital investment, reducing inflation rates, or stimulating economic growth may have little or no impact on patterns of trade. In contrast, viewing competitiveness in the context of individual sectors—such as steel—is more likely to suggest remedies tailored to the problems of these sectors. Alternatively, the sectoral perspective might suggest that Government support be directed to industries whose international trade position promises to improve. One danger was illustrated by the course of discussions over U.S. industrial policy during 1980, which were dominated by the issue of "winners" as opposed to "losers," or "sunrise industries" and "sunset industries "-a debate that hindsight shows to be beside the point.

This chapter begins by sorting through perspectives on competitiveness, primarily in the context of electronics. Discussion then turns to the practical problem of evaluating competitiveness and attempting to isolate factors that have affected the ability of American electronics firms to compete internationally. Attempts to measure [competitiveness in an industry with rapidly evolving technology are at best indicative. From the viewpoint of Government policy, choices then hinge on dynamics—directions and rates of change, their causes. Projections always carry uncertainty. It may not be easy to discriminate short-term competitive shifts from the longer term secular trends of most concern to policy makers. Some portions of an industry may be in competitive decline while others prosper; a few years later positions may reverse, Within a single firm, various divisions will differ in their ability to compete, Within a division, some product lines may fare better than others. Because technical change, itself not very predictable, is central to competition in electronics, "measuring" competitiveness in any simple sense is impossible. In order to link the technological elements with other business, economic, and policy variables, the chapter concludes with an examination of business strategies,

Comparing strategies pursued in various parts of the world—how firms in several countries have taken advantage of the technologies available to them—yields insights into competitive shifts. Corporate planners have options in deciding how to utilize existing technologies. At the same time, corporate strategies affect the course of technological development itself, as firms decide how to allocate resources for research and product development. In electronics, strategic patterns vary across national industries and among countries. In contrast to manufacturers of semiconductor devices and computers, U.S. consumer electronics firms have seldom approached their markets on a world scale; while taking advantage of offshore production sites and exporting technology when they could, they have otherwise been content with the large and formerly lucrative domestic market, On the other hand, Japanese entrants in consumer electronics-and to some extent the Dutch multinational Philips—produce and sell all over the world. In microelectronics and computers, the situation is reversed; here it is American firms that led—investing overseas and exporting long before Japanese firms were factors in this part of the industry,

Japanese firms now seem likely to take the lead in future generations of consumer electronic products. In part, this competitive success—including the massive inroads into the U.S. market for color televisions summarized in the previous chapter—was fueled by low manufacturing costs and supportive government policies. But compared to the aid Japan's Government has channeled to microelectronics and the information industries, assistance for consumer electronics has been relatively small: low costs and prices (including proven instances of dumping), good products, and aggressive marketing led the way. Technology is a more potent competitive weapon in semiconductors or computers than in consumer electronics—one of the reasons American firms, with their proven ability to turn technology into successful commercial products—have been able to preserve many of their traditional markets. Low costs are still important, but a unique integrated circuit or a better performing computer system offer advantages of a kind that can seldom be achieved in consumer products.

Comparative Advantage and Competitiveness

The Economics of Competitiveness

Is Comparative Advantage Still a Meaningful Concept?

To some, the traditional explanation of international trade flows in terms of comparative advantage is a relic—made obsolete by national industrial policies. Still, without denying the reality of government interventions and their effects—whether these be nontariff barriers restricting inflows of goods and funds for investment, or incentives to attract foreign capital—comparative advantage provides a useful backdrop for more detailed analyses of trade and competition.[1]

Definitions of competitiveness in terms of comparative advantage—with roots going back to the origins of social science--state in essence that nations tend to export goods (or services) that best utilize their available resources, and to import other items; i.e., they export goods in which they have comparative advantage. This is not so obvious as it first appears. For instance, it follows that any nation engaging in international trade must have comparative advantage in some products. Except for financial flows of one type or another, imports must be paid for by the proceeds from exports. Therefore, from the viewpoint of comparative advantage, it is meaningless to speak in terms of a nation being uncompetitive. *If a country trades at all, it must be competitive in something.*

The word "comparative" plays dual roles in the definition. First, how do industries relate one to another *within* a country on their effi-

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[1] For one view of the limitations of the comparative advantage perspective in a context of rapid technological and industrial change, see M. F. Cantley and J. A. Buzacott, "Industry Scale, Free Trade, and Protection," *Scale in Production Systems*, IIASA Proceedings Series, vol. 15, J. A. Buzacott, M. F. Cantley, V. N. Glagolev, and R. C. Tomlinson (eds.) (Oxford: Pergamon Press, 1982), p. 193.

ciency in using resources? In principle, this comparison should yield a list of industries ordered from most to least efficient. (The precise meaning attached to efficiency is not critical, but it refers essentially to costs.) All else equal, nations would be expected to export goods that appeared near the top of their efficiency listing, import those closer to the bottom. Such an outcome does not depend on how these efficiencies compare to the efficiencies of the same industries in other countries. It depends only on the relative standing of domestic industries. The fact is that industries at the top of one country's list can have ''efficiency" levels below those of the same industries abroad and still export. The first characteristic of an export industry, therefore, is that it be efficient in its use of resources relative to other domestic industries.

The second comparison adds the international dimension. Here, the efficiency structure of one nation's industries is compared with those of its potential trading partners. Where the efficiency structures of two countries differ —the usual case—trade can be advantageous to both. The United States might in principle be just as efficient in the production of video cassette recorders (VCRs) as Japan; but if U.S. efficiency is greater in, say, agriculture, it would pay both countries to trade—the United States shipping agricultural goods to Japan while importing VCRS, Even given identical cost structures, trade might be advantageous where demand conditions differ between two countries. Of course, such a discussion leaves out a host of other forces—ranging from tariff levels to export subsidies—that can affect trade patterns. Still, comparative advantage provides a starting point for examining these.

Technology plays a central role in electronics. Some countries may possess technological expertise unmatched elsewhere, hence be able to export products that no one else can make. More often, technology is a route to lower cost manufacturing or to products that perform better. A number of nations that could manufacture computers do not because countries like the United States can make better computers cheaper.

While U.S. exports have often been based on technological leads, in other cases trading advantages may stem from natural resource endowments. This country's exports of land-based products—food, fiber, timber, paper—are the consequence of an abundance of arable land combined with high-technology inputs. Conversely, Japan would be hard-pressed to develop agricultural advantages–regardless of technological expertise—because of her scarcity of good land.

Nations may also be able to maintain market-based advantages in particular industries, advantages that can persist over long time periods. The American lead in commercial aircraft, or some types of capital equipment—e.g., gear cutting machines—may not have resulted from unique technological skills so much as that certain kinds of products first found large markets in the diversified and affluent U.S. economy. Likewise, the Japanese lead in VCRs is now so great in terms of production scale and developmental experience that it would be very difficult to overcome.

None of these examples detracts from the primacy of relative costs of production and distribution in determining international trade flows. When a nation has comparative advantage in a given product, that advantage is usually visible as lower costs and prices, Sometimes manufacturing costs themselves may be the chief indicator—this has generally been the case in consumer electronic products. Sometimes price/performance ratios must be examined—the more typical situation for computer systems. In an industry like steel, where it has been clear for more than a decade that Japan has a comparative advantage in production costs with respect to the United States, the crucial questions—particularly for public policy—then concern sources of advantage or disadvantage, from the national perspective how to capitalize on the former while minimizing the latter.

As the discussion above suggests, most cost-based comparative advantages can be explained, at least to first order, in terms of resource availability and technology, Countries with ample supplies of capital relative to labor can expect to excel in industries that rely on capital-intensive production methods—e.g., synthetic fibers or primary metals. On the other hand, where production methods call for large numbers of unskilled workers, nations with abundant supplies of such labor—hence low labor costs—are likely to be the more efficient producers. Clothing and apparel, where much of the output is still hand-stitched, are well-known examples. In consumer electronics, low labor costs have helped Asian nations such as Japan, South Korea, and Taiwan achieve strong competitive positions; although automation has increased, assembly remains labor-intensive. Several American industries that have been losing competitiveness depend on substantial inputs of *both* labor and capital. To make either steel or automobiles requires large capital investments (in most but not all cases), while labor content is also high. Labor is expensive in the United States, while the Nation's advantages in technology and capital are not so great as 25 years ago. These long-term shifts are creating difficult problems for this pair of traditionally important American industries.

Consequences

For every comparative advantage, such as the United States has had in computer systems, there must be a comparative disadvantage, as now found in steel. Given flexible exchange rates, the value of a country's exports will normally counterbalance its imports almost exactly, since in a very real sense nations must use the proceeds from exports to purchase their imports. While this may seem straightforward, the consequences are not so obvious, Listed below are four general conclusions that follow from the earlier discussion,

1. *If a nation engages in international trade, some of its industries are by definition competitive, but some are also uncompetitive.* It is, to reiterate, impossible for a trading economy to lose competitiveness overall, since the very existence of trade implies that some sectors are price competitive while others are not. From a comparative advantage perspective, it makes no sense to state that the United States is losing its ability to compete. What can happen is that, over time, shifting patterns of comparative advantage may leave the United States less competitive in industries that once were leading exporters.

Some observers argue that the competitiveness of the United States has declined because its percentage of total world exports of industrial products has fallen relative to nations like West Germany or Japan. Such changes, however, are virtually inevitable in a world where industries in other countries have been growing much faster than those in the United States —overseas growth built in many cases on technologies painstakingly developed here. Similar fates are likely to befall the countries that today are experiencing the highest rates of economic expansion. Such nations as Brazil, South Korea, Mexico, and Taiwan are steadily increasing their share of world trade in manufactures. As these and other economies continue to industrialize, the current leaders are likely to find themselves losing ground in sectors that might now be mainstays. Certainly Japan's relative advantages in steel or consumer electronics are not nearly so great as they once were.

2. *If a nation overall rate of productivity growth—however productivity be defined and measured—is lower than in other countries, this need not result in losses of competitiveness for all that nation's industries, provided exchange rates are free to adjust.* Instead, real per capita income will decline relative to other countries, This may be a serious consequence, but should not be confused with impacts on *competitiveness.* Productivity growth does affect international trade flows, but again in a relative way: firms and industries where productivity growth is lower than average can expect to find themselves moving downward in a nation's efficiency ordering.

Nothing has yet been said about U.S. levels of productivity, cost, or efficiency compared to other countries, The comparisons have been internal. But it does follow that, if U.S. per capita *income* is to remain high, productivity levels must keep pace with those of our trading partners. At the same time, the sad fact is that an American firm or industry might be *more* productive—or otherwise efficient in its use of resources—than its overseas rivals and still not be competitive. The examples drawn on earlier can illustrate the point. In American industries like steel, apparel, consumer electronics—even shoes—labor productivity is as high or higher than in most foreign countries, yet these industries are in competitive difficulty. (The primary exceptions to this statement come when recessions in the United States are out of phase with those in other parts of the world; productivity levels depend on capacity utilization and can drop rapidly during downturns.) While these industries may be more efficient than their ***international*** rivals, other domestic sectors do better still. U.S. manufacturers of color TVs have not been sufficiently more productive than the average U.S. company to maintain their competitiveness; other American goods are more attractive to our trading partners, import competition in TVs stiffer, The first comparison for domestic industries is then their performance with respect to the rest of the domestic economy, again leaving aside distorting factors such as trade barriers or subsidies.

3. This conclusion follows: When *industries experience relatively rising costs in world markets, and lose market share both at home and abroad,* ***the price system*** *may* ***be signaling that resources should be reallocated internally—i. e., that domestic restructuring is necessary.*** To restore the competitiveness of declining industries would often require productivity improvements—for instance, through improved manufacturing technologies—greater than experienced elsewhere in the economy.

This may seem an especially harsh reality. It implies that a firm can take advantage of the, latest developments in product technologies, manufacturing processes, or both—but still not improve its ability to compete. Whether or not it can strengthen its position will depend on factors such as:

- the attributes of the technologies the company invests in (or the other investments it makes),
- the subsequent impacts on productivity compared with the rest of the domestic economy,
- responses to the investments by both domestic and foreign competitors, and
- the opportunities available to ***other*** trading sectors both here and abroad—far from last in importance.

It is an unpleasant fact that the realities of global comparative advantage may leave no simple remedies for a firm or industry bent on regaining its competitiveness. Substantial capital investment might be necessary to maintain the status quo but insufficient for improving competitive ability.

A brief example will illustrate: American automobile firms have been undertaking extensive programs of product redesign, accompanied by investments in new manufacturing facilities, intended to restore price competitiveness and profitability. The investments are huge, and clearly necessary if the industry is to again be competitive. Still, to succeed, these spending programs must do more than keep the U.S. industry on a par with productivity levels in Japanese automobile firms–if only because wages here are considerably higher. These wage levels reflect, not only the high productivity levels attained by U.S. automakers over the years, but also the lead in ***aggregate*** labor productivity that the United States still maintains with respect to Japan. To be competitive, the U.S. automobile industry must find ways to exceed the productivity levels in the factories of its overseas rivals—the same problem American steelmaker have faced since the 1960's. Given the available production technologies, this might not in fact be possible; certainly the steel industry has not found the key.

4. A further conclusion, relating to Government initiatives aimed at improving overall productivity: if such policies succeed—that is, ***if average productivity across all industrial sectors were to increase faster here than in other countries—then some formerly competitive American industries might become uncompetitive,*** Productivity improvements do not occur uniformly across an economy; some firms and industries improve faster than others. In terms of competitiveness, when some improve others will decline—even if the declining firms or in-

dustries experience productivity improvements of their own, and even if they improve faster than their rivals overseas.

This is a nontrivial conclusion. Phrases such as "getting the economy moving again" or "reindustrializing America" often seem to suggest that all industries can begin to compete internationally once new policies—whether changes in Government regulations, a revised tax structure, encouragements for exporting—are put into place. Unfortunately, this is highly improbable, if not impossible. The actual outcomes will depend on ***relative*** impacts—for instance, on how changes in tax law affect capital investment decisions and hence manufacturing efficiency across industries. Likewise, Government programs aimed at encouraging exports —removing disincentives, promoting American goods overseas, even providing subsidies such as tax benefits or low-interest loans—are unlikely, by themselves, to have more than marginal effects on competitiveness. Export incentives are puny weapons for combating structural problems, and—as experiences in several European countries show—even massive subsidies may be little help to an industry whose costs are too far out of line.

Many of these points apply across firms within an industry as well as across industries. Manufacturing sectors are typically populated by a spectrum of companies ranging from most to least efficient. In a relative price sense, some of the producers in a given country maybe fully competitive while others face difficulties. A particular Government policy might help all firms in a given industry; an alternative measure might help some firms but not others; still other policies might hinder all uniformly. In electronics, tax credits for research and development (R&D) are more likely to aid semiconductor firms intent on being at the leading edge of the technology than those that concentrate on low-cost production of standard devices, In a complex economy like that of the United States, it is not easy to determine a priori the outcomes of any particular set of policies. Even if the objective is to aid all firms, this may be impossible, A neutral policy—either among firms within an industry, or among industries within the economy—is a theoretical outcome that is seldom very closely approached. On the other hand, differential effects can rarely be quantified with much precision—and if they could, political choices among alternatives might be more difficult than they are now.

The essential lesson is that any policy adopted by Government will result in winners and losers, In an open economy, it is not possible to simultaneously help all sectors compete with foreign enterprises, The nature of the economic process dictates that choices be made when formulating public policies—choices that discriminate implicitly if not explicitly among sectors, and sometimes among firms.

Market Distortions and Nonmarket Factors

In assuming that prices in world markets depend only on costs and on the qualitative characteristics of goods that lead customers to perceive value in them, the previous section left aside many of the forces affecting competitive events. In reality, market distortions of several types can affect prices, as well as resource allocations and other economic decisions. One example occurs when governments provide otherwise uncompetitive industries with subsidies—direct payments, preferential allocations of credit, tax benefits, protection from import competition, As such a list suggests, distortions can be introduced by policies having targets—whether direct or indirect—quite apart from international trade, Several European countries openly subsidize industries in order to maintain employment levels, Some of these same countries point to the alleged advantages American high-technology firms get from R&D expenditures by the U.S. Department of Defense.

Pricing practices can also create distortions —e.g., dumping, normally defined as selling exports at prices less than charged domestically. Dumping is considered an unfair tactic under the rules of GATT (the General Agreement on Tariffs and Trade, ch. 11); governments typically attempt to counter such distortions in rather direct fashion, aiming to improve the operation of the price system. At least in principle, dumping margins can be offset by added tariffs, subsidies by countervailing duties. Remedies are less straightforward when the sources of impacts on pricing decisions are remote from the marketplace. The Tokyo Round Multilateral Trade Negotiations, completed in 1979, addressed one of the more complicated of these: implicit subsidies to exporters. Examples include government payments for R&D directed at domestic objectives —such as military security—which also, possibly as a side-effect, improve international competitiveness. In the United States, technologies such as semiconductors and computers (in their early days), jet engines, and nuclear powerplants have benefited from such expenditures, All have been strong export sectors for the U.S. economy. In recent years, countries like Japan and France have targeted commercial technologies and commercial industries quite overtly (ch. 10). While the Tokyo Round negotiations resulted in a new subsidies code to be implemented through GATT, this is only a small step toward resolving such issues.

In other cases the problem may not be distorted price signals, but market outcomes judged unacceptable. The most common instance—at least in terms of the frequency with which the argument is invoked—has probably been the uncompetitive industry claimed essential for national security. A number of countries have refused to allow open competition in computers because they believe domestic manufacturing is vital to their military strength. In the United States, spokesmen for the machine tool, steel, and automobile industries have advanced the national security argument,

At other times, unfettered competition is opposed for social or political reasons, The U.S. textile and apparel industry receives trade protection partly because it employs large numbers of low-skilled minority workers who might have difficulty finding jobs elsewhere. When, in early 1981, the Japanese were persuaded to limit exports of automobiles to the United States, the ostensible reason was to give American firms time to recover from recession and adjust to rapidly shifting market conditions; this step was taken even though there were few indications that trade restrictions would be a significant aid to recovery. In consumer electronics, orderly Marketing Agreements have been negotiated to soften the impacts of rising import levels. In these and other cases, political pressures—here and abroad—often carry more weight than economic indicators. The latter, for example, might instead suggest a need to shift resources to more competitive sectors. It is precisely when political pressures are most intense that the benefits of alternative policies should be widely aired before decisions are reached; the travails of the American steel industry have been aggravated by refusals, spanning many years, to directly confront the fact of shifting comparative advantage.

The Role of Technology

Any given technological development—a new or improved product, a more efficient manufacturing process—is likely to make some countries more competitive, others less competitive. For example, user-friendly software for numerically controlled (NC) machine tools would improve productivity most in countries that have a large base of NC machines coupled with a shortage of skilled parts programmers. More generally, even if the technology is widely available and all nations are able to implement it, some economies will benefit more than others. If a new manufacturing process reduces labor intensity, the competitive gain will be greatest for countries with high labor costs, least for those with large numbers of available workers. Even the most sophisticated new consumer electronic products may continue to be manufactured largely in the Far East so long as production requires sizable labor inputs. The effects of new technologies on international competitiveness depend, therefore, on attributes which must be related on a case-by-case basis to the resources available in each country and their costs, the mix of products manufactured and sold, and existing patterns of trade, Impacts of R&D projects—developments in both products and processes—are inherently difficult to predict. This can be troublesome for policymakers. When, if ever, does it make sense for government to select promising research areas for generalized support? To provide direct funding intended to maintain existing technological leads or foster new competitive enterprises? To support the development of avowedly commercial products? Different countries give different answers at different times. Even when the thrust of an R&D strategy might seem sensible, the consequences can be other than anticipated, It is entirely possible that a program sponsored by the U.S. Government could result in new products or processes better suited to the economic environments of our competitors.

"Technology gaps" have been an important source of U.S. comparative advantage in the past—notably in computers and semiconductors. Europeans tended to believe, as recently as the late 1960's, that technology gaps favoring the United States would be a permanent —and undesirable—feature of international trade, z These technological advantages have never resided so much in fundamental knowledge—whether of the sciences or engineering—as in the abilities of American firms to build on the existing knowledge base. Applying new technical knowledge can be a greater challenge—a different kind of challenge—than generating that knowledge in the first place; the guideposts are seldom so clear, the skills differ. In sectors as dissimilar as agriculture and electronics, the United States has been at the forefront in R&D and its applications; in both, exports by U.S. multinationals have been characterized by continual product/process developments. Even so, in microelectronics, these commercial developments have often proceeded without a well-established foundation in the physics and chemistry of electron devices. Such patterns are not uncommon; computer software, which has very sketchy theoretical foundations, is another case. Under such circumstances, the successes and failures of individual firms at product development have more direct consequences for competitiveness than do government R&D policies, although the latter help shape and direct technical progress.

Today, it is difficult to maintain purely technological leads. Unless knowledge of the technology is coupled with unusual resource requirements—large capital investments, sophisticated research facilities—diffusion among industrialized nations will be rapid. Moreover, the flow of technical information is no longer so one-sidedly from the United States overseas as during the 1950's and 1960's. Firms in many countries now have the ability to locate and license the technologies they need, or to quickly duplicate products and processes developed elsewhere.

In essence, this means that gaps in technology should be viewed as largely self-closing, if only because it is easier to catch up by imitation than to create new knowledge. While some Americans continue to lament the passing of clear-cut leadership by the United States, there is little to be done except to work hard on our own technical abilities; it is plain that other countries can make a great deal of progress with imported technologies provided they have capable people and adequate capital for investment. virtually all the nations that compete with the United States have taken advantage of this avenue. Japan consciously followed a strategy of purchasing technology from European and American companies.[3] Importing foreign technology has, in fact, been a central element in Japanese economic development since the late 19th century.

Although Japan has recently been the most conspicuous in adapting foreign technologies, virtually all countries lean in one way or another on more advanced economies to foster development. Nations such as Taiwan and Korea are doing so today. During the 19th century, and earlier in the 20th, the United States

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'See, for example, J. J. Servan-Schreiber, *The American Challenge (New* York: Atheneum Press, 1968).

[3] T. Ozawa, *Japan Technological Challenge to the West, 1950-1974: Motivation and Accomplishment*(Cambridge, Mass.: MIT Press, 1974).

imported a good deal of technology—e.g., for making iron and steel. In the postwar period, German expertise in rocketry helped build the U.S. space program. When the United States develops a synthetic fuels industry, it will depend to considerable extent on the technology base developed earlier by countries without our petroleum reserves.

In essence, flows of knowledge among developed countries have returned to a situation more like that before World War II; diffusion of technology has also been accelerated by the activities of multinational corporations. Particularly in electronics, foreign investments by U.S. firms have aided infrastructure] development in many countries, industrial as well as industrializing. Even in the absence of joint ventures or other corporate connections, electronics firms in many parts of the world now have the ability to monitor and learn from developments elsewhere, taking advantage of the multiple pathways by which technology moves internationally.

From the standpoint of the individual firm, that technology transfers take place so rapidly makes R&D more rather than less essential. Companies that are leading try to stay ahead. Those that are behind must do their best to utilize the technologies available to them. The United States still maintains technological leads in electronics—computer software, minicomputers, microprocessor designs, office automation equipment such as word processors. These leads are not as large, nor as broadly based, as a few years ago. Because commercial advantages are short-lived, continuous effort is required; in today's economy, cutting R&D expenditures is often tantamount to accepting a position of dependency on technology developed elsewhere, Nations without the resources to stay at the leading edge may have no alternative. On the other hand, economies now at the forefront have evolved industrial structures adapted to a leadership position. To slip back means a painful adjustment-not only technical stagnation, but marked shifts in trade patterns.

Other Perspectives on Competitiveness

Productivity

Some commentators hold that an industrial economy is losing competitiveness if its aggregate productivity-i,e., gross domestic product (GDP) per capita—is growing more slowly than the GDPs of its rivals. The United States, by this definition, would be declining in competitiveness relative to most other industrial nations. Q Great Britain is the obvious example of a nation losing competitiveness, in this view, over several decades.

To what extent are definitions of competitiveness based on relative productivity levels meaningful? The question hinges on the relation between aggregate productivity, or GDP, and economic competition, This relation is not a close one; as pointed out in the previous section, even countries with very high rates of productivity growth cannot be competitive in all industries. Japan's agricultural sector is inefficient and unable to compete internationally–as a result of which farmers have used their political power to exact trade protection from the Japanese Government. Nor do rapid increases in productivity necessarily correlate with technical leadership. Japan, with unmatched productivity improvements over the postwar period, has depended on the United States and Europe for much of its technology. Early applications of robots—an area where Japan has lately gained a justified reputation for leadership (ch. 6)–were based on equipment imported from the United States. In electronics, Japanese companies have only recently begun to compete in product lines character-

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[4] See U.S. *Industrial Competitiveness. A Comparison of Steel, Electronics, and Automobiles* (Washington, D.C.: U.S Congress, Office of Technology Assessment, OTA-ISC-135, July 1981), p. 62, for trends in gross domestic product in four countries compared to the United States.

ized by the newest technology; for the most part, inroads have been in such products as radios, TVs, and standard semiconductor devices. As Japanese firms move into high-technology product lines, these patterns change; still, they belie the significance of aggregate trends in productivity or GDP by themselves. Indeed, for many years other countries expressed little concern over Japan's competitiveness despite the explosive growth of that nation's economy—some even continued to denigrate Japanese products as the cheap and shoddy output of low-cost labor.

Nevertheless, relative productivity gains—considered either in the aggregate or on a sector-by-sector basis—are central to the dynamics of any nation's economy. Differing rates of productivity growth will, over time, lead to shifts in the structure of international trade and thus the competitive positions of firms and industries throughout the world, In the United States, sectors where the pace of technological change has been modest—steel, automobiles, shoes, consumer electronics—have borne the brunt of restructuring; penetration of American markets varies considerably among these industries, but in each the Federal Government has resorted to trade restrictions to control imports and blunt competitive pressures. At the same time, even in such industries, the stronger U.S. firms have often maintained their ability to compete with overseas rivals; most often, the companies displaced were in trouble before imports became a factor. In consumer electronics, Zenith and RCA have lost little in the way of market share, though imports and U.S. investments by foreign corporations have driven others from the business. In steel, domestic minimills have steadily won sales in selected product lines from larger American steelmaker; they have done so in the face of stiff import competition, Thus, the primary effect of import competition may be to accelerate processes of industrial adjustment already underway. Market penetration by imports in such industries need not imply that an economy is in overall decline. These same industries may eventually find themselves revitalized; indeed, many economists contend that exposing industries to competition is crucial to their continued health[5] This is an attitude long reflected in U.S. antitrust law.

One reason for slow productivity growth in the United States is simply this Nation's greater industrial maturity compared with many of its rivals—shown, for instance, by the much greater proportion of economic activity devoted to services than manufacturing. As figure 32 indicates, by 1980 two-thirds of the American work force was employed in the service sector. Other industrial countries continue to employ more of their people in industry, fewer in services; even in the United Kingdom, services account for only a little over 55 percent, Productivity improvements in the service sector are more difficult to achieve—or at least to measure. Despite the much lamented decline in U.S. productivity growth, the *manufacturing* portion of the American economy continued to increase its productivity about as fast during the 1970's as over the preceding 20 years.[6] Even if productivity improvements have lagged in the service sector, the shift has brought compensations internationally. Revenues to American firms for such services as the engineering and construction of public works projects—airports, hospitals, dams—have increased rapidly. As one result, other portions of the economy have moved downward in the rank ordering of U.S. comparative advantage, In other words, the United States is substituting exports of services for shipments of industrial products, importing more of the latter. The substitution need not imply either rise or decline in competitiveness,

Of course, greater aggregate productivity in the United States as measured by GDP per capital—one of the fundamental indicators of living standards—is a desirable goal wholly apart from its possible influence on competitiveness, But public policy instruments directed at the

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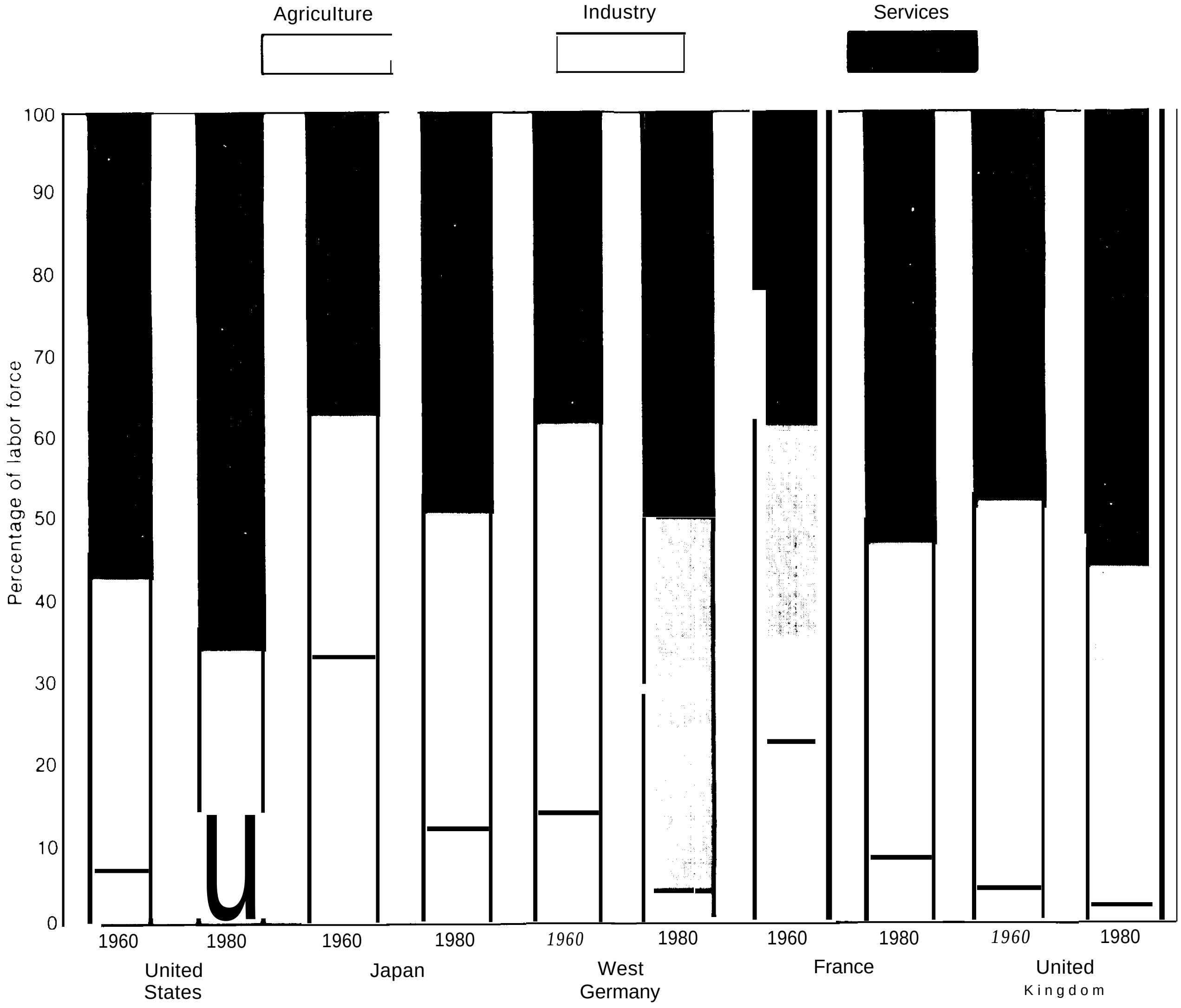
[5] For a well-known statement of this view, see B. Klein, *Dynamic Economics* (Cambridge, Mass: Harvard University Press, 1977).

[6] *U. S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles,* op. cit., table 10, p, 61. Annual productivity growth in manufacturing was 2,4 percent from 1950 to 1970, 2.3 per-cent from 1970 to 1979.

Figure 32.— Distribution of Economic Activity in Several Countries



SOURCE *World Development Report* 1982 (Washington D C World Bank, 1982)

general dilemma—i.e., macroeconomic and market promotion policies—would be more likely to achieve such objectives than measures aimed at improving the positions of particular industries. The tax reductions and savings stimuli embodied in the Economic Recovery Tax Act of 1981 are examples of steps that should help improve productivity. Still, even if they lead to greater productivity growth, there may be little change in the competitive positions of many American firms. All else equal, aggregate productivity improvement will be reflected in shifting exchange rates, which in turn will increase the price competitiveness of some industries while decreasing that of others,

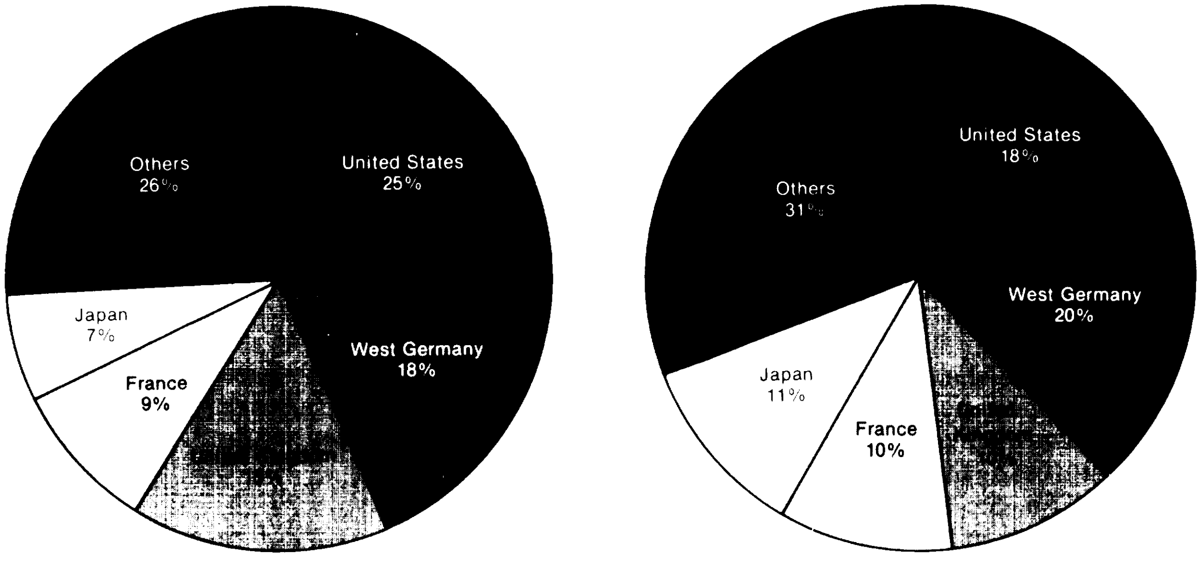
Market Share

Another common perspective on competitiveness starts with market shares of different countries. In this view, a drop in the U.S. share of world manufacturing exports could indicate a loss in competitiveness. The popularity of market share as a measure of corporate performance helps account for the application to international competitiveness. For measurement purposes, markets can be defined globally, nationally, or regionally. Figure 33 compares the U.S. share of world trade in manufactures to the shares of several other countries. Perhaps the most striking point made by the figure is the huge expansion in total world trade: a sixteenfold increase between 1960 and 1980; changes in country market shares, in contrast, are matters of a few percentage points. The United States is now less prominent among exporting nations, but to transfer a parameter such as market share—with real though limited meaning in a corporate setting–to the arena of trade between nations risks misunderstanding. Losses in the U.S. share of world markets are virtually inevitable as other nations progress economically. Starting from a lower postwar base, growth rates elsewhere have frequently exceeded those here. As a result, the United States has been left with a smaller portion of total world output, and a smaller share of trade; to some extent, market share is nothing more than a surrogate for comparing economic growth rates.

Rather than worldwide exports, would shares of the U.S. domestic market or particular third country markets make better indicators of competitiveness? If the U.S. market is the basis for comparison, the expansion of trade as a percentage of GDP must be considered. Growth in trade—exports as well as imports—has exceeded income growth in the United States, as table 43 indicates. That growth in imports exceeded that for national income does not, by itself, imply a loss of competitiveness; indeed, the growth rate for exports over the period in the table is a bit higher,

If the intent were to evaluate competitiveness by examining the exports of advanced economies to nations in the developing world—where the United States has, on the whole, declined—the question is then whether American corporations have slipped in their ability to compete with foreign exporters. Is this so?

Figure 33.—World Exports of Manufactured Goods[a]



1960
Total $55 billion

1980
Total. $880 billion

[a] Exports of 14 major industrial nations excluding exports to the United States Total export figures are approximate

SOURCE *International Economic Indicators*, Department of Commerce, International Trade Administration, March 1978, p 59 and December 1981, p 34

Table 43.– U.S. Gross Domestic Product (GDP), Exports, and Imports

	Value in billions of constant 1972 dollars	
	1960	1980
GDP	$732.0	$1452.4
Total U.S. exports	38.4	161,1
Total U.S. imports	30,7	109.1

SOURCE Department of Commerce, Bureau of Economic Analysis

Not necessarily, and for several reasons—the first being rates of economic growth in particular developing country markets. Long-established ties still link traditional trading partners-e. g., France and her former colonies. Such patterns tend to be rather stable; the proportion of U.S. trade with Canada and Latin America remains high, European firms tend to have a greater presence in African markets, Japan has high export shares in the Far East. If market position in the developing world were to be treated as an indicator of competitiveness, relative shifts in the position of a country such as the United States might simply reflect the economic growth rates of traditional trading partners relative to other developing nations. Moreover, changes in the American share of exports might indicate nothing more than a varying mix of goods and services sent abroad. If the United States is moving toward increased exports of technologically sophisticated products and services—and if the imports of developing countries tend to be lower in technology–then U.S. market share might decline for this reason alone. Should it be taken as a sign of reduced competitive ability that Japan replaces the United States in exports of automobiles to, say, Canada at a time when American exports of computers to both Canada and Japan are rising? Finally, U.S. trade performance on a relative basis could slip because of the activities of multinational corporations. American firms have invested heavily abroad compared to their counterparts in other countries, Foreign direct investment by U.S. corporations averaged $15.5 billion annually over the period 1977-81; in contrast, West German companies invested an average of $3.9 billion, Japanese $2,8 billion, while British firms spent $5.8 billion.[7] Overseas manufacturing by subsidiaries of American multinationals may substitute for goods earlier shipped from the United States. Furthermore, subsidiaries may themselves export, adding to the shipments of countries with which the United States competes. Does this diminish U.S. competitiveness? It would be hard to argue for such a conclusion in the common case of subsidiaries that owe much of their competitive advantage to technology and skills developed by the American parent.

The point is not to slight the significance of relative market shares, but to note that trade statistics reflect economic currents that may be unrelated to competitive ability. Furthermore, wholly exogenous events can have great impact on comparative trade figures. Virtually all the countries with which the United States competes depend far more heavily on imported energy. Changes in oil prices have much greater effects on the trade positions of such countries; when energy costs jumped in the mid-1970's, European and Japanese imports swiftly rose in value terms, creating sudden trade deficits. Among the consequences, exchange rates eventually adjusted to bring exports more closely in line with new levels of imports (while many countries were able to cut quantities of energy imports, the value of these imports still tended to increase). One result was a reduction in the U.S. share of world exports. Again, there is no reason why this should imply a shift in competitiveness.

Indicators Based on Technology

According to yet another view, U.S. competitiveness has declined because other nations have gained ground in technical ability--i.e., the technology gaps that once benefited the United States have narrowed or vanished.

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[7] *International Economic Indicators*, Department of Commerce, International Trade Administration, June 1982, p. 54. The figures for the United Kingdom exclude investments by oil companies. Investment levels fluctuate markedly from year to year; for instance, U.S. foreign investments fell by more than half from 1980 to 1981,

While often true in particular cases, such conclusions can only be substantiated by careful examination on a technology-specific basis; generalizations about technological capability are often suspect. Moreover the implications for competitiveness are not always straightforward; many Japanese companies have followed behind and benefited from the experience—including mistakes—of innovators in the United States.

Attempts to develop indicators of technological competitiveness founded on some basis other than case-by-case evaluations have generally focused on patents, occasionally on dates of introduction of new products or processes. By such measures, the relative position of the United States has been declining in many industries.[8] Yet patent statistics or product/process introductions are highly imperfect measures of technical competence, particularly if used in isolation. There are simply too many factors other than the characteristics of the technology that affect them. In some portions of electronics-semiconductors for one-firms tend to view patenting as a routine tool of business. Rather than a means of "protecting" technology, or capitalizing on it in any concerted fashion, a patent may be something to be bartered. Under such circumstances, correlations between patent statistics and technological ability have little meaning. Some observers point to the high rates of patenting by Japanese electronics firms (see ch. 10, table 77) as a foreboding sign; however, it seems clear that reward systems in Japanese firms encourage patenting regardless of the value of the technology patented.[9] Even in the United States, only a small fraction of the patents granted could be considered meaningful advances in the state of the art.

Patents or similar indicators give an especially oversimplified picture in industries like electronics where technological change is rapid and product cycles can move more quickly than the patenting process. Again, there is no substitute for case-by-case analysis. In semiconductors, American companies are generally still the first to introduce new or improved designs for microprocessors or more specialized memory circuits—static random access memories (RAMs), various types of read-only memories (ROMs)—but today their lead is brief. Where new products from American firms win acceptance in the marketplace, Japanese manufacturers have been quick to follow with cheap, reliable devices of their own. They appear to have taken the lead in dynamic RAMs, a product where the path of technical evolution is well marked, with little uncertainty over what the market wants.[10]

Likewise in the computer sector, several countries can match American capabilities over a range of hardware. This rough technological parity does not so readily translate into competitive ability. Selling computers demands much more than hardware; commercial success depends heavily on software—a field in which American companies maintain a useful lead, even more so as software costs continue to rise compared to hardware. Also important are service, a good appreciation of user needs, and other customer support functions. Although prospective mainframe purchasers tend to have a relatively sophisticated understanding of the technologies offered by competing manufacturers, customers for small business or home systems may know less about computers than about the family car. Selling

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[8] *Science Indicators 1980* (Washington, D. C,: National Science Board, National Science Foundation, NSB-81-1, 1981), pp. 16-22.

[9] A number of other factors act to encourage patent registrations in Japan, including very low fees. See S. Fleming, "IFO Offers View of Rise in Japanese Patents, " *Financial Times, May 7, 1982.*

[10] Pilot production of 256K RAMs by the major Japanese manufacturers began at the end of 1982—evidently well ahead of the plans of American merchant manufacturers, though Western Electric announced a 256K chip in mid-1983. See "Recent Developments in Japanese 256K DRAM Production, " *Japan Report,* Joint Publications Research Service JPRS L/11128, Feb. 8, 1983, p. 39. Nonetheless, introduction dates do not tell the whole story, Hitachi was the first to announce a 64K RAM for the merchant market, early in 1978. (IB M's 64K chip entered volume production the previous year.) However, Hitachi's design required two supply voltages, was rapidly superseded by single-supply designs from other manufacturers, and never mass produced. See "64K RAM Sweepstakes: Round 4 Winner Is . . . ," *Morgan Stanley Electronics Letter,* June 29, 1979, p. 1; E. W. Pugh, D. L. Chritch10W, R. A. Henle, and L. A. Russell, "Solid State Memory Development in IBM, " *IBM Journal of Research and Development,* vol. 25, 1981, p. 585.

in such markets is just as much an art as designing the system in the first place. But the main point is that even in rapidly evolving technologies, the United States cannot expect to maintain the kind of technological leads that existed in the 1950's and early 1960's. Other countries can now keep close—perhaps abreast —in fields they choose to emphasize, if not across the board.

While there is no need for pessimism, it should be clear that the United States cannot live off its past achievements. U.S. R&D expenditures fell as a proportion of GDP for 15 years before beginning to turn back up at the end of the 1970's. Meanwhile countries like West Germany and Japan have been stepping up their research spending, at the same time devoting far smaller fractions to military R&D. Still, the United States continues to spend substantially more on R&D than any other country. ” Furthermore, if the United States is able to borrow from other countries as they have borrowed from us, increased R&D spending in other nations could ***help*** U.S. competitiveness. In any event, figures on royalty and license payments continue to show the United States maintaining a large and growing surplus against other industrial nations; although technology gaps may be shrinking, the United States is still predominately a source of knowledge rather than a user of skills developed elsewhere.[12]

Other aspects of the U.S. environment for technology development, several discussed more thoroughly in subsequent chapters, do give cause for concern. As one example, this country has been lagging in the education of the technically trained people upon whom technological progress depends.[13] Japan, with half the population, now graduates more electrical engineers than the United States. And, far more than here, the people occupying leadership positions—whether in business or government—in Japan, West Germany, or France tend to have technical backgrounds, These signs suggest that other nations may be better placed to understand and exploit future technological opportunities.

Furthermore, the United States allocates as many as 25 percent of its best technical people to defense-related R&D and production, a higher percentage than most other countries except for the Soviet Union and its allies. While it is true that military research sometimes spills over into commercial products, with benefits for technological competitiveness—as happened with computers, aircraft, semiconductors, and nuclear power—it is also true that these are the exceptions, Certainly the fears expressed by Europeans in the “technology gap” debate of the 1960's proved exaggerated: U.S. spending for defense and space has by no means allowed American firms to continue dominating high-technology markets.

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[11] *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles,* op. cit., pp. 62-64, See also ch. 10 of the present report.

[12] *U.S. Industrial* Competitiveness: *A Comparison of Steel, Electronics, and Automobiles,* op. cit., pp. 64-65.

[13] Ch. 8; see also J. A. Alic, M, Caldwell, and R. R. Miller, ‘“1’he Role of Engineering Education in Industrial Competitiveness ” *Engineering Education,* January 1982, p. 269.

International Competition in Electronics

Evaluating Competitiveness

Assessing the competitiveness of the United States is more difficult in electronics than in most industrial sectors. This is partly a matter of the diversity of the industry; few parallels exist between the current situation in consumer electronics and that in computers. The importance of the technology and its rate of change means among other things that production costs—often the primary determinant of a nation's ability to compete—are less central. Certainly this is true compared to, say, agriculture or steel. But if cost is less critical in computer manufacture than for color TVs, it is never irrelevant—certainly not for firms trying to compete with IBM.

Manufacturing costs in electronics are closely tied to a firm's ability to utilize product as well as process developments. In most parts of the industry, the advantages of incorporating new *product* technologies as a means to lower costs—more generally of providing greater value per dollar—far outweigh those of simply manufacturing conventional designs more efficiently. Even in mature segments of the industry such as color TV, advances in microelectronics may lead to new product features or simpler and cheaper design approaches not feasible earlier.[14] Companies that fail to keep pace find their vulnerability heightened, particularly at the low-priced end of the market where import competition is stiffest.

Because of the changing technology, trends in the usual indicators of competitiveness—such as labor productivity (output per hour)—are either unavailable or of little relevance to electronics.[15] While chapter 9 examines productivity in electronics for insights into impacts on employment, output per man-hour or value-added per man-hour has less to tell about competitiveness. Today's TV set is a different product than those of 10 years ago. Labor productivity statistics ordinarily assume that goods remain qualitatively the same—a ton of steel, a bushel of wheat. The more their characteristics change over time, the less meaning productivity trends convey. The problem extends to many economic sectors, Even steel or wheat change; the physical properties of steel improve with better control of chemical composition and processing, the nutritional value of wheat increases as hybrid varieties are introduced, But the rates of change are slow compared to electronics.

Technological advance also means that many products selling in large volume today did not exist a few years ago—thus productivity gains cannot be calculated at all. How can productivity improvements be evaluated for integrated circuits (ICs) with a lifetime of 4 or 5 years from large-scale production to obsolescence? Can measures of productivity such as value-added or output per worker-hour for a 64K RAM manufactured in 1983 be compared to those for the 4K RAMs of 1975? What does labor productivity mean for pocket calculators—where this year's offering may be twice as powerful as last year's? Although manufacturing costs can be a vital ingredient in determining sales volumes for all these products, conventional approaches to international competitiveness must be applied with care.

Regardless of the pitfalls and uncertainties, policy guidance demands insights into whether the United States is gaining or losing ground. Electronics is a high-technology field par excellence, one in which this country has been a leader for decades, If U.S. competitiveness declines here, there is more to worry about than the shifting patterns of comparative advantage that affect textiles or even steel. The concerns extend beyond declining productivity growth, beyond the possibility of relative losses in per capita income; while these are far from trivial matters, it is fair to say that a loss of technical leadership in electronics would do much greater harm. The Nation's military security depends in many ways on electronics technology. Even more, decline would have dire implications for the future vitality of the entire economy. If the United States were displaced as the primary technical innovator in electronics it would be a symptom that this country was following Great Britain on the path to industrial decay,

But is this the case? Much that has been said on such matters is impressionistic and emotional—all the more reason to collect and evaluate the evidence with care. The remainder of this chapter examines the question of U.S. competitiveness in electronics primarily through examination of business strategies. While consumer electronics, semiconductors,

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[14] For example, digital rather than analog Circuitry for Processing incoming TV signals carries the potential for greatly reducing numbers of chassis parts, thereby cutting assembly costs. In addition, many of the adjustments needed during manufacturing could be eliminated. See T. Fischer, "Digital VLSI Breeds Next-Generation TV Receivers, " *Electronic.~*, Aug. 11, 1981, p. 97. Ch. 6 outlines reductions in parts counts in TV chassis over the past decade. These reductions have helped keep prices stable despite inflation.

[15] Comparative shifts in labor productivity over time are one of the more useful measures of changes in the competitiveness of a nation's industries, See U. *S. Industrial Competitiveness; A Comparison of Steel, Electronics, and Automobiles.* op. cit., ch. 4, especially pp. 54-58.

and computers are treated separately, some of the distinctions risk becoming artificial; semiconductor manufacturers, following their earlier attempts to enter consumer markets with products such as watches and calculators, are busy designing "systems on a chip" to help them move into markets for industrial end-products. Meanwhile, computer firms integrate backward to make ICs. Desktop computers sold at retail blur the line between consumer and original equipment markets. Are personal computers a product of the consumer electronics sector or the computer sector? The microcomputer market was developed first by entrepreneurial firms, later by companies like Tandy Corp.—largely consumer oriented. Now that Digital Equipment and IBM have entered, vastly different enterprises-in size, style, market power—are competing with one another. I B M's tactics, involving heavy reliance on outside suppliers (including imports of industrial robots from Japan to be controlled by the company's personal computer) mark a turning point for a firm that in the past has designed and produced virtually all its own hardware and software-evidence of the flux within this part of the industry.

While many industries go through periods of rapid expansion and change, evaluations of competitiveness are more problematic in the midst of such a process. The marketplace will eventually sort out the winners and losers in desktop computers, but no one can predict with much confidence which firms will survive and prosper, Because in the end a nation's international trade position is built on the successes and failures of individual business enterprises—the competitive tactics and strategies pursued, here and abroad—the remainder of the chapter discusses competitiveness from the strategic perspective. While such an approach does not result in direct indicators of competitiveness, it leads to an understanding of the dynamics of trade and competition not possible by other means.

International Business Strategies

Corporations compete on much more than product technologies and efficiency in manufacturing; success depends on effective approaches to markets, approaches that take account of a particular firm's strengths and weaknesses. As Texas Instruments' experiences with digital watches and small computers exemplify, state-of-the-art technology is no guarantee of ability to bring to market products that consumers will purchase.

The following pages review some of the moves and countermoves by participants in world markets for electronic products. That strategic considerations are vital comes as no surprise: explications of corporate strategy are a staple of the business press; they provide fodder for professors of business administration, handsome fees for management consulting firms, And for good reason. A not inconsequential part of U.S. economic growth can be traced to the ability of American firms to move rapidly into emerging markets, to commercialize evolving technologies—ability embodied in the managers, technical staffs, and other employees of these companies. The success record of American corporations extends to technologies originating in other countries. The technical underpinnings for digital computers have been fed by the efforts of engineers and scientists in many parts of the world. One aspect of the American genius has been turning arcane developments such as the computer into thriving commercial industries. The skills needed for success in the marketplace can be quite different from those called on in basic research. The British built the first jet transport plane, but are no longer much of a factor in the industry; today, the Comet is remembered chiefly for its lessons in metal fatigue.

Most privately funded R&D—in the United States as elsewhere—is directed toward product development. Marketing strategies based on product differential ion have a place even at the leading edge of microelectronics or computer technologies. Bell Laboratories devotes around 90 percent of its efforts to development, 10 percent to basic research (a considerably higher proportion of basic research than found in most electronics firms), That an R&D organization known best for its more fundamental work—including research that provided much of the foundation for solid-state electronics—in fact gives most of its attention to development points to the central importance of such activities. As the focus on development suggests, many of the "technology gaps" separating the United States from its competitors have been associated with product design rather than underlying differences in technical capability. The microprocessor was an innovation in the semiconductor design; it did not depend on new manufacturing technology, still less on improved understanding of the physics of electron devices,

More recently, American electronics firms have sometimes found themselves in reactive positions rather than leading in product and process developments, Innovation remains a source of U.S. competitive advantage, but other countries have become more active in introducing new products, as well as new manufacturing techniques. This has been one cause of slipping U.S. competitiveness in industries like steel and automobiles; while innovation in the electronics industry has certainly not stagnated, the U.S. lead is no longer unchallenged. Executives of American firms have repeatedly found themselves responding to competitive thrusts from foreign firms rather than taking the initiative. These thrusts have involved imaginative, well-researched, and well-designed products, In electronics, new competitive pressures have come most notably from the Japanese, but in some cases also from countries that are still industrializing.

Strategies in Consumer Electronics

More than in any other industry, Japanese companies have come to dominate world markets for consumer electronics, Beginning with portable radios, the Japanese moved successively into a broad range of other products: monochrome TV, high-fidelity sound systems, CB transceivers, pocket calculators, color TV, VCRs. Many of these were developed first in the United States. Video recorders are a telling example; Japanese firms make well over 90 percent of the world's VCRs—a product with origins in the laboratories of Ampex and RCA. The product development, manufacturing, and export strategies followed by Japanese firms in consumer electronics—discussed below in the context of the U.S. market, although applying with only minor variations to export thrusts into Europe as well—have often been transferred to other parts of the industry.[16] Thus, they are a logical starting point for an examination of business strategies in electronics,

Japan

Efforts by Japanese firms to sell TVs in the United States—beginning in the mid-1960's—included three parallel strands, First, the export drive began with a focus on market niches that appeared to be served inadequately or not at all by American manufacturers—the kind of opportunity that firms anywhere look for when attempting to enter new markets (app. C describes how Phase Linear, an American manufacturer of stereo components, created a new market category with its first product). The second strand in the Japanese thrust was to draw on product technologies and manufacturing experience gained in their highly competitive, if protected, home market—as well as in exporting to other Far Eastern nations; Japan's manufacturers had a strong foundation for selling in the United States. Third, TV shipments were part of a continuing effort by Japanese companies to export a succession of products of increasing technical sophistication. The strategy, while carried out by firms that competed among themselves, plainly was guided and encouraged by the Japanese Government through MITI (the Ministry of International Trade and Industry) and other agencies.

Success was by no means guaranteed. In the 1960's, the U.S. TV market was served by more than a dozen domestic entrants, These in-

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[16] See, for example, R. Ball, "The Japanese Juggernaut Lands in Europe," *Fortune, Nov.* 30, 1981, p. 108.

eluded some of the largest merchandisers and electrical equipment manufacturers in the country. Firms like RCA, Zenith, GE, Sylvania, and Magnavox had patiently constructed nationwide distribution networks. Their dealers generally handled servicing and repairs as well as sales. Much of the production of smaller companies consisted of private-label sets for retailers like Sears, K Mart, and J. C. Penney. Although the market was still expanding rapidly, its structure was relatively mature, Such a market is not an easy one to enter, especially from abroad.

The Japanese manufacturers recognized their disadvantages: 1) lack of an established distribution and service network; 2) lack of recognized brand names, a deficiency accentuated (at that time) by the lingering reputation of Japanese goods for shoddy quality. These factors argued against direct competition with entrenched industry leaders such as Zenith and RCA.

The Japanese sought ways around these barriers through both technical developments and marketing strategies. First of all, manufacturers in Japan moved quickly toward solid-state chassis designs, following their earlier successes in exporting transistorized portable radios. The intent was to lower manufacturing costs over the long run, and—perhaps more important—improve reliability and reduce the need for service (ch. **6).** Japanese TV manufacturers could not be certain of reaching either objective, American producers chose to stay with older technologies, partly in the belief that it was too early to expect improvements in either costs or performance from solid-state components.

The development of solid-state TV designs in Japan during the ***1960's*** illustrates the selective nature of government assistance. The Kansai Electronic Industry Development Center served as the coordinating body for a multiyear R&D project directed at using ICs in TV chassis, The cooperative effort, with funding from MITI, included five Japanese consumer electronics manufacturers, seven parts suppliers, four universities, and a pair of research institutes.[17] Despite this, perhaps the most important policy support came through TV broadcasting; Japan's Government has gone farther than most by actively promoting such new technologies as stereo sound for TVs, multiplexing to give multiple language capability, and direct satellite broadcasting. Such measures have fueled demand in the domestic market, helping build a base from which Japanese manufacturers could achieve scale economies and export.

The second leg of the Japanese plan centered on their selection of products. Here—as later the case in automobiles—the choice may have been more fortuitous than brilliant. The first Japanese exports were small-screen sets (ch. 4, especially table 9), where they had experience, and where solid-state designs contributed to light weight and portability. For a variety of reasons, the product lines of American firms were thin in this part of the market. The Japanese emphasis on small-screen TVs turned out to coincide with rising demand for second sets in American homes, demand that was more price elastic than for the first of a family's purchases.

Design improvements such as solid-state chassis helped Japanese exporters bypass traditional distribution channels. Greater reliability reduced the need for service and repair facilities, as well as for large stocks of spare parts, opening the way for distribution through outlets where low price would have immediate impact, Japanese exporters first sold their TVs through private-brand and discount retailers, a tactic that had worked earlier with portable radios.[18] As part of their marketing plans, it appears that exporting firms frequently induced retailers to carry their product lines by offer-

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[17] E. Sugata and T. Namekawa, "Integrated Circuits for Television Receivers," *IEEE Spectrum*, May 1969, p. 64. Three of Japan's largest TV manufacturers were included: Matsushita, Sanyo, and Mitsubishi.

[18] Toshiba began supplying Sears with small-screen color sets as early as 1964. This marked the beginning of Japan color TV exports to any country, and the beginning of U.S. imports of this product. See "International Technological Competitiveness. Television Receivers and Semiconductors, draft report under National Science Foundation Grant No. PRA 78-20301, Charles River Associates Inc., Boston, Mass., July 1979, p. 2-18.

ing higher than normal margins.[19] In essence, the Japanese tried to make TVs an "off-the-shelf" item. Note again that this strategy depended on producing TV sets with considerably greater reliability than had been common.

Instead of head-on competition with entrenched American producers, the Japanese thus located a market niche that was relatively open, and offered low-priced but well-designed TVs of high quality through price-sensitive retail outlets. Indeed, price was a dominant aspect of the Japanese thrust; dumping complaints brought by U.S. interests were repeatedly upheld, as discussed in chapter 11. Still, low prices by themselves were far from sufficient for the steady expansion of exports that followed this opening wedge. In a pattern now familiar, Japanese exporters widened both their product lines and distribution channels. Eventually, they began to assemble TVs in the United States. Japanese manufacturers now compete virtually across the board with American consumer electronics firms, utilizing many of the same retail outlets.

Some accounts have emphasized the dependence of Japanese pricing strategies on the closed nature of their home market. This was a central claim in the dumping proceeding initiated by the Electronic Industries Association in ***1968.*** In this view, low-priced Japanese exports were only possible in the early years because of trade protection that kept imports out of Japan; closing their domestic market to TVs produced by more advanced American and European firms allowed the Japanese to charge high prices at home, effectively subsidizing their exports. Investigations following the 1968 dumping complaint provided support for these allegations.

On the other hand, dumping in international markets implies monopolistic pricing by Japanese firms that, most observers concede, compete intensely within Japan. The implication, then, is that these companies colluded only with respect to exports—or that manipulation by higher authority, presumably MITI or some other agency of the Japanese Government, took place behind the scenes. Such possibilities cannot be rejected out of hand, but are not wholly consistent with the rest of this view: that Japanese TV manufacturers took advantage of their protected domestic market to generate the economies of scale needed to compete in the United States. From the perspective of highly competitive Japanese firms, price-led expansion at home might well have seemed a more attractive way to maximize learning and scale benefits.

The American Response

Exports to the United States by Japanese consumer electronics firms were by no means new. As early as 1954, Japanese companies had begun to manufacture transistors, with much of the output going into portable radios. Within 5 years, fully **80** percent of the radios produced in Japan were solid-state, many of them destined for sale in the United States.[20] In exporting radios, the Japanese gained valuable experience that could be brought to bear on the more lucrative TV market.

As a consequence of the Japanese emphasis on small-screen TVs-and also because of the market focus of American producers—most imports have been lower priced models, as shown by the consistently lower percentages in the value column of table **44.** Conversely, American manufacturers have continued to concentrate on higher priced, more profitable sets—large screen and console models. While imports have moved up-scale over the years, they still account for a considerably smaller proportion of the market in dollar terms than in units. Now that many Japanese companies assemble TVs here, more of the imports come from Taiwan and South Korea. Firms in those countries have followed Japan's lead in emphasizing low-priced, small-screen sets.

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[19] L. Landro, "Technology, Competition Cut Price of Electronics Gear as Quality Rises, " *Wall Street Journal* Dec. 1, 1981, p. 37.

"J" The U.S. Consumer Electronics Industry and Foreign Competition, Executive Summary," final report under EDA grant No 06-26-07002-10, Department of Commerce, Economic Development Administration, May 1980, pp. 46-47.

Table 44.—imports of Color Televisions as a Percentage of Total U.S. Sales

	Imports as a percentage of unit sales	Imports as a percentage of value of sales
1968	11 .0 ”/0	5.1 “/0
1970	17.0	8.4
1972	14,9	8.3
1974	16.0	9.6
1976	35.9	18.9
1978,	26.4	15.7
1980	11.3	7.4
1982	19.1	12,8

SOURCES ***1968-72***—"The U S Consumer Electronics Industry and Foreign Competition," final report under EDA grant No OE-26-O7OO2-1O, Depart. ment of Commerce, Economic Development Administration, May 1980, pp A-75, A-76
1974-82—*Electronic Market Data Book 1983* (Washington, D C Electronic Industries Association, 1983), pp 15 and 31

Table 44 also points to the reactive strategies of the major American TV makers; when confronted with low-priced import competition, U.S. producers essentially ceded that portion of the market.[21] Part of the reason was simply that, even in the absence of imports, profits would have been lower on small-screen sets. Given expanding markets, the strategies pursued by American firms enabled them to utilize their production facilities in optimal fashion, at least in the shorter run. With the portable radio experience in the background, U.S. manufacturers must have been well aware that concessions at the lower end of the TV market would give the Japanese a foothold—making for stiffer competition in later years across the rest of their product lines, Viable counterstrategies needed to be developed—and were. At present, the major U.S. manufacturers have strong product offerings in all parts of the market, small sets as well as large.

Domestic firms found themselves in different situations as a result of import competition, and reacted in different ways. The major producers, RCA and Zenith, each held between 20 and 30 percent of the market in terms of unit sales, higher in value terms, at the end of the 1960's. Through the 1970's—and today—each has retained a market share in the vicinity of 20 percent (ch. 4, table 10; RCA's market share dipped below 20 percent once, in 1975); brand recognition and strong distribution networks, combined with an emphasis on larger sets, lessened their vulnerability to imports. Both Zenith and RCA automated some of their facilities to hold down costs, and moved other production overseas. Firms with smaller market shares, on the other hand—especially those that depended heavily on private label sales–quickly felt the impact of Far Eastern competition. For several, lower production scales—and higher manufacturing costs—combined with foreign competition to move their operations into the loss column. Companies like Philco, Admiral, Warwick—most recently Sylvania—left the market.

Prominent in competitive responses by the U.S. industry were efforts to persuade the Federal Government that Japanese imports were entering via unfair trade practices. While companies like RCA and GE that get substantial revenues from overseas sources have taken a

Photo *credit* ***RCA***

Color TV assembly

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[21] The *U.S.* Consumer *Electronics Industry* (Washington, II. C.: Department of Commerce, September 1975), p. 1 I.

"free trade" stance, others, whose orientation has been primarily domestic, have been vigorous in pursuing trade remedies over many years. The intent has been to raise import prices through antidumping penalties or countervailing duties. Chapter 11 outlines the sequence of events; briefly, collection of additional duties imposed on TVs from Japan was delayed for years by a series of interdepartmental disputes within the Government. Petitions seeking adjustment assistance under the Trade Expansion Act of 1962 were denied in 1973, as were parallel efforts to have countervailing duties assessed on Japanese TVs. Attempts by American interests—labor unions and suppliers were active along with domestic manufacturers—continued in one form or another from the late 1960's on through the 1970's, indeed are still underway. But from the viewpoint of U.S. producers, these efforts to stimulate Government action that would raise import prices were less than successful, Even so, the constant stream of claims that competitive tactics by Japanese firms were both unfair and damaging had considerable political impact: a reluctant administration was forced in 1977 to take action. The results were the import quotas termed Orderly Marketing Agreements (OMAs) mentioned in the previous chapter. The initial OMA with Japan was followed in 1979 by agreements with South Korea and Taiwan.

A second response by domestic firms was technological. Far Eastern competition forced U.S. TV makers to move into solid-state designs both to lower costs and to improve reliability. But these efforts came too late for many American manufacturers. Japanese exporters had achieved the volume required for economies of scale, and could continue to drive prices downward. By 1971, Matsushita was the biggest manufacturer of TVs in the world, and 5 of the top 10 firms were Japanese (ch. 4). These companies were expanding worldwide, while the efforts of even the strongest U.S. firms were largely restricted to their home market. Meanwhile, American consumers were choosing small-screen TVs—where imports were strongest—in ever-larger numbers. Table-model and portable sets went from 12 percent of U.S. color TV sales in 1965 to 68 percent in 1974.[22] Those American suppliers that remained economically viable did so in part by improving labor productivity at relatively high rates; they also transferred many of their more labor-intensive manufacturing operations overseas.

The U.S. response was, therefore, mixed. On the one hand, American firms sought trade protection—a reaction not untypical of businesses experiencing foreign competition in lucrative domestic markets, particularly when they find themselves in this situation for the first time. On the other hand, a number of U.S. manufacturers successfully reduced costs, enhanced quality, and managed to keep most if not all of their traditional market share; RCA and Zenith together still account for some 40 percent of U.S. color TV sales, But the majority of American companies were unable to keep pace in the newly competitive environment.

Foreign Markets

U.S. and Japanese consumer electronics firms have approached markets in third countries quite differently. Companies like RCA have sold technology overseas—most recently, RCA has licensed its new video disk technology in Europe—but have seldom embarked on major efforts to market consumer products elsewhere, The exception is ITT—an American-owned firm which is one of Europe's larger producers of color TVs but does not manufacture consumer products in the United States. In contrast, Japanese manufacturers have exported products as well as technology; in recent years they have also invested extensively in industrialized as well as developing countries.

In Western Europe—which offers a market for color TVs about the size of that in the

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[22] *Electronic Market Data Book 1975* (Washington, D. C.: Electronic Industries Association, 1975).

United States—Japanese firms have made significant inroads. For many years, trade barriers and patent protection helped European producers fend off imports (ch. 4). Now many of the barriers are weakening. Nearly half the high-fidelity equipment sold in Germany is already imported from plants in the Far East.[23] The Japanese share of the West German color TV market more than doubled from 1979 to 1981, reaching an estimated 15 percent. Color TVs are made in the United Kingdom by five of the major Japanese manufacturers; a substantial fraction of the output is shipped to other European nations. One-third of the picture tubes used in TV sets manufactured in Europe are imported from Japan; few if any of the 10 remaining factories making picture tubes in Western Europe are profitable. Japanese eports of VCRs to European countries more than doubled in 1981, and doubled again —to nearly 5 million--in 1982; threatened with dumping complaints, Japan recently agreed to limit VCR shipments to the European Community.

Japan's entry into the European TV market has been remarkably similar to that here. As the PAL licensing agreements continue to expire, the Japanese will broaden their product ranges; they are now beginning to compete in the upper reaches of the European market. One response by local firms has been to move toward Tv broadcasting accompanied by stereo sound. Through a new round of restrictive licensing practices, European companies hope to keep the Japanese out of new high-end products.

Japan's electronics firms have also been active in the Far East, where the U. S. presence is limited to offshore production. Still, as Asia has developed economically, the advantages of Japanese manufacturers have diminished. Markets are expanding in Taiwan, South Korea, Singapore, and Malaysia—with local industries aiming both to export and to supply rising domestic demand. While it is no surprise to find Japanese firms with a greater presence in Asia, one might expect the situation to be reversed in Latin America. But here too, many of Japan's TV makers have established subsidiaries, joint ventures, and licensing agreements—in addition to their export activities. The U.S. presence, except for assembly plants in Mexico that ship back across the border, appears limited to scattered licensing arrangements.[24]

Japanese consumer electronics firms have taken a long-term approach to the development of world markets. They have been willing to adapt their strategies to the constraints imposed by foreign governments, and to local laws and regulations. Where governments have limited imports, they have invested. Where investment is restricted, they enter into joint ventures. As one example, Toshiba commissioned a Costa Rican company to make Toshiba-brand TVs in 1971, several years before color broadcasting began in that country. Later, Toshiba purchased part of the local firm, establishing a joint venture for manufacturing a broader line of their consumer electronic products. In pursuing such activities, Japanese firms have taken significant risks. They have invested in economically depressed regions, in countries where the initial markets for their products have been small, and in regions of questionable political stability. In their early years, many of these operations probably lost money. Now, Japanese companies are firmly established in such countries, and appear well positioned to take advantage of growing demand in nations ranging from the Arab states to the People's Republic of China. If American firms were, at this late date, to try to emulate the Japanese strategy and compete on a global scale, they

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[23] J. Gosch, "German Consumer Firms Face Bad Times," *Electronics*, Sept. 11, 1980, p. 97. Also see "Philips—An Electronics Giant Rearms To Fight Japan," *Business Week*, Mar. 30, 1981, p. 86. For Europe as a whole, three-quarters of all high-fidelity equipment is imported. On TVs and VCRs, below, see J. M. Geddes, "West German TV Producers Plan Stereo Sets," *Wall Street Journal*, June 24, 1981, p. 34; J. Tagliabue, "Europeans Battle Japanese TV Tubes," *New York Times*, Feb. 10, 1982, p. D4; A. Sato, "Japanese VTR Output, Exports Soared in 1981," *Asian Wall Street Journal Weekly*, Feb. 22, 1982; E. J. Dionne Jr., "Japan Video Accord Leaves Europeans Wary But Hopeful," *New York Times*, Feb. 22, 1983, p. D5.

[24] "Sources of Japan's Competitiveness in the Consumer Electronics Industry: An Examination of Selected Issues," prepared for OTA by Developing World Industry and Technology, Inc. under contract No. 033-0110.0, p. 130.

would face a formidable task in overcoming the head starts of their rivals,

Other Consumer Electronic Products

Not only home entertainment goods like VCRs, but pocket calculators, electronic watches, and CB radios are now produced mostly in the Far East. The older, established consumer electronic firms in the United States—those that have made radios, TVs, audio equipment—seldom participate in these markets. More often, the American entrants have been small specialty manufacturers, semiconductor firms, or suppliers such as Tandy, which sells under the Radio Shack name. U.S. electronics companies with little prior experience in the consumer arena attempting to diversify have, not surprisingly, sometimes misjudged demand, introduced products that proved to have little appeal to customers, or failed to establish adequate distribution channels. Among the semiconductor firms, even the most successful—e.g., Texas Instruments—have had a difficult time learning to develop and market consumer products.[25] profits have not always been high enough to convince U.S. entrants to persevere, particularly where foreign firms with low production costs were already well established.

What then of the future? Will American firms attempt to develop new strategies for marketing future generations of consumer products? How will their approaches contrast with those of manufacturers in other parts of the world? Some of the trends can be discerned, at least as they relate to product developments. Bottom-end pocket calculators will offer more features as sophisticated models evolve into handheld computers. Watches may incorporate games, calculators, perhaps even radios. Speech synthesis—and later voice recognition—will appear, enabling TVs, for example, to switch channels in response to spoken commands, Integrated home entertainment systems combining TV reception, video tape and/or disk players, and computing capability will be developed, with component TV one of the first steps,

To a considerable extent, the future of the U.S. consumer electronics industry will depend on its ability to keep up in such products, How successful will American manufacturers be? On the one hand, new product offerings like the RCA video disk system are favorable signs. Although thus far something of a disappointment in the marketplace, RCA's investment in the video disk demonstrates that U.S. Consumer electronics firms are still willing to take risks. Zenith's venture into personal computers is another indication that American suppliers are not ceding their home market to foreign producers; so are the efforts of smaller companies marketing electronic games, projection TVs, and innovative audio products. At the same time, the failure of U.S. companies to participate in the manufacture of VCRs will make it more difficult for them to regain product leadership.

With U.S. sales of VCRs growing rapidly, the approaches of Japanese and American firms now stand in stark contrast. Broadcast videotape recorders were introduced by Ampex in 1956, with RCA following in 1959; at least eight Japanese firms–starting with these U.S.-developed technologies—pursued consumer versions during the 1960's, with various degrees of resource commitment and success.[26] None of the American consumer electronics firms followed suit, although some made attempts later on. Sony's Betamax, which opened the market, was in fact a fourth-generation machine—the result of many years of persistent and often-disappointing efforts, The other major VCR system—developed by Matsushita (a third, built by Philips, has only a small share of the market)—was also the result of years of engineering, and a number of false starts. U.S. firms were unable or unwilling to match these

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[25] See, for example, B, Uttal, "Texas Instruments Wrestles With the Consumer Market, " *Fortune,* Dec. 3, *1979, p. 50,*

[26] See W. J. Abernathy and R. S, Rosenbloom, "The Institutional Climate for Innovation in Industry: The Role of Management Attitudes and Practices, " *The 5- Year Outlook for Science and Technology 1981: Source Materials,Volume 2* (Washington, D, C.: National Science Foundation, NSF 81-42, 1981), pp. 411-416, for a fascinating case study of the commercialization of consumer VCRs,

development programs, and now have chosen to sell Japanese VCRS under their own brand names.

The point is that, once having lost product leadership-as has occurred with VCRs–American firms will find it increasingly difficult to compete in new technologies, and may eventually find themselves importing or adapting other products as well. Because U.S. manufacturers cannot expect cost advantages, they may be left with only their distribution systems and brand recognition as prime competitive weapons. To a considerable extent, Japanese firms have already countered these advantages; thus, the long-term prospects for American firms in consumer electronics do not appear bright.

Semiconductors

Technological forces have dictated the marketing strategies of semiconductor companies in all parts of the world since the inception of the industry. The case study on 4K RAMs in appenalix C points to the importance of engineering capability for U.S. merchant firms such as Mostek or Intel, Technology is no less important now than a decade ago, when the 4K RAM was being developed-but as late as the mid-1970's the business strategies of foreign semiconductor manufacturers were of little interest to Americans. As the 4K RAM case demonstrates, U.S. firms appeared to have little to fear from producers in Japan--certainly not from those in Western Europe, But from a minor position in 4K chips, Japanese firms went on to claim about 40 percent of the world market for the following generation of 16K RAMs. By 1982, the perception was widespread that U.S. firms had "lost" the market for dynamic RAMs. Certainly this is an overdramatization, and the RAM market can by no means stand for the industry in microcosm; but the picture has changed. How did it change so fast?

During the 1970's, Japanese companies exported considerable numbers of electronic components--including transistors—to this country, but the major growth segment, ICs, was dominated by American suppliers. Even though Japan's Government protected the local industry, U.S. shipments took a substantial part of the expanding Japanese IC market. Customers in Japan depended on American firms for devices that domestic manufacturers could not provide—high performance or large-scale chips, custom parts, even some types of linear circuits needed for consumer products. As the technological level of Japan's semiconductor industry caught up with that of the United States, many of these imports were replaced by indigenous production. The phenomenon, termed import displacement, has been characteristic of Japan's computer industry as well. Displaced items quickly become potential exports for Japanese firms.

During the **1970's,** awareness of the possible consequences of foreign competition grew within U.S. industry and Government, although the production and trade data showed little cause for concern. The Federal Trade Commission, reporting on interviews conducted in 1976, stated: ". . . a number of company executives expressed the opinion that competition from foreign companies would be much tougher to handle than competition from other U.S. companies in the next 5 or 10 years. In contrast, some other executives felt that U.S. companies would not have a difficult time maintaining their technological lead over foreign companies."[27] Hindsight shows those of the first persuasion closer to the mark.

One sign that patterns of international competition would change came from subsidies and promotional efforts adopted by foreign governments with the aim of fostering indigenous production. Japan, France, West Germany, the United Kingdom—all in one way or another marked the semiconductor industry as critical to continued economic vitality, an in-

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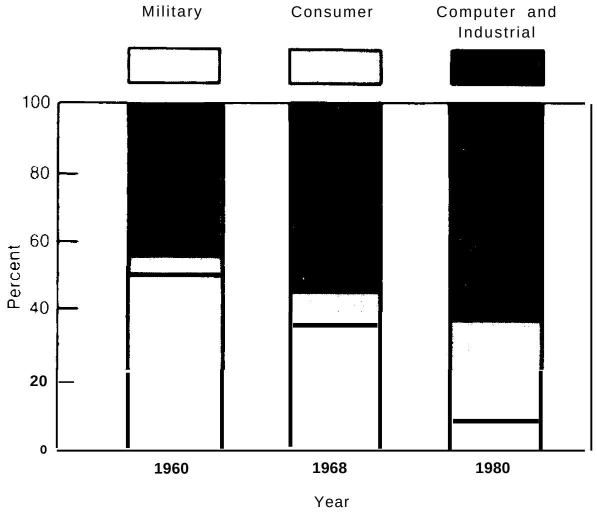
[27] *Staff Report on the Semiconductor Industry: A Survey of Structure. Conduct and Performance* (Washington, D. C.: Federal Trade Commission, Bureau of Economics, January 1977), p. 130.

dustry not to be given over to foreign interests. Since the United States was far ahead in both technological expertise and production volume, the implicit targets were American companies, not excluding those that had invested in local production facilities. These government-led attempts to build competitive semiconductor industries have had mixed results. Joint projects involving public and private sectors in Japan were quite successful—in semiconductors as in earlier Japanese industrial policy initiatives. European attempts have been far less fruitful, for reasons that may have as much to do with the characteristics of the industry and marketplace on the continent as with the policies pursued.

Figure 34.— Distribution of U.S. Semiconductor Sales by End Market



SOURCES 1960, 1968 Innovation, Competition, and Governmental Policy in The Semiconductor Industry Charles River Associates, Inc final report for Experimental Technology Incentives Program, Department of Commerce March 1980, p 213
1980 *Status 80 A Report on the Integrated Circuit Industry* (Scottsdale, Ariz Integrated Circuit Engineering Corp , 1980) p 34

United States

Applications of semiconductors reflect ongoing synergistic relationships among merchant suppliers and their customers. Purchasers outside electronics have lately presented growing market opportunities—e.g., in automobiles. Nonetheless, from a technological viewpoint, firms building computer- or microprocessor-based systems remain the most influential customers (fig. 34). Manufacturers of consumer electronics, communications systems, instruments and controls, and office equipment have considerable impact as well. While most of the attention below goes to merchant firms, captive operations have played a vital role in the technological development of the U.S. industry. Furthermore, production decisions by the larger integrated manufacturers sometimes have major consequences for the merchant market,

Figure 34 shows that the phenomenal expansion in semiconductor output during the 1970's was accompanied by a major shift from defense purchases to consumer and industrial applications; competitive success in the most rapidly growing market segments depended on the ability to make the transition from specialized military requirements to the demands of private sector customers. Some companies that fared quite well in the military market could not compete effectively for commercial sales, where the needs of customers are more diverse, and nontechnical dimensions like price and delivery schedules more important.

Factors in Strategic Decisions

Competitive strategies adopted by merchant semiconductor firms revolve around factors such as size, market power and technological capability, internal need for devices (if any), and stage of development relative to others in the industry. A company's technical strengths shape its product line, Process technology—whether a manufacturer is strong in bipolar or MOS (metal-oxide semiconductor), which varieties of MOS a firm knows best—is one aspect, design capability another. Some companies are known for innovative circuit designs, others for prowess at mass production—some for both. Smaller entrants tend to specialize; only a few merchant suppliers have broad product lines (the world's semiconductor manufacturers supply perhaps 50 billion devices a year—of 100,000 different types—to several hundred thousand customers).

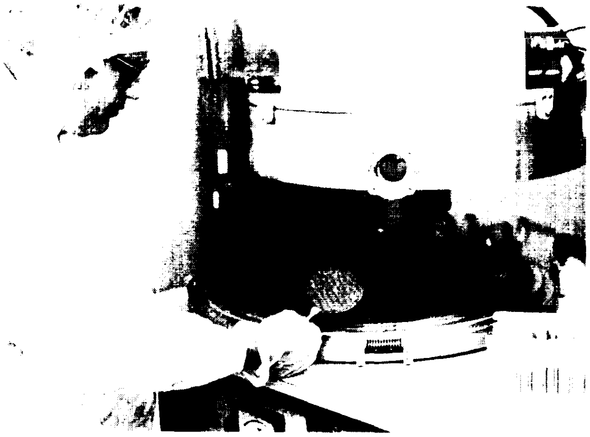


Photo credit Western Electric Co

Technician loading plasma reactor with semiconductor wafers

A number of U.S. merchant manufacturers have integrated to some extent into systems. A few, such as Texas Instruments, have always been diversified. Others have been purchased by larger enterprises but still sell the great bulk of their production on the open market (ch. 4, table 24). As merchant suppliers expand, so does the range of their product offerings, Smaller companies with limited resources aim at niche markets, Newer entrants set out to develop specialized or custom devices of less interest to larger corporations; the 1981 startup Linear Technology—a spinoff from National Semiconductor—specializes in linear ICs, in which the founders have expertise.

Captive semiconductor producers have different strategic aims. While most of the larger computer firms make some of their own logic chips, IBM has traditionally produced most of its memory circuits as well. The company consumes so many that, for products such as RAMs, on occasions when it chooses to purchase from outside vendors it can account for a sizable proportion of total demand (the company is probably the largest single purchaser in the merchant market, as well as the world's largest producer of semiconductors). This then affects the business decisions of merchant suppliers: IBM's external purchases were a powerful and rather unpredictable force on the market for 16K RAMs at the close of the 1970's, the company's unexpected entry contributing to shortages of these devices. Capacity shortfalls by American firms—primarily stemming from failures to invest in additional production facilities in the wake of the recession of 1974-75 —left an open door for Japanese IC suppliers to sell in this country.

Captive manufacturers contribute in a major way to the overall strength of the U.S. position in microelectronics through their R&D activities; in particular, IBM and AT&T's Bell Laboratories have been responsible for much of the basic research underlying the semiconductor industry in this country, indeed around the world. Merchant firms—because of the pace and intensity of product development, the continuing cycles of improvement in design and production that characterize succeeding generations of ICs—must set different priorities; they also have more limited resources for R&D.

Technological Factors

A company introducing a new device must assume that even if their design is at the forefront of the state of the art it will be superseded later if not sooner. Timing is critical; technological windows sometimes open, providing opportunities for leapfrogging the competition. Companies that quickly mastered production of dynamic RAMs, or concentrated on microprocessor design architectures in attempts to tie up large portions of that market, were aiming at such advantages, Needless to say, some firms have better records at exploiting these opportunities than others. A number of companies that had been strong in bipolar technology–including Fairchild and Texas Instruments—did not move as rapidly into MOS as the competition; Texas Instruments staged a quick recovery, while Fairchild has continued to lag. Mostek, as its name connotes, was founded with the intention of specializing in MOS; the company has emphasized memories, designing their own RAMs—the de facto industry standard 4K RAM was a Mostek design (see app. C)—while serving as an alternate source for microprocessors. Electronic

Arrays, now owned by Nippon Electric, had specialized in read-only memories (ROMs). Other firms seeking to exploit particular technological paths have had less success: American Microsystems' work on v-MOS ICs is one example, RCA's pursuit of silicon-on-sapphire c-MOS another. Internationally, Japanese firms moved into MOS ICs much more rapidly than the Europeans, most of whom are still well behind their competitors in the United States or Japan and relying on technology imports to try to catch up; this has been one of the objectives of Le Plan des Composants—a major industrial policy effort by the French Government (ch. 10). In the United States, some firms —Signetics, Monolithic Memories—continue to specialize in bipolar devices. IBM likewise remains relatively stronger in bipolar than MOS; the speed advantages of bipolar circuits have led many computer manufacturers to continue emphasizing the older technology.

Quality and reliability comprise another competitive realm where strategies depend both on circuit design and manufacturing practices (ch. 6). While Japanese firms have zealously publicized the quality and reliability of their ICs —in much the same way that Japanese consumer electronics firms used reliability as a wedge into the American TV market—domestic producers like Advanced Micro Devices have also pursued an image of quality and reliability as a marketing tool.

Products and Prices

One of the attractions of memory circuits—in addition to the vast market—is the relatively orderly and predictable progress of the technology itself; circuit design is vital—along with excellent process capability—but more straightforward than for logic or microprocessors. Everyone in the industry knows that the next generations of dynamic RAMs will be 256K chips, followed by 1 megabit; circuits offered by various firms are much more similar than the designs of competing 16-bit microprocessors, One result is the fierce price competition that has often seemed the dominant characteristic of the memory market. Progress in static RAMs, and in the various types of ROMs, is likewise rather easy to predict. Under such circumstances, Japanese suppliers quite naturally emphasize memory products.

In contrast, market acceptance of logic circuits or microprocessors is less predictable. Investing in a new microprocessor design—the 32-bit Intel iAPX 432 cost more than $100 million to develop—is risky, but the potential rewards are great; designs with an edge over the competition—in performance, ease of programing, adaptability to a wide range of applications—sell for premium prices.[28] Furthermore, microprocessors—best thought of as families of related ICs rather than unique devices—have longer product cycles, extending the period over which investments can be recouped. Memory circuits are manufactured as long as demand holds up, but sales tend to peak and decline more rapidly than for other device types. Five or six years elapsed between the onset of high-volume production for 8-bit microprocessors and mass production of the succeeding generation of 16-bit parts, while lifecycles for RAM chips—though slowly lengthening—have been perhaps 3 years, sometimes less.[29]

Abbreviated product cycles dictate strategies aimed at profitability within a narrow time window, along with continuous efforts to develop new or differentiated offerings. The latter can be original designs but need not; second-sourcing has been widespread for many years, in part because customers often insist on more than one supplier before they will design an IC into their end products. Thus, second-sourcing can accelerate market expansion for everyone, Semiconductor firms choose to become alternate sources for chips developed

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[28] On the costs of microprocessor design, see R. N. Noyce and M. E. Hoff, Jr., "A History of Microprocessor Development at Intel, " *IEEE MICRO,* February 1981, p. 8. Intel's first microprocessor, a 4-bit device, was designed in 9 months by a single engineer; 100 man-years went into the iAPX 432.

[29] Intel's 8080 family—introduced in 1974 and the largest selling 8-bit microprocessor—will no doubt remain in production for many more years, Worldwide, more than 10 companies still produce 8080 chips. Mostek—an alternate source for another popular 8-bit processor, the Z-80—for a number of years produced more of these devices than Zilog, the originator. See "The Antenna, " *Electronic News,* Mar. 12, 1979, p, 8; "Eight-Bit Level," *Electronic News,* July 5, 1982, p. 12.

by other companies to beef up their own product lines, perhaps by complementing circuits they already build, as well as to reduce market risks and save on R&D expenses. From the viewpoint of the originator, it may be more sensible to settle for a smaller piece of a rapidly expanding market than to try to keep others from duplicating an IC design. Attempts to prevent duplication are virtually impossible if a circuit finds an enthusiastic reception in the marketplace. As one consequence, formalized alternate sourcing agreements have largely replaced the copying that was once commonplace. Sometimes alternate source manufacturers acquire the originator's technology —e.g., mask sets for lithography. Other times only drawings or specifications are provided. The recent agreement between National Semiconductor and Fairchild, the latter acquiring the right to build National's model 16000 microprocessor in exchange for developing a complementary line of peripheral chips, is an increasingly popular route.

Cost reductions via the learning curve (ch. 3, fig. 5) help shape competitive strategies, As production volumes increase, yields rise and manufacturing costs drop. Pricing decisions have often been based on projections of expected cost reductions into the future, For a firm early to market with a new design, cost advantages over potential rivals can build rapidly, increasing with leadtime. Firms that are late to market face a dilemma; they may have to choose between foregoing participation or pressing on with their own design in the hope that it too will win acceptance, In early 1982, with six Japanese entrants mass-producing 64K RAMs, versus only two American manufacturers, a number of U.S. firms were confronted with such decisions; Advanced Micro Devices, for one, decided not to build a 64K chip,

In different circumstances, then, firms assume different strategic postures. Companies entering the market with a new device, particularly one incorporating proprietary technology—product or process—may have several advantages over competitors that follow. An early entrant will normally try to remain ahead on the learning curve, keeping production costs below those of its rivals, margins above. Companies with proprietary designs often license alternate sources, but at least at the outset second-source suppliers will be at a cost disadvantage. If the initiator decides to follow a pricing strategy keyed to anticipated cost improvements, follow-on firms may find it difficult to make a profit. Texas Instruments, for instance, has had the reputation of practicing advance pricing whenever possible, In a very real sense, then, later entrants can be at the mercy of innovators should the latter choose to cut prices and exercise the cost advantages of being farther down the learning curve. On the other hand, an innovating firm might choose to increase margins by holding price levels high. Under such circumstances, an alternate source may itself be able to carve out a place through price. One facet of Intel's corporate strategy has been to choose products where it could enter the market first, reap high profits, then move on—leaving later sales, at lower margins, to others, Nonetheless, in many cases, especially where the innovating company is small, lining up an established supplier as a second source may be a prerequisite to sales in any volume.

A further strategic choice, increasingly critical for American firms, is whether to design and produce commodity-like chips or to concentrate on custom or semicustom devices, The first option entails high-volume production of ICs that are, or may become, shelf items—standard circuits serving the needs of customers who design them into end products, The alternative, customizing, can be accomplished in a variety of ways; semicustom chips such as gate arrays or programmable logic arrays are specialized only at the last stage of processing. Regardless of the technological approach, firms in the custom or semicustom business create specialized ICs meeting the needs of one or a few, rather than many, purchasers. Because circuit design is expensive, prospective order quantities must be large enough to cover engineering costs; alternatively, the buyer must be willing to pay a higher price, Custom chips for automotive applications are an example of the high-volume case, military systems of custom chip markets where production volumes tend to be small. Occasionally, end users design their own ICs and contract out production.

At the center of competitive strategies in semiconductors—as for many industries—then lies the choice of products. Firms with broad product lines may offer devices based on a variety of technologies while attempting to stay at the technical frontier with only some of these. Others—such as Mostek in the mid-1970's—operate within narrower boundaries where they attempt to be leaders. Some entrants are content to follow the obvious trends, offering unique designs infrequently while relying on other strengths—perhaps low prices or a reputation for quality—to attract customers, In its early years, Advanced Micro Devices took such an approach (see app. C).

Beyond these common themes, mostly hinging on aspects of the technology, companies plan their strategies according to the strengths and weaknesses they perceive in their own positions compared to those of their rivals. No single company has the resources to manufacture and sell all the tens of thousands of semiconductor products now marketed in the United States—one of the reasons for the periodic emergence of startups, Extensive product lines can confer advantages where customers prefer to deal with only a few vendors; broad-line manufacturers may also be able to achieve economies by spreading marketing costs over many items. Nonetheless, such factors are secondary compared to choice of product and process technology, along with a variety of ingredients that could be labeled "entrepreneurship.' Successful new companies have frequently been established to exploit a particular product, often one that larger companies have failed to pursue—perhaps because of limited resources, or simply a judgment that the potential market was too small,

No matter the decisions they themselves take, managers of semiconductor firms can be certain of two features of their market: 1) competition will eventually drive prices downward (it has been extremely difficult to capture significant monopolistic profits from new technologies), and 2) just as inevitably the pace of technical advance will render new product offerings obsolete within a few years at most. The price history of the 64K RAM illustrates the first point: offered in sample quantities at $100 each in 1979, and $20 to $30 during 1980, prices dropped to the $10 to $15 range in early 1981 and $5 to $7 a year later; during 1981, 16K RAM prices were driven down from $4 to about $1, largely as a result of price declines for 64K parts.[30] Such pricing trends have meant that all firms, U.S. and foreign, have had to work continuously at cost reduction, In contrast to numerous other industries, passive or reactive pricing policies are hardly possible; although product differentiation is a viable alternative under some circumstances, price competition in semiconductors is a constant force–enough by itself to set this industry off from many others. The second market characteristic, rapid technological change, has forced managers and technical personnel alike to adapt constantly; firms that have remained wedded to older technologies have faltered or disappeared from the marketplace,

International Dimensions

From an international perspective, the larger U.S. merchant firms have shared three major strategic thrusts: 1) offshore manufacturing to reduce labor costs, 2) foreign investment to serve overseas markets, and 3) attempts to do business in Japan. This last effort–on which a number of companies are just embarking, or reembarking after past rebuffs—may prove critical to the continuing ability of U.S. merchant firms to compete with large, integrated Japanese manufacturers, particularly in commodity products like memory.

Offshore manufacturing investments have been concentrated in developing Asian nations, Generally, the more labor-intensive assembly operations—e.g., wire bonding and encapsulation—have been moved. In the semi-

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[30] A, Alper, "Buyers Hedging on Long-Term 64K Pacts Until U.S. Firms Ramp Up, " *Electronic News,* Feb. 8, 1982, p. 1; C. H. Farnsworth, "Japanese Chip Sales Studied, " New *York Times,* Mar. 4, 1982, p. D1. Prices for 64K chips eventually fell to lows of about $3 during the 1982 slump.

conductor industry, the stimulus for these transfers has not been import competition, as in consumer electronics, but domestic rivalry. Transfers offshore began in the early 1960's, long before Japan appeared a significant threat in semiconductor production. By 1970, American companies operated more than 30 subsidiaries in such locales as Hong Kong, Singapore, Malaysia, the Philippines, and Mexico.[31] Relocating labor-intensive production operations has been especially attractive because transportation costs are low; chips are often shipped by air. A cost comparison illustrating the advantages of offshore assembly is included in appendix B (table B-2).

A second international involvement of U.S. semiconductor companies has been point-of-sale production to serve developed country markets, Investments in point-of-sale plants began about the same time as offshore assembly, but from the standpoint of industry strategy the motives were quite different. These have been twofold, First, foreign governments have often taken steps to make local production attractive, or, conversely, to make exporting from the United States onerous. European countries, in particular, have relied on incentives combined with tariff and nontariff barriers to attract U.S. high-technology investments. Second, point-of-sale production can become a competitive necessity to the extent that other firms have already made such moves.

Efforts to establish sales, production, and/or R&D facilities in Japan—now a bigger market than all of Europe—comprise the most recent overseas thrust by American firms. While Texas Instruments had been able to establish a wholly owned subsidiary in Japan, other American firms were kept out until recently. Semiconductor manufacturers attempting to invest in Japan suffered much the same fate as other U.S. companies; the Japanese Government, through the Foreign Investment Council, MITI, and other agencies, controlled inward investment flows and for the most part prevented the establishment of manufacturing facilities under foreign ownership.[32] Joint ventures in which a Japanese company held the majority interest met a more favorable response. The purpose was obvious: to provide shelter for Japanese companies which at the time were well behind in semiconductor technology. MITI believed—with good reason, if the European case is indicative—that allowing American firms to produce in Japan would stifle the domestic industry, particularly when it came to more advanced device types. In acting this way, the Japanese Government was behaving much like others that have sought to protect infant industries, but Japan has often been accused of maintaining protectionist measures long past the point at which her industries have been able to fend for themselves,

In any event, as a consequence of protectionism in Japan, American suppliers were forced to adopt business tactics different from those pursued on the continent. Most responded to MITI's entreaties and entered into licensing agreements with Japanese producers.[33] Such steps were entirely rational, provided the U.S. firm could be reasonably certain the technologies transferred would not find their way into products they would face at home or in third-country markets. With this proviso, it would pay to sell technical knowledge, the proceeds from which could then at least partially offset the costs of generating that knowledge, The outcomes of licensing agreements with Japanese firms have led to many second thoughts within the American industry. Nonetheless, clear-cut cases in which U.S. technology was an irreplaceable ingredient in the growing capability of Japanese semiconductor manufacturers are rare, particularly in later years—the exceptions being perhaps developments flowing from Bell Laboratories.

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[31] W F. Finan, "The International Transfer of Semiconductor Technology Through [J, S.-Based Firms, " National Bureau of Economic Research Working Paper No. 118, December 1975, p. 57 This figure excludes point-of-sale facilities in industrial oat

[32] M. Y. Yoshino, "Japanese Foreign Direct investment, " *The Japanese Economy in International Perspective, I.* Frank (cd,] [Baltimore: Johns Hopkins University Press, 1975), p. 248.

[33] See, in particular, W. F. Finan, "The Exchange of Semiconductor Technology Between Japan and the United States, " *First U.S.-Japan Technological Exchange Symposium,* Washington, D.C., Oct. 21, 1981. Finan points out that American firms generally did *not* transfer proprietary information to licensees (p, 9).

Texas Instruments became the single exception to MITI's licensing rule—in reality only a partial exception. Because it held a series of fundamental patents covering ICs, Texas Instruments was in stronger position than other American companies. As a condition for licensing its patents to Japanese firms, Texas Instruments demanded that it be allowed to establish manufacturing operations there. When MITI refused—consistent with its decisions regarding other electronics firms—the stage was set for prolonged negotiations.[34] Texas Instruments and MITI eventually compromised in a 1968 agreement permitting a joint semiconductor manufacturing venture with Sony. Four years later, Sony sold its share to the American company.

Thus, Texas Instruments, although reportedly subject to a production ceiling, became the only U.S. semiconductor firm to both manufacture and sell its devices in Japan, just as IBM had—a few years earlier—become the only American company to build computers there. (IBM was also able to gain entry by taking advantage of its patent position.) Only recently, as the Japanese have gained confidence in their own technical abilities, has MITI softened its attitude toward foreign investment; a growing number of U.S. electronics manufacturers are now contemplating wholly owned subsidiaries in Japan. While the longer term consequences of these decisions are not yet clear, investment *within Japan could—given the examples of other industries—prove a vital support for American firms seeking to compete with Japanese rivals in third-country markets as well as in Japan.*

Current Trends

The competitive strategies of American semiconductor firms have been aimed first and foremost at survival in a highly competitive, rapidly changing market. Companies big and small have had to stay abreast of and adapt to technological change. Flexible management and organizational structures have been a necessity. The usual explanations for the exits of a number of large corporations during the earlier years of the industry revolve around rigid decisionmaking styles.

More recently, the character of the market has been shifting; American companies have been forced to alter their thinking. In some respects the changes are a continuation of familiar patterns: more complex ICs–large and very large-scale integration (VLSI)—make still more applications cost-effective, creating new and different puzzles for chip-makers. More fundamentally, VLSI has altered the cost structure of the industry in at least two ways. First, production is growing more capital-intensive; new sources of financing are needed to purchase more expensive manufacturing equipment (ch. 7). Some of the capital has come via mergers, which have changed the industry's structure. The second way in which VLSI is affecting the structure of the industry stems from shifts in product design. What had been a hardware-oriented business is now systems- and software-based as well. ICs are becoming more than components, To tap the vast potential markets made possible by microprocessors coupled with cheap memory, semiconductor manufacturers must commit substantial resources to computer-aided design and software development, This comes at a time of intensifying international competition—but with or without the Japanese in the picture, the problem facing U.S. merchant firms is one of locating sources of new capital in substantial amounts while battling to preserve even their existing profit margins. As companies devise their responses, several trends are emerging,

Greater vertical integration will probably have the farthest reaching consequences. Larger merchant companies—e.g., Texas Instruments, which has entered a variety of consumer markets, including that for personal computers—are taking advantage of broad-based positions in microelectronics to integrate downstream into the manufacture and sale of final products, The reasoning behind such decisions is straightforward. If much of the technology of data processing and other electronic systems is incorporated in ICs, why not make

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[34] J. E. Tilton, *International Diffusion of Technology: The Case of Semiconductors* (Washington, D. C.: The Brookings Institution, 1971), pp. 146-147.

end products too, increasing value-added and profitability? To this strategy—essentially an offensive one—could be added a defensive element. For semiconductor manufacturers with the resources to contemplate entry into systems markets, greater vertical integration reduces vulnerability in the event that customers begin to integrate backward into device production. The fact is that backward integration is on the upswing, as manufacturers of computers, office equipment, consumer durables, and a host of other products sense the need to develop inhouse capability in microelectronics. One path is purchase or merger with a semiconductor company. Merger activity in the industry has been high since the latter part of the 1970's; by 1983 only a few of the larger, broad-line merchant suppliers remained independent.

Mergers have been of several types: some semiconductor firms have been absorbed into conglomerates—one example is United Technologies' purchase of Mostek. Other acquisitions have been more directly motivated by internal needs, as in General Electric's acquisition of Intersil. Foreign takeovers have been prominent—Schlumberger's purchase of Fairchild. Sometimes the apparent motive on the part of the semiconductor company is the need for new financing; this was no doubt a factor with Mostek, explicitly so with IBM's purchase of a substantial interest in Intel. The motives of foreign investors have varied: buying an American firm can be a quick way to get technology as well as a convenient entrance into the U.S. market.

In a related development, many American semiconductor companies are seeking alternatives to "going it alone" in the development of new technology-largely because of rising costs. New variations on accepted technology sharing arrangements have been devised. Some semiconductor manufacturers have prevailed on customers for assistance in developing specialized chips and software. Both General Motors and Ford have supported such efforts. Semiconductor firms have also sought new ways to share product development costs among themselves, sometimes through extensions of past practices in second-sourcing, where it is becoming common for such agreements to spell out in considerable detail the R&D and/or circuit design obligations of each partner.[35]

Arrangements in which two or more companies independently develop different members of a family of chips fall at one end of the R&D spectrum—complementary product development. At the other end, closer to basic research, industry groups are moving toward cooperative rather than independent but complementary projects, The Semiconductor Industry Association and the American Electronics Association have each established programs that will channel contributions from member firms to university projects. The Semiconductor Research Cooperative is funding research directly, while the Electronics Education Foundation aims to improve training in electrical and computer engineering, primarily through fellowships and faculty support.[36] Another effort, Microelectronics & Computer Technology Corp., will be an independent profit-seeking R&D organization capitalized by the participating firms.[37] At least six universities are also establishing centers for R&D in semiconductor technology and/or systems applications of microelectronics.[38] Whether all these efforts will survive and flourish remains to be seen.

The emerging strategic picture in the United States, therefore, is fluid and uncertain. Semiconductor manufacture, along with other portions of electronics, is undergoing far-reaching restructuring, with outcomes that are hardly obvious. Given settlements in the IBM and AT&T antitrust cases, the way also seems clear

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[35] For examples, see S. Russell and S, Zipper, "Intel, Motorola Tighten Hold on General-Purpose MPUs: See Peripherals Key Market for Niche Suppliers, " *Electronic News*, Mar. 8, 1982, p. 1. U.S. merchant firms are also negotiating such agreements with Japanese manufacturers—S. Russell, "Zilog, Toshiba to Swap MPU, CMOS Technology, " *Electronic News*, Apr. 19, 1982, p. 53; "National Semiconductor Sets Venture With Japanese Firm, " *Wall Street Journal*, Jan. 23, 1983, p. 22 (the Japanese participant is Oki).

[36] S. Russell, "SIA Eyes $5 M Funding for Research Cooperative,'' *Electronic News*, Dec. 21, 1981, p. 6.

[37] C. Barney, "R&D CO-01) Gets Set To Open Up Shop, " *Electronics*, Mar. 24, 1983, p. 89.

[38] C. Norman, "Electronics Firms Plug Into the Universities," *Science*, Aug. 6, 1982, p. 511.

for continued expansion by these two giant semiconductor/communication/computer companies. AT&T's manufacturing arm, Western Electric, plans to be the first American firm to deliver 256K RAMs—a rather spectacular entrance into the merchant market. Other firms—Xerox is one—are also contemplating broad, systems-oriented strategies. Meanwhile, smaller companies continue to seek specialized product niches that will prove lucrative while not attracting large and powerful competitors. And in the background are the Japanese, adding another dimension that will continue to influence the strategies of American firms both domestically and internationally.

Japan

Until half-a-dozen years ago, few in the U.S. semiconductor industry gave much thought to Japan as a serious competitive threat. Japanese manufacturers—almost exclusively divisions of large corporations—mostly produced devices for consumer products; even today, nearly half of Japan's semiconductor output goes to consumer applications.[39] During the 1970's, Japan's budding computer manufacturers depended on American suppliers for advanced ICs. While Japanese companies were clearly on the way to the skill levels needed for more advanced devices, the prevailing belief in the United States was that they could not really hope to catch up. The primary concern was the closed Japanese market. American companies had been prevented from establishing a presence remotely comparable to that which they had achieved in Europe; customers in Japan bought only those devices that were not produced locally.

Today the situation seems quite different. Japanese firms have emerged as viable global competitors in VLSI devices. Although their prowess has centered on memory chips, they have made up a great deal of ground in logic circuits and other device types as well. By 1980, the gravity of the threat had become obvious; quite suddenly, Japanese firms captured nearly half the American market for 16K RAMs. Two years later, Japan's manufacturers seemed well on their way to comparable levels of penetration in the next-generation 64K RAMs; indeed, as sales began to build, the Japanese share soared toward 70 percent. While there is considerable feeling that ultimately they will not be able to hold more than about half the U.S. market for 64K chips, any temptation to underestimate the capabilities of Japan's semiconductor manufacturers has long since passed. Seemingly countless studies recount the strategic attack, tracing the targeting practices of government and industry.

From Linear to Digital Circuits

Firms in Japan had long since become major producers of linear semiconductors, a mainstay in consumer electronics. By the early 1970's, some American companies began to abandon this part of the market, especially as domestic sales seemed to be drying up. Leading U.S. producers put their resources into rapidly expanding digital IC technologies. Meanwhile, for the Japanese, strength in consumer devices was both a blessing and a curse. While giving their engineering staffs experience in circuit design and—more important—in high-volume production, the concentration on linear circuits did little to raise overall levels of competence. At the time, the primary customers for digital ICs—computer manufacturers—were a relatively minor component of Japanese demand.

This was the situation when, in line with its longstanding policy of fostering internationally competitive industries, MITI acted to break the impasse created by the focus on consumer products, The agency helped fashion an R&D program intended to increase Japan's capabilities in large-scale digital ICs, particularly MOS devices, and accelerate movement toward VLSI. The organization of the program, which began in late 1975, is described in chapter 10; five companies and three separate laboratories were involved in the 4-year effort. Funding—totaling about $300 million—was provided partly by the participants and partly by government. The program has had far-reaching im-

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[39] *Japan Electronics Almanac* 1982 (Tokyo: Dempa Publications, Inc., 1982], pp. 142, 143.

pacts—as much through diffusing technology and training people as through the technology developed. A parallel government-sponsored VLSI program—this one focused on telecommunications—was carried out in the laboratories of Nippon Telegraph and Telephone (NTT), which had the most capable microelectronics R&D organization in Japan.

MITI's objective was not only to aid Japan's semiconductor manufacturers: the VLSI program was part of a much more extensive effort to move the nation toward knowledge-intensive products with high export potential. Like its counterparts within the governments of other industrialized countries, MITI recognized that semiconductors would be fundamental building blocks for many sectors of the Japanese economy. Supporting the computer and information industries was the first step. MITI was fully aware that technical competence in digital ICs would be essential, and that without some form of stimulus private companies would find it difficult to shift rapidly from linear to digital devices. From MITI's perspective, support for "cooperative" R&D was a natural extension of past efforts in other industries; the VLSI program itself has been followed by related work in computers and robotics, as well as further microelectronics projects.

Still, by American standards, MITI's subsidies were not large. Individual U.S. firms like Texas Instruments had R&D budgets that came close to matching the yearly outlays of the VLSI project; IBM's corporate R&D spending was an order of magnitude larger. Of course, participating Japanese companies continued their internally funded R&D programs; MITI spending thus gave a substantial incremental boost to Japanese semiconductor research, reducing risks and supporting longer term work. Even so, total expenditures in Japan remained well below those here. Nor did the VLSI project result in large and direct benefits to Japanese firms, at least in terms of product offerings. A great deal of attention in the United States has centered on the thousand or so patents associated with the program, but it is not clear what value these have. There are no signs of major innovations. Primary attention went to process rather than product technologies; one-third of the funds were spent in the United States simply on purchases of state-of-the-art manufacturing equipment. This suggests that the major thrust was to develop skills in low-cost production of commodity-like devices such as RAM chips.

Two aspects of MITI's approach deserve particular emphasis. First, *subsidization of microelectronics R&D was only the opening move in a broader strategy for building a competitive computer and telecommunications sector.* Hindsight provides ample corroboration of what was in fact an explicit goal: MITI's subsequent support of computer and software development, as well as the Japanese Government's reluctance to allow open competition for NTT procurements. NTT was a principal—though independent—actor in the VLSI program; the government evidently hoped to restrict its high-volume purchases to domestic manufacturers (the company does not produce its own semiconductors), helping generate the economies of scale so necessary for international competitiveness,

The second point—suggested by MITI's level of support, generous for a government R&D program but certainly not enough by itself to boost the Japanese industry past American firms—is that *the VLSI project was never conceived purely as an exercise in technology development.* Consistent with the usual Japanese approach to government-supported R&D, it was intended to focus industry efforts, help train engineers from private firms in state-of-the-art technologies, diffuse these technologies within the Japanese industry—in other words, to overcome weaknesses in Japan's technological infrastructure created in part by the lack of personnel mobility (ch. 8).

This makes it doubly difficult to assess the contribution of the VLSI project. While separating what might have happened from what did occur is impossible, pieces of evidence do exist: for instance, MITI excluded Oki Electric from participation and subsidies, yet Oki managed with NTT's help to develop a 64K RAM that the company now exports in considerable volume. Many of the events of the past few years—the upsurge in Japanese production and exports of RAMs—would probably have occurred in any event, albeit at a slower pace; memory chips were obvious targets for Japanese firms confident of their abilities to mass-produce relatively straightforward designs to high quality standards. They were also needed for the computers that these same firms were determined to make in greater numbers.

In the United States, the impact of the VLSI project has been exaggerated. It has come to symbolize not only direct subsidization of commercially oriented R&D but also interfirm cooperation that might be illegal under American antitrust law. In fact, as pointed out in chapter 10, cooperation among Japanese companies has been rather limited—evidence of the strength of the barriers within the Japanese industry that MITI was trying to overcome; this aspect has been overplayed by American manufacturers understandably distressed at inroads by overseas competitors, While the VLSI project makes a convenient target, by itself it is a far-from-adequate explanation for penetrations of what had been traditional American markets. Indeed, government policies in support of Japan's information industries have ranged far beyond R&D subsidies, Among the other policy tools have been:

- preferential government procurement;
- favorable credit allocations, especially during the formative years;
- special depreciation and other tax measures; and
- grants for training and education.

Domestic firms have been effectively protected from import competition as well as from production within Japan by foreign-owned concerns. Protection of growing industries through government action is hardly unique, but can only be judged to have succeeded if the protected companies eventually emerge as viable competitors. In microelectronics, the "infant industry" approach has been attempted elsewhere, most notably in several European nations, but only Japan has achieved success. Japanese industrial policy is discussed in detail in chapter 10; here the point is that none of the policy measures adopted by Japan's Government, taken separately, appear to have been major forces in the ultimate growth and maturation of the semiconductor industry. Taken *together, they paint a different picture—one* in which industrial policy provided vital guidance and support for the development of an independent capability in semiconductor design and manufacture. *Cumulatively, the policies of Japan Government have had a major impact.*

Strategy and Structure

Despite MITI's pervasive influence, the competitive strategies of individual Japanese semiconductor manufacturers are governed first by the basic structure of the industry, which is populated by companies for whom microelectronics comprises a relatively small part of their business. Most of these companies—Oki and Nippon Electric being partial exceptions—are large, integrated firms whose sales consist predominately of final products such as computers, consumer electronics, and telecommunications systems, Table 45 shows that only for

Table 45.—Proportion of Sales Accounted for by Semiconductor Products[a]

Japanese firms (1981)		U.S. firms (1979)	
Nippon Electric Co. (N EC)	19.8%	Mostek	93%
Fujitsu	12.9	Advanced Micro Devices	89
Oki Electric	9.8	Intel	75
Toshiba	8.1	Fairchild	69
Hitachi	5.3	Texas Instruments	36
Mitsubishi	5.3	Motorola	31

[a] Including internal consumption.

SOURCES **Japanese** Firma-Table 29 (ch 4).
U.S. Firma—"S.S. and Japanese Semiconductor Industries A Financial Compare son," Chase Financial Policy for the Semiconductor Industry Association, June 9, 1980, p 15

NEC and Fujitsu—the latter Japan's largest computer manufacturer, with heavy internal consumption—have semiconductors contributed a proportion of total sales even half as great as for those U.S. merchant firms that are least dependent on their semiconductor divisions—Motorola and Texas Instruments. Semiconductors account for less than one-tenth the sales of the other Japanese manufacturers. In this, they are closer to American companies like Rockwell or RCA, which nonetheless differ in being primarily suppliers of specialty rather than mass-market circuits.

The fact that the major semiconductor suppliers in Japan build end products creates potential intracorporate synergisms absent in companies that are primarily chipmakers. While some U.S. managers view integration as dysfunctional, likely to sap entrepreneurial drive and retard innovation, it has been an advantage for Japanese companies—which have different sets of strengths and weaknesses than American firms. To begin with, the same half-dozen corporations that produce most of Japan's ICs account for perhaps two-thirds of demand; given the focus on vertical integration and internal production, it should be no surprise that U.S. suppliers have had difficulty selling in Japan. Second, as the next chapter points out, the quality of Japanese ICs has been high–again, this might be foreseen, given that firms producing for internal consumption will find themselves bearing high downstream costs when quality lags. A further synergism associated with size and diversification stems from the ability to tap cash flows generated in other lines of business; these funds can be channeled to R&D or added production capacity, matters amplified on in chapter 7. Further, diversified companies can more easily tolerate short-term losses resulting from price-led penetration of new markets. Diversified Japanese companies have combined such tactics with an emphasis on quality—both image and reality—to drive boldly into markets once the province of American firms. Indeed, few other strategies could have worked. Unfortunately, from the standpoint of smaller and less diversified U.S. merchant manufacturers, unrelenting price competition in products representing a substantial part of their total business leaves few options for counterattacks.

The Japanese strategy—protecting domestic semiconductor manufacturers from overseas rivals while providing modest R&D subsidies and at the same time fostering domestic competition—parallels that in television. It has yielded equally impressive results: deep penetration in targeted markets based on low prices and quality levels above previous norms. There has been a fortuitous element as well; unexpected demand swamped U.S. suppliers during 1979 and 1980. As a result of continued capacity expansions during the preceding market slump, Japan's producers were ready to fill the void.

Some spokesmen for the American industry find other familiar features: claims have been repeatedly voiced that the Japanese practice price discrimination, maintaining high margins in protected home markets while slashing prices in the United States and Europe, Such tactics would imply either explicit or implicit monopolistic agreement among Japanese manufacturers—e, g., tacit acceptance of existing market positions at home, with price cutting confined to foreign markets. Even so, questions of dumping are problematic for integrated firms; companies making ICs for both internal consumption and open-market sales have a good deal of latitude in allocating costs and setting prices. Dumping, as defined under GATT rules and the laws of most countries, would be difficult to prove; nor would the usual rationales for prohibiting dumping necessarily be very relevant.

MITI's push toward ICs for computers and communications has contributed to Japan's strength in world markets for memory chips. At the same time—one legacy of the industry's roots in devices for consumer applications—Japanese product lines remain more narrowly based than those of the leading American suppliers. Microprocessors are a case in point; the major Japanese firms all continue to produce American designs. NEC, Toshiba, Mitsubishi, and Oki sell members of the Intel 8080 family; at least three Japanese firms are building Intel's 16-bit 8086.[40] Although several Japanese manufacturers have designed microprocessors for internal use, these have not found other markets. And if made-in-Japan dynamic RAMs now claim a major share of worldwide sales, the overall Japanese presence in the United States remains modest. In 1982, imports from Japan accounted for about 5½ percent by value of total U.S. integrated circuit consumption; although increasing rapidly (fig. 26, ch. 4), Japanese imports remain small in absolute terms. Still, the inroads have come in a market segment that American manufacturers rightly view as critical; U.S. firms heavily dependent on memory products have been severely affected, In other product categories, Japanese competition is also stiffening; a major effect was to further depress prices and profits during 1981 and 1982, when domestic firms were troubled by a deep recession,

In the longer term, American semiconductor manufacturers have every reason to be wary of continued pressure from powerful multinationals with headquarters in Japan—firms that have already demonstrated their ability to compete successfully in major world markets for other technically demanding products. The U.S. merchant manufacturers have their own advantages—they do well some things that Japanese firms do poorly–but they cannot expect an easy time of it in the future.

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[40] R. H. Silin, *The Japanese Semiconductor Industry: An Overview* (Hong Kong: Bank of America Asia, Ltd., January 1979), p. 148; "Background of VLSI War With United States Reviewed, " *Japan Report,* Joint Publications Research Service JPRS L/10662, July 16, 1982, p. 43.

Computers

If American manufacturers were for many years unchallenged in world markets for semiconductors, the United States has been still more preeminent in computers. Even in Japan, American-owned firms continue to account for over 40 percent of mainframe sales; the U.S. share of the Japanese market for small systems is lower, but such firms as Data General and Hewlett-Packard have recently established production facilities there. In Europe, U.S. companies are far out front except in the United Kingdom, where the government has actively supported ICL through procurements and subsidies. American-owned enterprises account for nearly three-quarters of all computer sales in Europe.

This section again concentrates on the United States and Japan. While Japanese computer manufacturers have not yet proven notably effective competitors outside their home market, they are at present uniquely situated to launch a campaign aimed at the U.S. position—in part because of their newly acquired strength in microelectronics, in part because of their active pursuit of joint venture ties with suppliers in Europe and the United States. It is too early to predict the extent to which the Japanese strategy may succeed, but structural changes in the world computer industry are creating new opportunities for firms everywhere. The Japanese will probably be able to exploit at least some of these, certainly better than European producers.

The Environment for U.S. Suppliers

By virtually any standard, the United States has far and away the most computer-intensive economy in the world, a position it can expect to maintain indefinitely. From the early days of the industry, the number of computers installed in the United States mounted at a pace that kept the total about an order of magnitude greater than for all of Western Europe.[41] By 1981 there was a computer terminal for every 48 people employed in the United States; by

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[41] *Gaps in Technology: Electronic Computers* (Paris: Organization for Economic Cooperation and Development, 1969), p. 16.

1986 there should be 1 for every 10.[42] American leadership in design, production, and sales—as well as utilization—is reflected both in trade data, where the computer industry continues to be a prodigious net exporter, and in the prominence of U.S.-owned subsidiaries in other parts of the world.

Strategic Patterns

For many years the story of American supremacy in the global computer industry was the story of one company—International Business Machines, Although IBM trailed Remington Rand, builders of the Univac, in marketing early computer models, by the late 1950's IBM had gained the huge lead it still enjoys. For the other old-line firms—including Burroughs, NCR, Honeywell—competition has mostly meant jockeying for places in the residual market left by IBM; these companies have found it difficult to reach the Wale needed to offer a full product line and to' support a sales/service organization competitive with IBM's. In general-purpose mainframes, IBM has accounted for 60 to 70 percent of the *world* market over the years, with lower figures in such countries as Japan and the United Kingdom balanced by even higher percentages elsewhere. To be sure, numerous entrants—mostly American—have attempted to carve out competitive positions against IBM, with much more success in rapidly growing markets for small systems than in mainframes. Companies ranging from Digital Equipment Corp. or Control Data in the United States to Fujitsu in Japan and Nixdorf in West Germany have established themselves solidly in some portions of the market. But none has come close to IBM's overall sales, despite the rapid shifts in overall market structure described in the previous chapter,

Most of IBM's American competitors have taken a straightforward approach to their situation: following IBM's lead in the development of faster and larger systems, trying to maintain product lines that match up reasonably well while at the same time staking out their own territory—e.g., Control Data in high-performance scientific machines, Burroughs in small business systems (on the latter, see the case study in app. C). In these efforts, American computer firms have been aided by the technological lead of the U.S. semiconductor industry, Although IBM has relied heavily on internal semiconductor design and manufacture, other firms—whether or not maintaining captive production facilities—have been able to take advantage of components available on the merchant market that were often superior by conventional yardsticks to IBM's devices, This is one of the reasons IBM has itself begun to purchase ICs on the outside. A major element in the strategies of other mainframe suppliers (excluding those making plug-compatible machines] has been to expand into new applications while tying their installed base to proprietary software—thus keeping old customers. None have had more than limited success; other mainframe-oriented firms have generally been a good deal less profitable than IBM, and have made little headway in eroding IBM's market share, Several have done better abroad; Honeywell's joint venture in France has been a greater force in the European market than the parent has been in the United States.

The Impacts of Microelectronics and Reliability Improvement

Because the market has enlarged and changed so radically, focusing on the older mainframe companies hardly gives a fair sampling of current strategies. As figure 35 indicates, market growth for general-purpose mainframes—the mainstay of the industry just a few years ago—is now much slower than for other types of systems. As sales of minicomputers, small business installations, and desktop and personal machines exploded, competitive dynamics altered fundamentally. Newer entrants have staked out major shares of markets for products like word processors. These structural shifts are continuing—indeed accelerating.

What are the implications for international competitiveness? As in semiconductors, prod-

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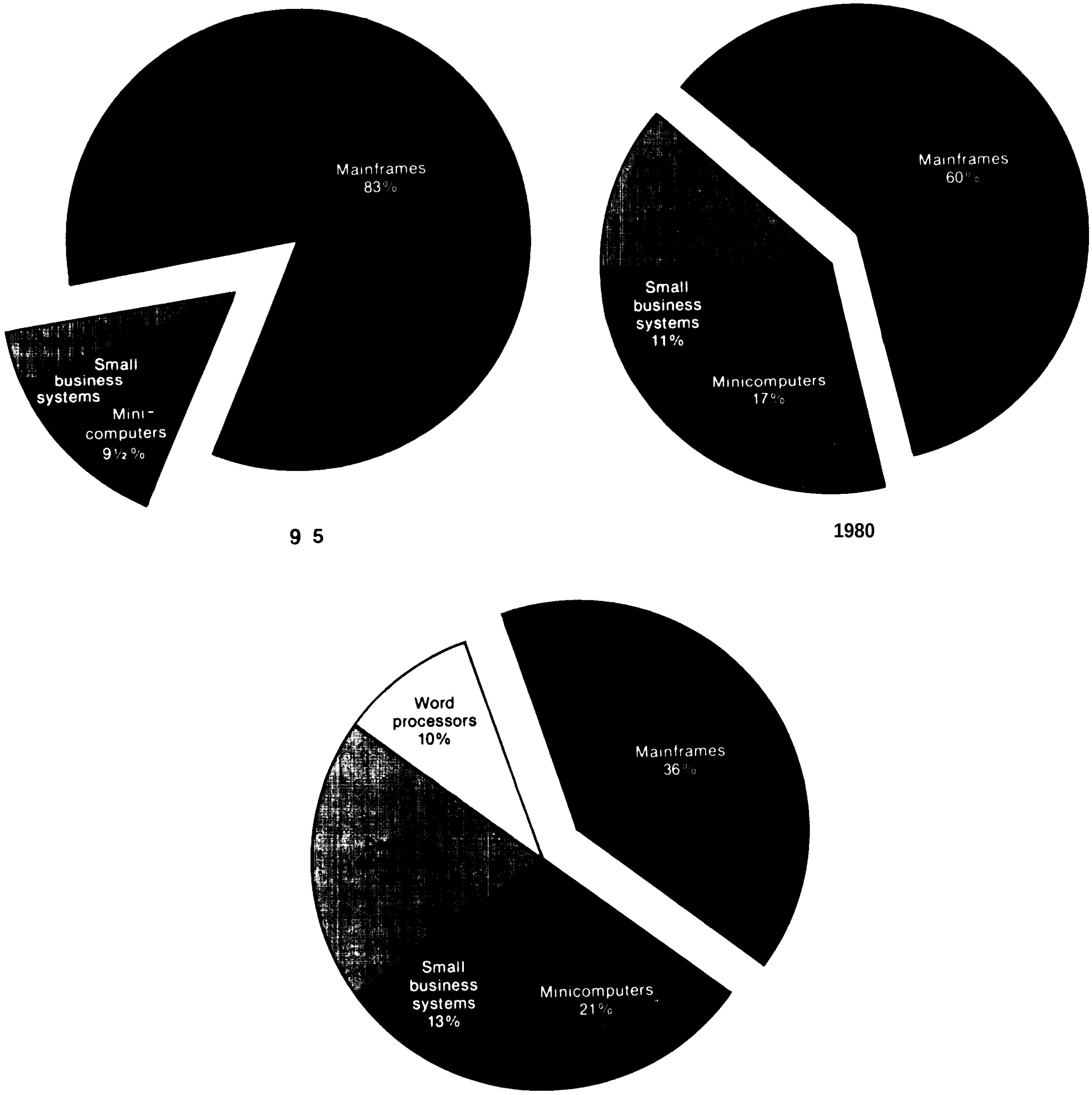
[42] L. M. Branscomb, "computer Communications in the Eighties—Time To Put It All Together," *Computer Networks,* vol. 5, 1981, p. 3.

Figure 35.—Market Segmentation of U.S. Computer Sales by Value



9 5

1980

1985
(projected)

SOURCE “Moving Away From Mainframes The Large Computer Makers’ Strategy for Survival, ” *Business Week,* Feb 15, 1982, p 78 uct planning decisions in the computer industry are shaped by technical possibilities. Specialized machines of all sizes have long had their place, but the turn toward small and versatile computers is a direct consequence of twin driving forces: advances in software for networking and distributed processing, plus advances in microelectronics. Computer systems need no longer be structured around a single processor. A central unit can be surrounded by a number of satellites, or the entire processing load can be shared throughout a network. Given cheap microprocessors and single-chip microcomputers, designers can put "intelligence' where they want it, Computer firms that fall behind in such developments—more broadly, manufacturers of systems incorporating machine intelligence, not all of whom think of themselves as part of the computer industry—will be poorly placed to compete in future markets.

Improvements in system reliability—flowing partially but not wholly from the growing reliability of microelectronic devices—yield another powerful driving force. Mean times between failure for computer systems have been increasing steadily despite greater complexity. Today's computers are orders of magnitude more dependable than those of even a decade ago; this not only cuts operating and maintenance costs but helps expand applications. Computers can now be used in a host of applications where the dangers of a failure were formerly too great–real-time air traffic control, electric utility load management, critical industrial processes.

Ever-greater reliability combined with ever-greater computing power per dollar has eaten away at IBM's traditional strengths—customer support and service, plus the ability to lock in customers via a product line broad enough to satisfy virtually every need. Now, so many applications have opened up that no one company can hope to cover them all; in many of these, IBM's market power—so valuable in selling general-purpose mainframes—has been, if not irrelevant, at least a far smaller advantage. New entrants can specialize in systems for banking or distributed word processing. Startups of earlier years—Data General, Prime, Tandem—have become substantial multinationals in their own right. Independent software vendors are creating a whole new industry.

Better reliability—in addition to broadening the applications of computers—has had a second, equally important, impact. As in consumer electronics, it has allowed manufacturers to skirt traditional distribution channels and reach customers through new outlets. This trend—which began as early as the 1960's with systems houses that purchased minicomputers and peripherals in quantity, assembling them, together with software, to supply turnkey installations—also promises to continue and perhaps accelerate. Greater reliability has reduced the need for onsite maintenance and repair; where field service was once a vital element in any marketing strategy, smaller manufacturers are now less constrained by the need to finance service networks. Moreover—while hobbyists, engineers and scientists, and many businesses could be reached through specialized distribution channels–selling personal or desktop computers to the general public requires retail distribution. This, in turn, is realistic only if the need for aftersales service is modest. Currently, the personal computer market is moving through a transition paralleling the earlier shift in color TV—desktop machines are becoming off-the-shelf items rather than products sold and serviced by specialty outlets. The personal computer is a product in which IBM had no great advantages beyond name-recognition and abundant internal resources for product development. While these are far from trivial assets, IBM will probably not be able to duplicate its position in mainframes in the far more diverse and competitive desktop market, just as the company has not been able to do as well in small business systems, supercomputers, or word processors. The general point is: to be in the computer business no longer necessarily means confrontation with IBM; it need not entail attempting to cut into the installed base of any mainframe manufacturer, much less trying to match IBM's hardware or software across a broad spectrum of products.

Even in small systems, only a few companies have been able to span a major portion of the market. Some—e.g., Hewlett-Packard—have specialized in powerful machines for sophisticated customers. Others, like Wang and Datapoint, have aimed at business applications, Digital Equipment Corp. (DEC)—which started as an OEM supplier—now has a relatively broad product line, including personal computers, As in the semiconductor industry, managers have had to search for market opportunities that match their organizations' strengths. Their choices and decisions, constrained by resource limitations and conditioned by government policies, will determine the future competitive posture of the U.S. industry. Mistakes will be made, and weaker companies—most likely those making peripherals, office automation equipment, and desktop computers—will find themselves being absorbed or merged with competitors.

Product Strategies: Hardware and Software

The mainframe-oriented companies do retain advantages in structuring complex and far-flung information systems. Designs for such systems are often shaped by existing software inventories, The original supplier has an easier time achieving compatibility; indeed, computer firms have had a good deal to gain by making it difficult for competitors to reverse-engineer their software and develop compatible systems. Some have gone so far as to replace portions of the system software with "firmware" stored in ROM chips which can be changed from time to time. Generally, such efforts have been intended to thwart plug-compatible manufacturers.

The importance of software extends far beyond the system level. Machines capable of data processing for business needs are now within the financial reach of even the smallest firms—and, of equal significance, can be used by people with little special training, Software that is user-friendly, as well as reliable, is a key element in selling to those without previous data processing experience. As the case study in appendix C points out, credit for the success of IBM's System/32 small business computer goes in large part to the specialized applications programs that were available, Even more, as hardware costs fall, specialized software becomes the pacing factor in applications ranging from office automation—where much of the competition for word processor sales revolves around software—to industrial robots. Limited growth in software productivity and high associated costs (ch. 3) are problems that now confront all firms in the industry, here and overseas; among the possible solutions are multinationalized software generation. In the future, the importance of software compared to hardware can only increase; the exceptions are perhaps at the very high and very low ends, where supercomputers remain hardware-intensive and small machines selling for less than a thousand dollars compete on the basis of price.

From a slightly different perspective, software can become a constraint: switching to new software, particularly system software, is time-consuming and expensive. Customers with extensive data processing installations and large software inventories become locked in because of the high costs of transferring. This is a constraint on the system manufacturer as well, who may be burdened with obsolescent software that cuts into potential performance. The picture is somewhat different for computers sold to purchasers who are technologically adept—e.g., OEMs who integrate computers into their own products, or those with needs in engineering or science. Such customers commonly have the internal resources for solving their own software problems, and find shifting to new systems, though a difficult task, not an insurmountable one. Still, given their software investments, virtually all customers have strong motives for replacing or augmenting their equipment with new models from the same manufacturer—and manufacturers strong motives for ensuring software compatibility within their product lines. Therefore, once markets begin to mature, a manufacturer's share of the installed base becomes a good indicator of future prospects; competitors need hardware that is substantially better or cheaper to stand much chance of convincing customers to switch allegiance, Brand loyalty has been high in general-purpose data processing markets, largely for such reasons.

Plug-compatibility is aimed at breaking this cycle. Originally referring to peripherals such as disk drives, plug-compatible manufacturers (PCMS) later moved into mainframes that can operate on IBM software; now some build equipment compatible with DEC minicomputers or IBM Personal Computers. Basically, the PCM strategy has been to make equipment that can be used interchangeably with IBM's, while undercutting the latter's price/performance ratios.[43]

The forces outlined above shape the strategies of companies striving to keep up in the marketplace. New approaches to product development are appearing throughout the industry; even IBM has begun to purchase more hardware outside, as well as software. In another new departure for the company, IBM has started selling disk drives on an OEM basis. As in semiconductors, technology-sharing agreements have become more common—cross-licensing of patents, direct purchases of technology, joint development—as firms conserve resources through specialization. This is the idea behind Microelectronics & Computer Technology Corp.—spearheaded by Control Data and presumably aimed not only at oncoming competition with the Japanese but the continuing struggle of smaller entrants with IBM. Movement toward technology purchases and technology sharing appears to have even more momentum in Europe, despite earlier failures of joint efforts like Unidata. Siemens, ICL, and Olivetti are among the companies now marketing Japanese-built mainframes in Europe.

International Aspects

The picture that emerges in the U.S. computer industry is one in which the long-dominant leader is being challenged on all sides, Structural change has been driven largely by the technology—although occasionally market demand outstrips what the industry can supply, as happened with word processors—and it is difficult to predict where it may lead. Some observers believe that IBM's market power will continue to deteriorate, even in areas where the firm's position has heretofore seemed unassailable. Others think the future lies with large and powerful companies able to combine far-flung communications and information networks into vast integrated systems. In fact, both views are probably correct, given the fragmentation and specialization brought by cheap hardware.

American computer manufacturers, living nervously with rapid technical change at home, face another series of choices in foreign markets. Governments in industrialized nations where American subsidiaries have long been dominant continue to follow policies transparently intended to reduce that dominance, Such policies are nothing new: France's Plan Calcul was set forth more than 15 years ago, and the Governments of Great Britain and Japan have, over the years, found many ways to support local computer manufacturers. While most such policies have had only limited effects in the past, certainly in Japan the technological fervor is now intense,

If competition from Japanese computer firms is on the rise, American entrants are themselves fashioning new international strategies. Already DEC operates six plants in Europe and three more in the Far East. A partial list of other American minicomputer manufacturers with foreign production facilities would include Hewlett-Packard, Wang, Data General, Datapoint, and Texas Instruments. U.S.-based multinationals specializing in desktop machines include Apple, with plants in Ireland and Singapore, and Tandy. Manufacturers producing plug-compatible mainframes have also begun to expand abroad: Amdahl has opened an Irish facility intended in part to supply the Common Market, as has Trilogy Systems.

The rules of the competitive game are in particular flux in lesser developed parts of the world. Developing countries are putting in-

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[43] The founder of Amdahl, the leading supplier of PCM mainframes, has said that surviving in competition with IBM requires costs that are 15 percent lower or performance that is 20 percent better, See "Makeshift Marriage, " *The Economist*, Aug. 11, 1979, p. 78.

dustrial policies to work attracting technology and fostering local computer manufacturing. Mexico's approach has been to restrict imports, limiting sales to companies that agree to establish production facilities. With an annual market now approaching $500 million, Mexico has been able to attract a pair of U.S. minicomputer firms willing to live with these rules. Brazil's Government has reserved the domestic minicomputer market for locally controlled enterprises; transfers of technology have been encouraged, but foreign investments are limited to minority interests. While American companies have generally chosen to stay out, several European and Japanese firms have agreed to participate—no doubt hoping for benefits similar to those now flowing to the Japanese consumer electronics manufacturers that accepted such conditions in earlier years.

How will the onset of local production in developing countries affect international competition in computers? While any answer remains conjectural, it would be foolish to dismiss the possibility that some of these nations may evolve into viable forces in the marketplace. Although their ability to compete will probably be restricted to simpler products over the foreseeable future, developing economies will begin by building equipment such as terminals, printers, and disk drives, where labor is a major cost element. It is not a big step from making TV receivers to producing the simpler types of computer terminals—indeed a step that countries like Korea and Taiwan have already taken. With the experience gained in such products, and with protected markets contributing to scale economies, a number of the newly industrializing countries could move fairly quickly into world markets.

As a final point, again consider software development. By its nature, programing has been labor-intensive–therefore increasingly costly in high-wage nations. Software generation depends on people with ability and experience—including an understanding of the problems faced by users, Such factors have prevented the transfer of this work to developing countries, even those like India where the raw programing skills might be available. Nonetheless, several industrializing nations are attempting to improve the capabilities of their labor forces so that they can produce software needed in advanced economies. Countries like Singapore, Hong Kong, and Taiwan are seeking to create "software centers" where Western computer manufacturers could establish subsidiaries that would transfer skills and provide training for the local work force while also producing much-needed software. Once the people were available, locally owned companies could take over at least some of the work.

Japan

Objectives announced by Japan's Government over the past few years herald a competitive onslaught directed at the U.S. computer industry. MITI is sponsoring a pair of long-term R&D projects dealing with computer systems, plus several related efforts.[44] The fifth-generation computer project—the origins and organization of which are described in chapter 10—is software-intensive, directed at artificial intelligence, information organization and management, and natural language input and output. In the second project, MITI is helping fund the development of a supercomputer intended to surpass the most powerful offerings of American companies like Control Data and Cray. A related lo-year project will support development of the high-speed microelectronic devices needed to implement the software concepts of both fifth-generation machines and supercomputers. The goal is nothing less than to thrust Japanese companies into the forefront of world computer technology, to leapfrog the United States in the design and marketing of both hardware and software. The objectives of

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‘*Outline of Research and Development Plans for Fifth Generation Computer Systems* (Tokyo: Japan Information Processing Development Center, Institute for New Generation Computer Technology, May 1982); *Computer White Paper: 1981 Edition* (Tokyo: Japan Information Processing Development Center, 1982], pp. 59-75; "Machinery, Information Industries '81 Programs Outlined, " *Japan Report*, Joint Publications Research Service JPRS L/10086, Nov. 2, 1981, p. 21; "Archetype of Fifth Generation Computer Described, " *Japan Report*, Joint Publications Research Service JPRS 1./11007, Dec. 14, 1982, p. 49; "MIT I Project To Develop Supercomputer Starts in January, " *Japan Report*, Joint Publications Research Service JPRS L/10348, Feb. 23, 1982, p. 34.

these programs are by no means unique to Japanese manufacturers; they are squarely in the mainstream of the evolution of computing. It is the strength of Japan's commitment—the backing by MITI and other government agencies, the lo-year schedules—that differentiate them from efforts in other countries.

As the rhetoric associated with such programs makes clear, Japanese firms, with the help of their government, hope within 10 or 15 years to lead the world in computer technology. Despite Japan's relatively successful experience with previous government-sponsored R&D efforts—the Pattern Information Processing System (PIPS) project, the VLSI project—this is a tall order. At present, the market position of Japanese manufacturers is modest; as of 1981, American-owned companies held more than three-quarters of the world computer market in value terms, Japanese-owned companies only about 7 percent. Still, Japan is now the second largest supplier of general-purpose computers to the world market, with a very high rate of export growth (ch. 4, fig. 30). The country is also second only to the United States in intensity of computer utilization. After the experiences of consumer electronics, automobiles, and semiconductor memory chips, few in the American industry would take Japan's goals lightly.

Nevertheless, because of the role that factors such as installed base and software inventories play in the marketing of computer systems, Japanese manufacturers must begin with the knowledge that—no matter how good their technology—they cannot hope to come close to the United States for many years. In this sense, the computer market is not at all like that for semiconductors, where purchasers quickly switch suppliers to take advantage of low prices, quick delivery, or new device types. Success in niche markets for computer systems is quite possible, indeed a necessary first step, but breadth in an industry expanding in as many different directions as information processing can only be a long-term undertaking, The U.S. position, both in technology and market share, is simply too strong. Leaders in Japanese Government and industry recognize their weaknesses, and have made plans accordingly.

Technology

Carefully targeted R&D is a central strand in the Japanese computer strategy, as in earlier ventures into other industries, Japanese producers and their government realize, just as they did in microelectronics, that international competitiveness in computers cannot be attained so long as they rely on technology from the United States, The reasons are twofold, First, American firms are far less likely to license technologies than in the past, The Japanese know that computer manufacturers in the United States, unlike at least some of their predecessors in other sectors, are acutely aware that technical leadership is a primary source of competitive strength, and that to make their technology too easily available would weaken their own position, The second reason is even more fundamental. In the basic building blocks of computer hardware, semiconductors, Japanese firms are near parity with American companies; in some areas they may be ahead. Japan can hardly depend on imported technology; rapid progress toward an eventual goal of leadership in information processing requires extensive indigenous capability of the sort that Japanese firms now have in high-density memory chips,

The Japanese also recognize that their shortcomings in the marketplace are not so much matters of hardware as of software and related applications-based constraints, Several Japanese firms now offer computer hardware as powerful as any. However, IBM's huge installed base and vast catalog of applications programs have forced Japanese competitors, as those elsewhere striving to break into the mainframe market, to build plug-compatible machines that run on IBM software. To get around this impediment is perhaps the major reason for the fifth-generation project. While companies like Amdahl have demonstrated that a comfortable business can be built supplying PCM mainframes, markets tied to another manufacturer's software are inevitably limited. Japan's gamble is that it can jump ahead of American entrants with families of computer systems having performance capabilities that will render present-day software inventories obsolete. This goal has shaped the hardware and software R&D planned for the fifth-generation project: to take full advantage of emerging microelectronics technologies in more closely linking the needs and abilities of people with the capabilities of the system. If these objectives are met, individuals—even those with little training—will be able to communicate with fifth-generation machines through ordinary language in spoken or written form, as well as through graphical or pictorial images. Such systems would not only be user-friendly, but might ultimately display something of the independent decisionmaking capability associated with human reasoning. * If the technical objectives of the fifth-generation project—and similar efforts in other countries—are achieved, even novice users would be able to harness enormous computing power. The commercial potential is immense.

Government Assistance

The Japanese Government has supported R&D activities in information processing over many years. MITI has been selective in financial aid, directing funds to potential bottlenecks, exemplified by the VLSI program's support for digital ICs, or to R&D that could help Japan's industries leapfrog the competition, the intent of the fifth-generation computer project. Funding for the latter is projected at about $500 million over a 10-year span (1981-91); the supercomputer project is expected to get another $100 million over roughly the same period.** A parallel microelectronics project—which goes by names such as "R&D on New Function Elements''—has a budget of about $150 million and is scheduled to run from 1980 to 1990, Money will go to three major development efforts:[45]

- Three-dimensional circuit elements—which can be visualized as more-or-less conventional ICs stacked atop one another, increasing the density.
- High electron mobility transistors (HEMTs), one variety of which consists of very thin layers of semiconducting materials such as gallium arsenide or gallium aluminum arsenide; HEMTs offer potentially higher switching speeds, hence faster computers.
- Radiation-hardened devices suitable for use in extreme environments such as nuclear powerplants or outer space (resistance to heat and vibration is a related objective).

The first two especially will support both supercomputer and fifth-generation projects. Among related government-sponsored programs, another of major significance for the corporate strategies of Japan's computer manufacturers has aimed at the development of software and peripheral devices with Japanese language input-output capability. Scheduled over the period 1979-83, nearly $200 million was allocated to this effort.[46]

As in microelectronics, R&D is but one of many ways in which Japan's Government assists the computer industry. The Japan Development Bank loans money to the Japan Electronic Computer Corp. (JECC), a jointly held firm which purchases computers from participating manufacturers and leases them to

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*An example from the field of artificial intelligence—the area known as expert systems—will illustrate, Research in expert systems aims at computer programs that mimic attributes of people who are "experts" in some realm of knowledge—e. g., medicine, where such programs might help automate diagnosis. The objective would generally be to augment or complement rather than supplant human skills; an expert system would not have the judgement of a physician, but could offer, for example, perfect recall of vast amounts of information. Expert systems typically depend on complex software and large data bases; thus, advances in hardware as well as software maybe needed if they are to be widely implemented.

* * Planning for the fifth-generation program began several years earlier, as outlined in ch. 10. A variety of funding levels for both projects have been reported; spending plans and schedules will no doubt shift as they progress.

[45] "FY82 Government Projects in Electronics Listed, " *Japan Report,* Joint Publications Research Service JPRS L/10676, July 22, 1982, p. 55.

[46] *Computer White Paper: 1981 Edition,* op. cit., pp. 4ff.

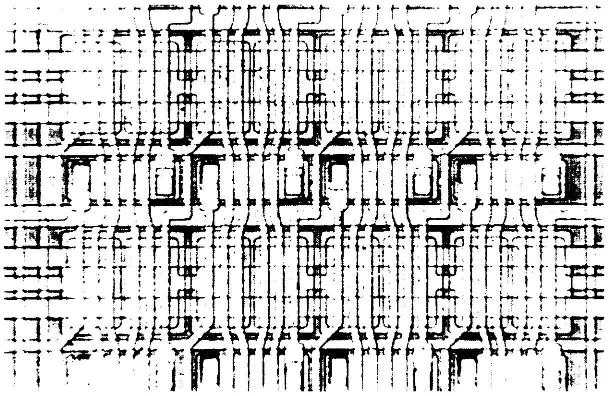

Photo credit IBM Corp

Memory cells in experimental Josephson junction integrated circuit chip

users. Manufacturers can set up tax-free reserves to offset losses incurred when lease contracts with JECC are canceled and equipment must be repurchased. Since 1979, tax-free reserves have been permitted for up to half the income associated with some categories of software. Purchasers of certain types of computers can write off 13 percent of their value, beyond normal depreciation, in the first year. The government has also established special depreciation schedules for high-performance remote data processing equipment.

A panopoly of support measures—of which many more examples could be cited—has thus been designed to help Japanese companies achieve technological superiority and commercial success in the **1990's.** At first glance, the sums of money involved may seem large; in fact, when viewed in the context of the world computer industry, they are modest; as chapter 10 stresses, it is the consistent *support provided by many individual measures acting in concert that gives Japanese industrial policy its impact.*

Table 46.— Research and Development Expenditures by Several U.S. Computer Manufacturers, 1981

	R&D spending (millions of dollars)
Burroughs	**$220**
Control Data Corp.	202
Digital Equipment Corp.	251
Hewlett-Packard	347
Honeywell	369
IBM	1,600

SOURCES Annual reports

To place the expenditures of the Japanese Government in perspective, table **46** lists R&D spending by **a** number of [J. S.-based computer firms. On an annualized basis, subsidies provided by Japan's Government for R&D in information processing come to less than the expenditures of any one of these American companies. (Total subsidies for the information industries in Japan—including indirect support through tax preferences—could only be estimated by making a large number of essentially arbitrary assumptions; see ch. 10.) MITI's R&D subsidies are also modest in comparison to the research budgets of Japanese companies. Fujitsu spent **$260** million on R&D in 1981, while Hitachi and NEC spent $610 million and $230 million, respectively .[47] The government money does have an important function: helping with the kinds of long-term R&D that individual companies might otherwise have difficulty in justifying. In addition, MITI-sponsored projects—though not cooperative in the usual sense-attempt to stimulate creative thinking, technology interchange, and the complex of synergies so vital to engineering research. The Japanese electronics industry probably benefits more from these factors—which tend to be lacking within the laboratories of individual corporations-than a strict comparison of funding levels would suggest.

Of course, other governments also provide assistance to their computer industries, not excluding the United States. European nations routinely channel direct financial aid to local companies, along with indirect subsidies through procurement and tax benefits. Handsome incentives designed to attract investments and technology have been dangled before the European subsidiaries of U.S. and Japanese companies. In the United States, funding by the Department of Defense through the Very High-Speed Integrated Circuit program and this country's own supercomputer project—still in the planning stages—will have

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[47] Annual reports

commercial spillovers. The lesson is that no industrialized nation has been content to accept a secondary position in technologies and markets considered essential to future economic development. The concern is that the Japanese may be more successful in implementing their policies than other countries.

Marketing Strategies and Multinational Operations

Individual computer manufacturers in Japan have begun to formulate product strategies based on technologies expected to flow from government-supported R&D projects, as well as their internal activities. Marketing computers presents special difficulties because the chief competitors are already well entrenched; only in peripheral equipment such as terminals, printers, and disk drives have Japanese manufacturers made a significant impact outside their home market. In Europe and the United States, where nearly two-thirds of the world's computer systems have been installed, Japanese companies are inconsequential as independent suppliers.

In an industry where sales depend on a thorough grasp of user needs at a technical level—software as well as hardware—late entry is a major handicap. American suppliers-including newer participants like DEC and Hewlett-Packard—have built networks of sales and service centers staffed by engineers and technicians who now have longstanding ties with customers; IBM has such a network within Japan, Even those Japanese firms with strong international positions in microelectronics or telecommunications cannot match the distribution systems of U.S. computer manufacturers. To make much progress, Japanese entrants will have to invest substantial sums over many years without the expectation of immediate returns. The history of fields like consumer electronics indicates that at least some Japanese companies will be willing to make this commitment.

Perhaps surprisingly, given the global perspectives of consumer-oriented firms like Matsushita, the Japanese computer industry as a whole suffers from a pronounced lack of international business experience compared to American firms of even quite modest size, Until recently, most (but not all) Japanese companies have preferred to manufacture at home for export; this could prove a major weakness in computers. While a few Japanese electronics companies—Toshiba is another—have expanded aggressively via overseas investment, most of Japan's past international successes have come in products where integrated manufacturing and marketing in foreign countries has not been essential. The examples include steel, automobiles, and semiconductors; consumer electronics is only a partial exception. In each of these cases, Japanese companies, at least in the beginning, concentrated on export sales. Generally able to take advantage of established distribution systems, they invested overseas only when import restrictions compelled local manufacturing. The competitive pressures that led U.S. semiconductor or computer firms to invest in Europe and elsewhere have only recently begun to impinge on the Japanese. By now, American computer firms not only operate wholly owned sales and service networks in many parts of the world, they have established internationally dispersed and integrated manufacturing operations—partly in response to governmental demands and partly due to the nature of the market. Japanese firms, on the other hand, have been largely unwilling or unable to make the enormous investments required to participate in the world marketplace for computers.

Managers of Japanese firms, along with bureaucrats within the government, recognize their lack of background and experience, and are seeking remedies. The international (as opposed to R&D) strategy appears to be an incremental one, geared to minimizing the resources at risk and taking advantage of existing strengths. As part of this strategy, Japanese electronics firms, with the encouragement of MITI, are beginning to establish manufacturing plants in other industrialized countries, Following investments by Japanese consumer electronics suppliers in the United States and elsewhere, tentative steps have been taken in semiconductors, a market in which the Japanese have already become well entrenched through exports. These same semiconductor manufacturers are of course the major computer firms. Experience gained from investments in semiconductor production will help in structuring multinational computer operations.

As a parallel step, Japanese manufacturers have established marketing links with a number of foreign firms, Fujitsu now furnishes Siemens [West Germany) and IGL (Britain) with large mainframes, while Hitachi has similar arrangements with BASF (West Germany) and Olivetti (Italy). Fujitsu has taken a minority interest in SECOINSA of Spain, while agreeing to a technology transfer tie with a company partially owned by the Brazilian Government. In the United States, Fujitsu holds a minority interest in Amdahl, the PCM pioneer to which it exports large machines; for several years, Fujitsu distributed its smaller systems within the United States through a joint venture with TRW. National Advanced Systems, a subsidiary of National Semiconductor, sells Hitachi computers here.

Such arrangements build from the fact of Japanese parity in hardware for large computers, parity which does not extend to software; both Fujitsu's and Hitachi's systems are IBM-compatible. European firms have been unable to attain the economies of scale that Japanese manufacturers get in their home market, and have chosen to compete with American producers by importing from Japan, From the collective viewpoint of Japanese firms, these ventures—even where the equipment is labeled with some other brand name—increase market exposure and add to production scale. For some time, such relationships will continue to be essential elements in the marketing strategies of at least several of Japan's computer manufacturers, Even so, they link companies none of which has more than a minor share of the global computer market. Siemens, ICL, and the other partners of Japanese firms together do not account for even 5 percent of world computer sales. With the possible exception of ICL, none has a scale of operation and distribution approaching that of the competing local subsidiary of IBM. None is strong in minicomputers or small systems. Moreover, the Japanese participants remain a critical step removed from the customers whose applications their equipment is intended to serve—joint ventures will provide limited help at best in remedying past weaknesses of Japanese firms in software or customer support and service. To become viable international competitors, Japan's computer companies will need to accumulate experience in dealing directly with the requirements of customers in markets where they hope to sell.

Computer manufacturers in Japan do not share these problems in equal measure; the industry is far from monolithic. Fujitsu, at the moment in a clear leadership position (ch. 4), has, along with Hitachi, chosen to stake its international position on supplying IBM-compatible equipment--decisions that will limit both companies' options for many years to come. NEC has taken a different route, developing its own system software (although derivative of U.S. technology). Nor has NEC yet entered into marketing arrangements with foreign concerns. Instead, the company's management appears to be shaping a strategy intended to take advantage of the overlap and merger of computer and communications technologies, areas where the company is already prominent. Despite its relatively small size compared to other Japanese electronics firms, much less IBM or AT&T, Nippon Electric's managers are attempting to position their organization for what they see as an eventual competitive struggle with these two American giants for dominance of the international information industry,

At several points above, the entry barriers created by the well-established sales and service networks of American firms have been described. This aspect of the market for computers effectively turns one of the supposed advantages of the Japanese system on its head. Barriers erected by government to keep out foreign firms have given Japan's manufacturers advantages in a number of industries, partly through scale economies. Closed markets created by import restrictions and foreign investment controls have been reinforced by complex distribution structures and a deeply ingrained “Buy Japanese” attitude. In computers, however, the longstanding customer ties maintained by U.S. firms combine with technological strengths to create formidable entry barriers for Japanese companies—indeed, new entrants from any part of the world. Windows do open because of technological advance; through these windows newcomers have moved into markets for microcomputers, small business systems, and other specialized products. Thus far, most of these entrants have been American firms—in part because the U.S. market is so large, but also because American companies control the distribution apparatus in most parts of the world. The going will be difficult for Japanese manufacturers, although they are beginning to find niche products—desktop computers may be one—suited to their strengths.

In medium and large systems, Japanese companies can choose from a number of alternative (or complementary) courses of action. One is to continue to build joint relationships with foreign enterprises. As noted above, such a strategy will require, first, deeper involvements with end users by the Japanese participants, and, second, movement into markets in more parts of the world. If firms such as Burroughs, Control Data, or Honeywell were to be enticed—each has a relatively small but well-established market share—the prospects for Japanese firms would look a good deal better. The constant pressure of trying to achieve costs comparable to IBM’s could well force one or more American companies to accept such ties.

As an adjunct to joint marketing ventures, Japanese manufacturers will probably seek other ways of incrementally expanding sales, while awaiting the fruits of the fifth-generation computer project. If Japan succeeds in pioneering a new generation of hardware and software, companies with multinational production and marketing experience will be able to exploit the new technologies most effectively. In this context, present efforts would not be so important in themselves; rather they would be preparatory steps for rapid growth in the 1990’s. Another path, one that some firms will certainly pursue, is to concentrate on selling smaller systems and personal machines. Here the now-traditional Japanese entry strategy is feasible because distribution networks are open to all comers, Thus far, attempts to challenge American companies like Apple or Tandy in personal computers, or the many U.S. entrants in the market for small business systems, have not been notably successful—in the United States or elsewhere. Still, if and when such products become more nearly standardized and interchangeable, Japanese companies could expect an easier time, But even if companies based in Japan were to expand into these markets, it is not at all obvious that this would help them in other types of systems.

Japanese producers of computers are thus taking what seem the only paths available in their attempts to break into the world market: independent technology development coupled with joint marketing relationships. That the marketing ties involve firms that are themselves weak and in need of partners is hardly surprising, but makes the establishment of a viable international presence that much more difficult. At this point, the Japanese have had only marginal impacts on global markets; at home, IBM-Japan remains a formidable competitor. Whether or not technical developments in microelectronics and software will thrust Japan into a position nearer the forefront remains to be seen. If Japan’s computer manufacturers do begin to increase their market shares significantly, the most likely victims will be smaller competitors—first in Europe, then perhaps in the United States.

Summary and Conclusions

While international competitiveness—in any industry—depends on many factors, the business strategies pursued by private corporations are central. Costs of labor and capital, technological resources, government policies, human resource endowments—all can, at least in principle, be looked on as forces impinging on management decisions, as features of the landscape for business tactics and strategies.

While a useful perspective, the strategic view of competitiveness is nonetheless an imperfect substitute for more quantitative indicators. Unfortunately, the swiftness of technical change in electronics precludes useful quantitative measures. Productivity trends mean little where the standard products of today—whether semiconductors or mainframe computers--have capabilities that may be orders of magnitude beyond those of a decade past. Comparative manufacturing costs carry weight in some cases, but not where one company can build products exceeding the reach of competitors. Little meaning attaches to patent statistics as surrogates for technical ability when incentives for acquiring patents vary widely among countries and nowhere correlate very closely with qualitative aspects of technology.

If shifts in international competitiveness cannot be extracted from statistical series, careful examination of business activities can yield insights into future prospects as well as past trends. In semiconductors and computers, not to mention consumer electronics, American firms--once undisputed leaders in technology, as in sales in their home markets and virtually around the world-face much stronger competitive pressures. Foreign enterprises, mostly Japanese but also entrants with headquarters in other Far Eastern countries, are selling larger volumes of electronics products within the United States; American corporations are having a more difficult time in foreign markets, The sources of these shifts are many, By-and-large, they are *not* due to mistakes or faulty strategies by American firms or by the U.S. Government. First and foremost, rising foreign competition flows from continued rebuilding of the electronics industries of Europe and Japan in the aftermath of World War II. It is not a new phenomenon. By the mid-1950's, when much of the basic reconstruction of overseas economies was complete, companies in Japan and much of Europe found themselves still well behind the United States in their ability to design, develop, and produce electronics products. But they were in a good position to catch up. The first signs of success came early, when Japanese manufacturers like Sony created new families of transistor radios smaller and lighter than those offered by American firms. The transistor was invented in the United States, the first transistor radios also made here, but Japanese firms pushed their product development efforts vigorously and outstripped their U.S. rivals within a few years. Now that Japan is in the lead with new generations of consumer products it will be difficult for American or European manufacturers to regain the lost ground.

In computers and semiconductors, Western Europe came out of the war well ahead of Japan. The Europeans had good fundamental technology, but were stymied by small and fragmented markets, as well as by managements that had neither the resources nor the vision of their counterparts here. Subsidiaries of U.S. corporations became the backbone of the European computer industry---they still are—and took the lead in microelectronics. In the Japanese market, American firms could not match their accomplishments in Europe because of the protective policies of Japan Government. Still, if not dominant, the United States was—and remains—a major force in Japanese computer sales, particularly for large machines, as well as in some types of semiconductor devices. *Continued efforts by American firms--backed if necessary by the U.S. Government--to participate on equitable terms within Japan, whether by exporting or by direct investment, appear vital for maintaining U.S. competitiveness in electronics. The* Japanese electronics market is large and still expanding rapidly; it is now more important than Europe.

Japanese industrial policy has been a more significant source of support in semiconductors and computers than in consumer electronics. The MITI-sponsored VLSI research program—while not as important as some Americans have claimed--did help Japanese firms master process technologies for very large-scale digital ICs. In standard device families like memory chips--where the path of technological evolution is clear for all to see, and technological success a function more of painstaking development and detail design than highly creative engineering—the Japanese have excelled. While they cannot as yet match the breadth of American product lines, they will certainly continue to improve their capabilities in circuit design as well as processing. If U.S. semiconductor manufacturers can expect intense competition, they too have their advantages—a different set than those of Japanese firms. *If American companies continue to capitalize on these strengths—the best trained engineers in the world, quick recognition and response to market needs, innovations in circuit design, applications of computer-aided techniques, specialized products pursued with entrepreneurial zeal—the United States should be able to maintain a leadership position.* Still, American companies will not be able to monopolize world sales as they did a decade ago.

Competitive pressures, evolving technology, and growing capital intensity—along with the continuing expansion of captive production by integrated firms—are changing the structure of the U.S. semiconductor industry. New structures bring new strategies. Structure is changing in the computer industry as well, driven by the technology of computing, itself depending heavily on microelectronics. As computing power becomes ever cheaper, more and more applications become cost effective. These attract new firms, designing and developing not only peripherals and software, but specialized processors—minicomputers, personal and desktop units, business systems, While the mainframe is hardly a dinosaur, a “computer” can now be a great many things—many never envisioned by the designers of the general-purpose machines sold two decades ago by a small number of companies such as Univac and IBM. Computing power is now cheap and widely dispersed, often invisible to users. As distributed processing and data communications continue to spread, new firms will try to establish themselves, entering through windows of technological or market opportunity. Some of the older firms will find themselves hard-pressed to keep up, even survive; their managers will face hard choices in allocating limited resources. Few companies—even including the largest, here or in Japan—will be able to cover more than a small fraction of product markets.

While no one can foretell competitive outcomes in the world computer industry, it is obvious for all to see that Japan has made a series of explicit decisions—going back as far as the 1960’s and involving both government and industry–aimed at claiming a major share of sales and applications. Based on past performance in other sectors of electronics, the probability of continued expansion by the major Japanese computer manufacturers is high. Because the characteristics of the market for data processing equipment differ from those for semiconductors, the United States remains in a stronger relative position. There is no reason why the United States cannot continue to hold an overall lead in both technology and sales.

As events in all three portions of the electronics industry demonstrate, competitive positions in global markets have shifted more-or-less continually over time. Some firms in some parts of the world rise, others decline. Of those that decline, a few may eventually revive, others disappear. No country can expect all its industries to thrive in international competition; any nation that trades will be more competitive in some industries than others, the leaders in competitiveness shifting over time. That U.S. competitiveness has slackened in consumer electronics does not imply that similar events will follow in other sectors. This could happen, but there is no reason to expect declines in microelectronics or computers paralleling those in color TV—particularly so long as the technology continues its rapid evolution and markets expand at high rates. These are conditions under which American firms have traditionally prospered. When the pace of events slows, other sectors of the Nation’s economy might begin to find themselves faring better than electronics in international competition.

CHAPTER 6

Manufacturing: Quality, Reliability, and Automation

Contents

List of Tables

List of Figures

CHAPTER 6

Manufacturing: Quality, Reliability, and Automation

Overview

Assuming comparable products–and a lack of subsidies or other strong exogenous influences—costs are a primary determinant of international competitiveness, in electronics as in any industry, Comparable products may not be identical, and small differences in performance or specifications can override small differences in costs in the eyes of customers. But even for military systems, manufacturing costs —which depend on both the design of the product and the design of the production system—are almost always a major consideration.

In electronics, costs are much more critical to the successful marketing of some types of products than others. Intense price competition in consumer electronics—televisions, video cassette recorders, stereo equipment—makes low manufacturing costs a vital competitive weapon. Much the same is true for standardized semiconductor products ranging from discrete transistors to random access memory chips; price cutting is the rule, costs highly sensitive to the yields of the production process (ch. 3). For other types of semiconductor devices, low manufacturing costs and low prices are less vital; if only a single firm makes a particular integrated circuit (IC)—perhaps one that meets unusual or demanding performance requirements such as a high-speed, high resolution analog-digital converter—it will probably set prices to maximize profits, given the lack of competition. Leading-edge computer hardware and software falls in much the same category. Even so, electronics firms are seldom able to establish and maintain technological advantages so large that manufacturing costs are of little relevance.

In addition to direct and indirect manufacturing costs, prices charged to purchasers reflect expenses associated with research, design, and development, as well as marketing and distribution. While accounting procedures vary, such costs are generally treated as *indirect* expenses–i.e., a percentage is added to the direct manufacturing cost of each item produced, as for other overhead. Depreciation of plant and equipment is handled the same way. *Direct* manufacturing cost then consists primarily of parts, materials, and labor, Research, design, and development costs are much higher for products such as computers or large-scale ICs than for consumer items where technical change is slow and incremental, major redesigns infrequent. In the production of semiconductor devices and computers, research and development tends to account for a considerably greater percentage of costs; depreciation charges are also likely to be greater because new production equipment must be purchased as the technology advances.

But costs are not the only way in which manufacturing operations affect competitiveness. Beyond production costs—which depend on wage rates, prices of materials, supplies, and components, capital charges, and related factors—lie dimensions such as the quality and the reliability of the goods produced. While more sophisticated purchasers are most interested in the quantifiable dimensions of quality and reliability, in markets for consumer products perceptions—whether or not well founded—influence the decisions of prospective customers. Along with other qualitative aspects, such as appearance, purchasers base their assessments of value for money on perceptions of quality and reliability.

These attributes—both the reality and the perception—depend on factors such as engineering design, how the people in the work force are trained, organized, and managed, and on the capabilities, indeed the quality, of the manufacturing equipment. Automation can improve quality by reducing the probability of human error or simply improving the consistency of the production process. In other instances, there will be no effect. In some cases, quality may be degraded; people are better at some jobs than machines, and vice versa—human skills far exceed those of machines for tasks involving pattern recognition, or where judgments must be made based on partial or imperfect information. Regardless of specifics, *the quality of a firm products will ultimately depend on the stress top management places on quality as a goal of the production process.*

By the end of the 1970's, issues of product quality were in the public eye for industries as disparate as nuclear power, automobiles, and semiconductors. Perceptions were widespread that the quality of American goods had declined compared to those from foreign countries.[1] Some observers speculated that American firms and American labor had slipped, others that consumers had become more demanding and were no longer satisfied by quality standards that had once been acceptable in the U.S. market. Either way, a "quality gap" with respect to imports, extending even to commodity items such as steel, has frequently been advanced as a contributing factor in the declining international competitiveness of American firms and industries. To take an example from electronics, the reputation of RCA's color TVs had slipped badly by the end of the 1960's.[2] Not only did this hurt the company's sales, RCA also lost some of its dealer base. Automated production was at the heart of the company's effort to improve the quality and reliability of its TV line.

Despite the importance of direct costs of production for competitive success in electronics, OTA has not attempted to estimate or compare manufacturing costs. Companies guard cost data closely, More important, the dynamics of shifting cost structures, rather than costs at a given point in time, are central to changing competitive fortunes. To some extent these dynamics can be inferred without the need for proprietary data. This chapter then focuses on aspects of manufacturing such as quality and reliability, plus automated production technologies.

Product quality is treated primarily from a hardware perspective: What *are* the relative levels of quality in the United States and Japan? (The comparison is limited to these two countries.) How do product design and the application of production engineering and quality assurance techniques affect quality? How do products fail?[3] Less tangible but equally important matters of the human element in manufacturing and quality control—including questions of management and organization, as well as the education and training of the work force —are also discussed in chapter 8.

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[1] OTA's contractor on quality and reliability notes that about 80 percent of the attendees at an April 1980 American Management Association seminar on Japanese techniques for quality control and productivity improvement felt that the products of their own firms were surpassed by products from Japan. Those surveyed were at the seminar to learn from the experience of Japanese companies-not a random sample. See J. Mihalasky and A. B. Mundel, "Quality and Reliability y of Semiconductors and CTVs: United States v. Japan, " report No. C972, prepared for OTA by Consultant Services Institute, Inc., under contract No. 033-1170.0, p. 6.

[2] R. A. Joseph, "Automation Helps RCA and Zenith Keep Color-TV Leadership in Face of Import s," Waif *Street Journal,* May 5, 1981, p. 56.

[3] Much of the material on quality and reliability assembled below is drawn from "Quality and Reliability of Semiconductors and CTVs: United States v. Japan, " op. cit. This report is based in part on a series of questionnaires and surveys—20(1 covering both manufacturers and purchasers of ICs, 60 covering independent TV service shops—plus 42 visits to facilities of U.S. and Japanese firms that make ICs or semiconductor manufacturing equipment.

While comparisons between products of American and Japanese firms were of primary interest, some of those surveyed also commented on the West European electronics industry. In general, the feeling was that European firms had been behind both American and Japanese manufacturers in the quality and reliability of their ICs and TV receivers. While European producers may recently have caught up to the United States in the quality and reliability of certain types of semiconductor devices, overall they probably still lag both the United States and Japan.

Quality and Reliability

Meanings and Measurement

Quality, meaning fitness for function–the extent to which a product meets the specifications of its designers and manufacturers, the expectations of users—can be treated subjectively or objectively, Consumers typically make subjective judgments concerning the quality of competing products. Manufacturers attempt to define quality in terms of parameters that can be measured quantitatively–e.g., the ability of a TV set to receive weak signals. In addition, they may adopt rating scales which trained inspectors apply to characteristics that are not inherently quantitative. Often the indices are based on comparisons with samples or standards; an example would be the appearance of the cabinet for a TV set—whether the trim fit properly and colors matched, whether the panels were free of waviness, the number of visible flaws and blemishes.

Through measures like these, manufacturers try to satisfy consumers' perceptions of quality as well as ensure that their products function properly—all at a reasonable cost, For products like ICs or computers, the quality image that a firm establishes is likely to be more nearly consistent with quantitative measures than for consumer goods; indeed, some electronic components are sold to specifications written by the purchaser. Nevertheless, the perceptions and subjective judgments of customers sell many computers, and ICs are inspected to be sure that logotypes and part numbers are properly printed and convey the desired image.

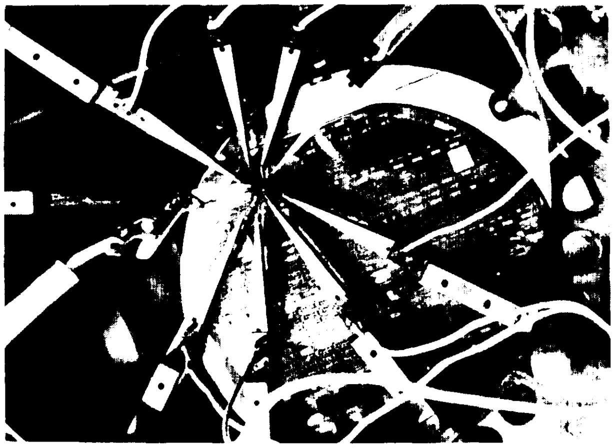


Photo credit Bell Laboratories

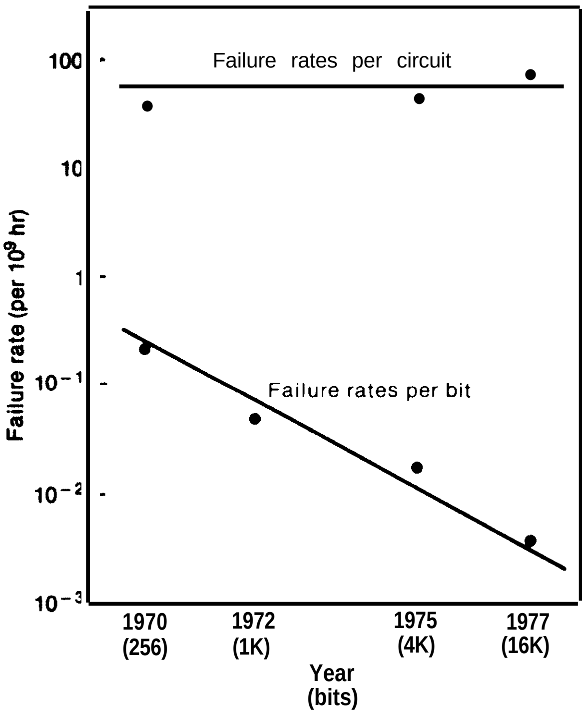
Probes for testing Integrated circuit chips

Reliability is a measure of *continuing* fitness for function once a product is placed in service. While quality is determined at a single point in time—generally the end of the manufacturing process or the beginning of service life—reliability is measured *over* time, as a failure rate or similar parameter.

The most common indicators of reliability are mean time to failure or mean time between failures–the interval between disabling failures averaged over a large number of items, usually in terms of actual hours of operation, Failures that average one per million hours can be expressed as a mean time between failures of 10^6 hours or as a failure rate of 10-~ per hour. The graphical presentation in figure 36 shows the number of ICs (from a much larger group) expected to fail in 10^9 (1 billion] hours of operation. A billion hours is 114 centuries; such plots are constructed from short-term data using statistical techniques. A failure rate of one per billion hours means that the expected or most likely lifetime for a single item chosen at random is 10^9 hours.

Definitions of reliability based only on failures that *prevent* the product from functioning are straightforward, Measurement can nonetheless be time-consuming, as well as presenting difficult statistical problems. Still, a light bulb works until it burns out—testing a large enough sample of nominally identical bulbs will yield a statistically valid mean time to failure. Partial failure, or gradual degradation in performance, is more difficult to quantify. A lo-year-old TV set may still function, but not as well as when new; there are no simple measures of "reliability" that apply to such phenomena.

Figure 36.—Data for MOS RAMs Showing Constant ‘Failure Rates per Circuit as Integration Levels Increase, Decreasing Failure Rates per Bit



SOURCE T. Goto and N. Manabe, “How Japanese Manufacturers Achieve High IC Reliability,” *Electronics*, Mar 13, 1980, p. 140

The reliability of computer software presents another type of problem. Software does not “fail” or “wear out” from physical causes as does hardware—although the media that store the software may suffer such failures. But software still needs continual maintenance; complex programs are altered and updated periodically—sometimes to correct errors that are caught only after the software has been placed in service, other times to improve performance, The reliability of a piece of software then depends on the frequency of modifications required to correct programing errors that could cause the system to malfunction.[4] As a result, the reliability of an entire computer *system* depends on both hardware reliability and software reliability—failures of the first type having physical causes (although ultimately depending on design and manufacturing practices), failures of the second type depending wholly on the design of the software.

Exhaustive engineering efforts are directed at ensuring the reliability of new and complex systems of all types, particularly where failures can be costly or dangerous—e.g., airplanes or nuclear powerplants. To improve reliability, designers apply techniques such as failure mode analysis—estimating the probabilities of different types of failures and attempting to minimize the more serious. A common practice is to add redundancy to the system, providing functional alternatives so that the failure of one part does not compromise the whole. A wire rope has a great deal of redundancy because one strand, or many strands in a large enough cable, can break without impairing the strength significantly. A chain, in contrast, has no redundancy. Complex computer systems often include redundant processors and other hardware components, as well as fault-tolerant software that can reconfigure the system following hardware failures. In any type of system, degraded performance will normally be preferable to sudden and total failure, For example, electronic control systems for automobile engines are designed so that component failures–perhaps of a sensor or a memory chip —will not cause the engine to suddenly stop running. Instead, the engineers aim for “soft” failure modes, or “limp-home” capability.

While quality and reliability are related, they are by no means synonymous. Reliability depends more heavily on design engineering, quality on control of the manufacturing process. In general, as experience in making a product accumulates, levels of quality and reliability both increase. Note the similarity with yield increases for semiconductors, as discussed in chapter 3. Figure 37 illustrates the reliability improvement over time of the Motorola 6800 microprocessor, a popular 8-bit circuit that has been in production since 1974.

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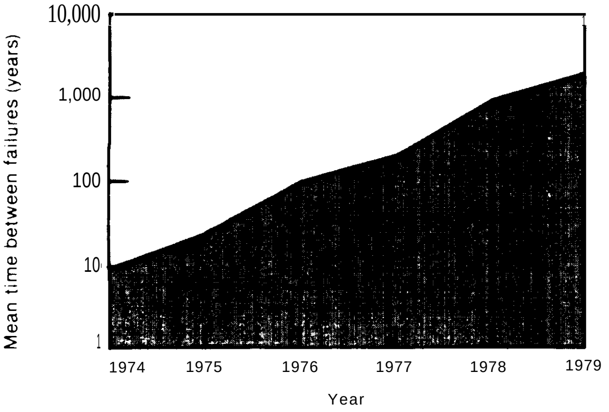
[4] J. D. Musa, “The Measurement and Management of Software Reliability,” Proceedings *of the IEEE,* vol. 68, 1980, p. 1131. More generally, see R. Dunn and R. Unman, *Quality Assurance for Computer Software (New* York: McGraw-Hill, 1982). New computer programs tend to have of the order of one mistake per hundred lines; some but not all of these will be found before the program is placed in service—M, Lipow, “Number of Faults per Line of Code,” *IEEE Transactions on Software Engineering,* vol. SE-8, July 1982, p. 437.

Figure 37.—Reliability Improvement With Cumulative Production Experience for a Microprocessor (Motorola 6800)



SOURCE D Queyssac, Projecting VSLI s Impact on Microprocessors, ' *IEEE Spectrum* May 1979 p 38

Statistical methods can be applied to quality and reliability problems during both the design and manufacturing stages, but the specialized discipline of statistical quality control is largely a tool of the production process.[5] As an example, defects in ICs can be monitored over time to give insight into the effects of processing variables. In contrast, reliability analysis techniques are applied, not to process variables but to tests conducted on finished products and to field service experience. Steps taken to improve quality sometimes but not always improve reliability.

Organizing and Managing for Quality

Managing the interface between design engineering and manufacturing engineering presents a classic set of problems that affect production costs, as well as quality and reliability. Designers specify the characteristics of products in great detail, while manufacturing engineers must determine how to make the product so that it will have those characteristics. Sometimes the same people are involved in both functions, but more commonly the responsibilities fall on different parts of an organization,

Separation of responsibility for design, production, and quality control characterize manufacturing enterprises all over the world, but perhaps more so in the United States than elsewhere (e. g., in Japan), One reason for the prevalence here appears to be the heritage of scientific management, an approach to job methods and the organization of production originating in the work of an American engineer, Frederick Taylor, during the early part of the century.[6]

Production engineering includes all the technical aspects of the manufacturing process: plant layout, process design, work methods, selection of equipment, quality assurance. In larger firms some of these functions may not only fall in different departments, but be further subdivided. Still, regardless of organization charts that isolate the design, manufacturing, and quality functions from one another, these activities are closely related functionally.[7] Product design affects the choice of manufacturing technology. The equipment that a firm has on hand, together with the costs of investing in new equipment, can severely constrain the design of its products. Inspection and testing, quality and reliability, depend not only on the choice of manufacturing technologies, but on the overall control of the process. Application of statistical quality control techniques to individual steps in manufacturing may be straightforward, but overall integration and control of a complex production process is much more than the sum of control of the individual steps.

Although design and production are inherently interdependent, in some cases even simple communication is lost. Stories of design and production supervisors who are not on speaking terms—or the commonplace of the design group "tossing the drawings over the

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[5] See, for example, J. M. Juran, F. M. Gryna, Jr., and R. S. Bingham, Jr. (eds.), *Quality Control Handbook*, 3d ed. (New York: McGraw-Hill, 1974), especially sees. 22-27,

[6] See, in particular, *Quality Control Handbook*, op. cit., sec. 48 on "Quality Control and the National Culture, " which points out that the sharp divisions of responsibility typical of larger organizations in the United States—e. g., separate departments for quality control or inspection–create reservoirs of specialized expertise, but at the same time may hinder the widespread *application* of this expertise, Scientific management is discussed in more detail in ch. 8.

[7] J. A. Alic, "Manufacturing Management: Effects on Productivity and Quality, " *Efficiency of Manufacturing Systems* (New York: Plenum Publishing Corp., 1983), p. 281.

wall" to the manufacturing department—are rife. There is at least anecdotal evidence that *foreign firms may handle, not only the problems of training design and manufacturing personnel, but of managing the interface between design and production, better than many American companies.* One approach is to make the same individuals or groups responsible for both design and production, or at least extend management responsibility for integrating design and manufacturing farther down into the organizational structure.[8] In Japan, for example, companies often rotate design engineers through production departments early in their careers.[9] Not only do Japanese electronics firms tend to stress integration of product and process design within their organizations, but they frequently involve vendors, distributors, and customers in the work of their manufacturing engineers.

While some American firms have grappled with such problems more successfully than others, companies here begin with a fundamental handicap: low prestige and low pay tend to be associated with white-collar jobs in manufacturing relative to other categories of engineering or management; the best people are seldom attracted to such jobs. Manufacturing carries higher status in European or Japanese corporations. And, on the manufacturing side of an American firm, quality control tends to be at the bottom of the pecking order. Too often it seems that manufacturing managers see quality control only as an obstacle to production.

American management has been criticized for overemphasizing the costs of quality, whereas some quality control professionals argue that a comprehensive program for designing and building quality (and reliability) into a product at all stages can save money. Again, there seems to be a contrast with the typical attitude in Japanese companies—discussed in more detail below—where prevention of defects is emphasized more strongly than detection through inspection.

One reason for the low status of manufacturing in the United States is simply the low priority that industry places on it, as indicated by low pay scales in manufacturing relative to other parts of the firm; engineers employed in manufacturing and quality control get salaries near the bottom of the range for their age and experience groups at all points during their careers; engineers doing administrative work earn 50 percent more than those involved in production.[10]

Another indication of lack of attention to manufacturing is that only 4 percent of graduates of engineering technology programs in the United States specialize in the "manufacturing, quality control, industrial" category.[11] Engineering technology is a relatively new field intended to provide practically oriented training meeting the needs of industry (see ch. 8 for further discussion of technology education), thus it is particularly surprising that such a small fraction of graduates are oriented toward careers in manufacturing. In engineering programs, so few U.S. graduates receive degrees in manufacturing that they are not separately tabulated. Although students who have studied mechanical or industrial engineering often find manufacturing jobs, many programs in these fields have dropped the once common required courses in such topics as manufacturing processes and plant layout,

The Importance of Design

Figure 38 contrasts schematically the effects of design and manufacturing on reliability. Reliability tends to improve with production experience, but failures stemming from design weaknesses sometimes show up only after long periods in service, hence may even increase over time. Such behavior is typical of many

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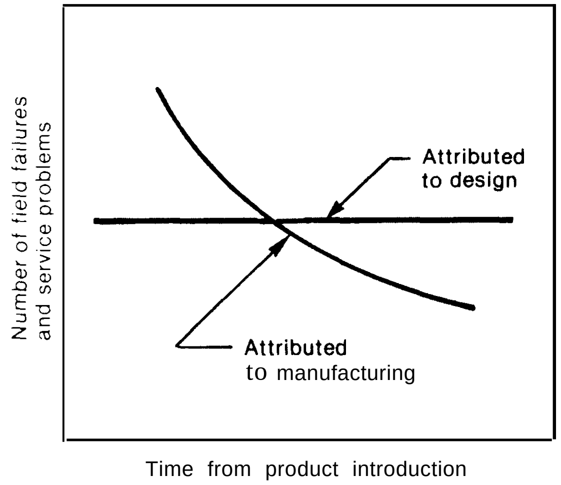
[8] R. E. Cole, "The Japanese Lesson in Quality, " Technology *Review,* July 1981, p. 29. See also "Sources of Japan's International Competitiveness in the Consumer Electronics Industry: An Examination of Selected Issues, " report prepared for OTA by Developing World Industry and Technology, Inc., under contract No. o33-101o.o, pp. 103-104.

[9] J. M. Juran, "Japanese and Western Quality–A Contrast," *Quality Progress,* December 1978, p. 10.

[10] R. Connolly, "Career Outlook," *Electronics,* June 16, 1981, p. 266.

[11] P. J. Sheridan, "Engineering and Technology Degrees, 1982," *Engineering Education,* April 1983, p. 715. The percentage is the total for associate and bachelor levels.

Figure 38.—Typical Trends in Failures Attributed to Design and Production



SOURCE *Quality and Reliability* of Semiconductors *and CTVS United States v Japan* report No C972, prepared for OTA by Consultant Services Institute Inc under contract No 033.11700 p 18

types of manufactured products, not just electronics.

Table 47 indicates the extent to which the reliability of color TVs depends on design as compared to production. According to the table, a greater percentage of service failures have their sources in the design and development process than in assembly. One of the reasons that Japanese TVs achieved better reliability than American-made sets during the 1970's appears to have been more conservative design practice. For example, Japanese sets were designed to draw less power. Picture tubes operated at lower voltages, with some sacrifice to picture quality but lower internal temperatures and less stress on components. In some contrast, the vice president for engineering of an American TV manufacturer, now taken over by a Japanese firm, has been quoted as saying, "At Warwick, much of the design work happened after the product was introduced. We relied on field failure information to tell us where we had a problem."[12]

Table 47.—Causes of Field Service Failures in Color TV Receivers

Attribution	Percentage of field failures
Design (and development) . . . . ., .	20-40%
Quality of components	40-65%
Final assembly ., ...	15-20%

SOURCE: J M Juran Japanese and Western Quality—A Contrast," "Quality Progress December 1978, p 10

According to the estimates in table 47, about half the failures in TVs are due to defective components. Some of these maybe purchased, others manufactured internally—some components fail because they themselves suffer from design problems. Many of the components in a television receiver are transistors or ICs. As illustrated by figure 36, failure rates per chip tend to remain about the same as circuit density increases. If so, going to higher levels of integration and increasing the number of circuit functions per chip will have two important consequences. First, it will cut assembly costs because the total number of components will decrease. Second, there will be fewer components to fail, hence reliability should improve. The cost and quality/reliability advantages of chassis designs based on fewer but more complex ICs have led to rapid reductions in the numbers of components in TV receivers, In 1977, Zenith's 25-inch color TV contained 685 components. Less than 2 years later, the number had been reduced to 441.[13]

As part of their strategic thrust into the U.S. market, Japanese consumer electronics firms set out to create an image of high-quality, reliable products (ch. 5). They needed trouble-free products in reality as well as appearance in order to exploit the distribution channels available to them. Reductions in parts counts were one of the techniques adopted. Likewise, by the end of the 1970's Japanese semiconductor products had attained enviable reputations for

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[12] "American Manufacturers Strive for Quality—Japanese Style," *Business Week*, Mar. 12, 1979, p. 32B.

[13] Ibid. Over roughly the same time period, the Japanese-owned Quasar firm reduced its parts count from 516 to 406, while Toshiba claims a 60-percent decrease in parts count between 1971 and 1979. Other Japanese firms have reported similar reductions, typically coming earlier than for American TV manufacturers. For example, the number of parts in a particular Panasonic color TV model went from 1023 in 1972 to 488 in 1976—see "Quality and Reliability of Semiconductors and CTVs: United States v. Japan," op. cit., p. 47. Japanese TV manufacturers often pursued simpler chassis designs in parallel with the development of automated production facilities, as discussed later in the chapter,

quality and reliability. But manufacturers in Japan have not relied on design improvements alone; employees of the large, integrated Japanese electronics companies tend to have considerably more training in quality control and production technologies than their counterparts in the United States.

The Japanese Approach

Managements of Japanese electronics firms profess to believe that improvements in quality and reliability will automatically cut costs and increase productivity, as well as aiding their marketing strategies, The rhetoric emanating from top managers in Japan emphasizes quality to a greater extent than statements by American executives. More concretely, Japanese manufacturing companies rely much more heavily on line managers for quality assurance, rather than the staff specialists common in American firms.

Despite this and other organizational differences, most of the methods that Japanese manufacturers use in pursuit of quality and reliability have been borrowed from the United States, just as for product technologies. Japanese industrialists have been noted for their study missions to visit foreign companies and research laboratories. Engineers and managers from Japan have become skilled at picking out useful ideas from such visits—whether related to product technologies or to aspects of manufacturing such as quality control—and improving on them. The theory and practice of quality assurance may have diverged more in the United States than in Japan,

Origins of Quality Consciousness

Stress on quality and reliability within Japanese manufacturing firms goes back at least to the period of postwar reconstruction.[14] Managers realized that Japan's exports were widely viewed as cheap and shoddy. Much of the early effort toward improving Japanese products was orchestrated by the Union of Japanese Scientists and Engineers (JUSE), which helped to locate foreign expertise in quality and reliability, and diffused this knowledge through publications, training courses, and conferences. As many as 10 million workers may now have passed through JUSE training courses.[15]

During the 1950's, well-known Americans such as W. E. Deming and J. M. Juran traveled and lectured extensively in Japan; Juran, in particular, is credited with much of the visibility that quality control now enjoys at upper management levels in Japanese companies, In many respects, the quality control movement in Japan began at the top and spread downward—in considerable contrast to the situation in the United States, where the principal advocates of quality assurance have often been lower level technical specialists. The well-known Deming Prizes–established in 1951, and given to both companies and individuals for achievements in quality control—illustrate the prestige of such activities; they are among the most coveted industrial awards in Japan.[16]

Japanese executives like Hajime Karatsu, Managing Director of Matsushita Communication Industries, have been quality control advocates for years; the Reliability Center for Electronic Components of Japan was formed in the early 1970's at the urging of industry leaders, including Karatsu. Financed privately by more than 200 electronics firms, the center conducts tests on components and systems, establishes procedures for determining reliability, drafts specifications, and diffuses information on quality improvement within the industry.[17]

The Japanese emphasis on line responsibility has led to extensive training programs for assembly workers and foremen. Efforts to reach the latter have included radio and TV

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[14] " Quality and Reliability of Semiconductors and CTVs: United States v. Japan," op. cit., pp. 38-40. The historical material that follows is drawn largely from this report.

[15] " American Manufacturers Strive for Quality—Japanese Style," op. cit.

[16] *Quality Control Handbook*, op. cit., sec. 48, p. 48-9. On the prominence of the Deming Prizes, see U. C. Lehner, "Japanese Firms' Stress on Quality Control Is Reflected in Dogged Vying for Award, " *Wall Street Journal*, Sept. 24, 1980, p. 52. There is even a widely publicized "Quality Month" in Japan.

[17] " Guide to REI, " Reliability Center for Electronic Components.

broadcasts; about 100,000 of the accompanying textbooks were sold in the first year (1956) of the radio series alone, A monthly magazine Gemba-to-QC (QC for the Foreman), was established about the same time and evidently served as a breeding ground for quality circles—a technique that has recently received a great deal of attention in the United States (see ch. 8). The first quality circle was registered with JUSE in 1962; within 15 years, memberships in registered quality circles had grown beyond 800,000. JUSE reports that about 100,000 circles are now in operation, with about 80 percent of the nation's blue-collar work force involved.[18]

Standards

In the United States, product standards tend to be voluntary, but Japan's Industrial Standardization Law, passed in 1949, places the responsibility with government. The law deals explicitly with quality and provides that all Japanese exports must carry the approval of the Japanese Institute of Standards (JIS).[19] Consumers in Japan are also said to look for the JIS mark. In 1957, the Japanese Government took a further step aimed at upgrading the quality image of the country's products, passing the Export Inspection Law. This regulation created an additional set of standards aimed mostly at smaller companies, and also provided for the establishment of testing laboratories.

Organizing for Quality

Despite the visibility of quality circles, they are only one tool among the many that Japanese electronics firms have adopted, Because training in quality is widespread, and responsibility for quality assurance diffused within the organization, quality control departments in Japanese firms tend to be small compared to the United States. Companies in Japan have often dispensed with some fraction of in-process inspectors, making each worker responsible for accepting or rejecting the parts passing through his or her station. This is but one example of the diffusion of responsibility through the organization. It is effective in part because—at least in the larger companies—employees are carefully selected even for unskilled, entry-level jobs. Transfers of blue-collar employees within the firm are common—a practice facilitated by unions organized on a companywide rather than craft basis, and newly hired workers, or those transferred to an unfamiliar job, typically pass through training programs that are lengthy compared to those in the United States. At Matsushita, for instance, new assembly line workers are given a month of training—with a week devoted to quality control—before they begin to work on the line.[20] In the United States, new assembly line workers would typically get a few minutes informal instruction by a foreman, who would then monitor their performance as they learned by doing. Both approaches have their advantages.

An apparent paradox has developed in the wake of the 30-year history of quality control activities in Japan outlined above. Many of the original techniques imported from the United States were concerned with statistical quality control—a subject in which Deming and Juran were authorities, Yet there is little evidence that the application of statistical techniques to quality or reliability has advanced any further in Japan than elsewhere. In fact, applications of statistics are seldom mentioned in descriptions of the quality control procedures of Japanese electronics firms, Rather, the *Japanese appear to have focused their efforts on making individual employees aware of—and committed to—the achievement of quality*. Statistical quality control is no more than a small part of the

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[18] "Quality and Reliability of Semiconductors and CTVs: United States v. Japan, " op. cit., p. 60. Circles also enroll clerical and management personnel, It has been claimed that the average quality circle in Japan saves an employer about $100,000 per year.

[19] Ibid., p. 66. A number of other Asian nations have followed the Japanese example in trying to improve the quality image of their exports. In Taiwan, a small tax is levied to cover the cost of inspection; the tax drops as quality levels go up. See "American Manufacturers Strive for Quality—Japanese Style, " op. cit.

[20] "Quality and Reliability of Semiconductors and CTVs: United States v. Japan, " op. cit., p. 52. While three-quarters of the workers in Japanese electronics firms were classed as unskilled at the end of the 1970's, the proportion of skilled as compared to unskilled employees is expected to rise rapidly as automation proceeds. Presumably this is an important motivation for the training programs found in many companies.

quality programs of typical Japanese electronics manufacturers, which the companies themselves often refer to as "companywide quality control. " Intangibles and consciousness-raising are at least as important.

Quality and Reliability of Integrated Circuits

Manufacturing and Testing

Chapter 3 outlined the steps in making ICs. Most of the larger American merchant firms perform some but not all of these in domestic plants, with labor-intensive operations carried out offshore, A typical pattern might be as follows:

Ž Operations performed in the United States:

1. Silicon crystals, generally purchased from outside vendors, are sliced into wafers and prepared for lithographic processing,
2. Wafer fabrication processes such as lithographic patterning, oxidation, etching, diffusion of dopants, metallization, and annealing are carried out; some of these may be highly automated.
3. Each of the hundreds of ICs (chips) on a wafer is tested; those that fail are marked, typically with an ink drop.

Ž Operations often performed in offshore facilities:

4. Individual circuits are separated from the wafer, and the defective chips detected in step 3 discarded.
5. Each good chip is mounted on a substrate (chip carrier).
6. Lead wires are bonded to pads on the chip (the lead wires connect to external pins, which plug into sockets installed on circuit boards).
7. The chip is encapsulated in a metal, plastic, or ceramic package that provides mechanical and environmental protection (metal and ceramic packages are normally hermetically sealed).[21]

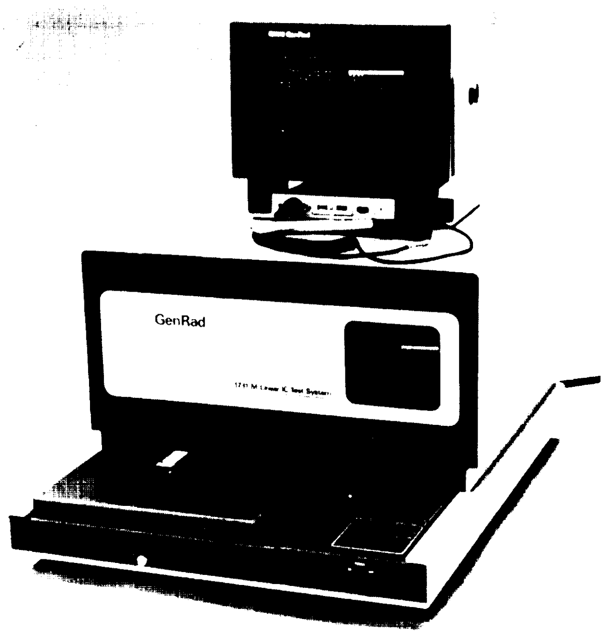

Photo credit GenRad, Inc

Test equipment for integrated circuits

8. The packaged ICs are subjected to functional tests.

Often the circuits are shipped back to the United States for the final testing in step 8, particularly if destined for American rather than third-country markets. (Economic aspects of offshore assembly are outlined in app. B.)

Outcomes at all these stages in processing—purity of the silicon crystal, wafer flatness, lithographic precision, integrity of wire bonds, hermetic sealing—can affect quality and reliability. Some are more important than others; patterning flaws and poor wire bonds are among the most common causes of failures.[22] During the manufacturing process, inspection

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[21] For a more complete description of packaging and assembly, see A. B. Glaser and C. E. Subak-Sharpe, *Integrated Circuit Engineering: Design, Fabrication, and Applications* (Reading, Mass.: Addison-Wesley, 1977), ch. 10.

[22] For a discussion of failure modes in semiconductor devices, see E A. Doyle, Jr., "How Parts Fail, " *IEEE Spectrum*, October 1981, p. 36. An important technique, particularly for ensuring reliability, is the analysis of failures. ICs that fail during testing or in service can be examined by a variety of methods—e. g., direct observation in a scanning electron microscope—and the causes of failure diagnosed. Corrective action, which might range from a modified circuit design to simple adjustments in process parameters such as temperature, can then be taken. A comprehensive treatment of reliability, emphasizing the importance of the *design* of the circuit, is C. G. Peattie, et al., "Elements of Semiconductor-Device Reliability," *Proceedings of the IEEE, vol. 62, 1974, p. 149.*

and testing are possible at some points but not others; in the absence of good methods for direct testing following a particular processing step, the engineers must rely on control of process parameters based on downstream test results.

Customer Requirements

Differing customer demands lead to a range of standards for the quality and reliability of semiconductor devices. Purchase agreements often specify the testing procedures to be followed. Military circuits must meet especially demanding specifications for resistance to shock, vibration, and severe environments (including radiation); reliability is emphasized for satellite applications. Limited-volume markets for parts intended for military or space applications are often served by small firms specializing in ultrahigh-reliability components. While semiconductors for commercial markets have seldom faced *specifications* as demanding as for military and space applications, the actual functional requirements-particularly for longevity--may be at least as severe. For instance, some computers operate virtually continuously for years, albeit in a service environment that is well controlled and benign; semiconductor devices for automobiles must function reliably--also over many years—in an environment characterized by vibration and extreme temperatures, as well as exposure to gasoline, oil and grease, rain, road salt, and do-it-yourself repair efforts.

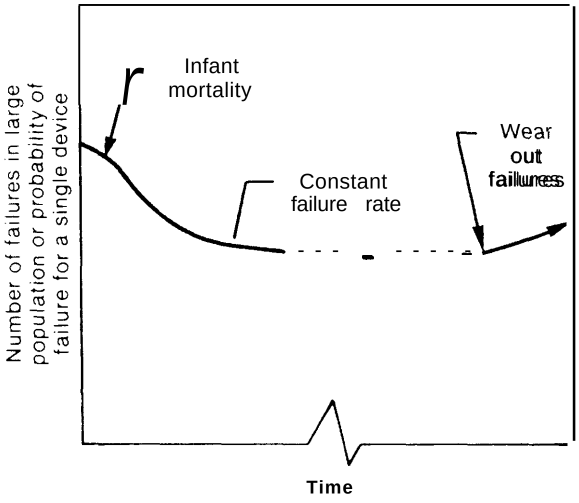
Reliability estimation—e.g., by accelerated life testing—is costly, thus life testing of devices intended for consumer products is minimal, Considerably more reliability testing is carried out on parts destined for computers or communications systems. Because the service record of their products is critical for future sales, and because the costs of locating and replacing faulty parts are high, particularly after the system has gone into service, manufacturers of complex electronic systems demand reliable components. This is one of the reasons firms like IBM or Western Electric chose to build many of their own ICs. Regardless of application, however, the chip manufacturer seeks a production process sufficiently well controlled that testing becomes simply a verification of that control.

Because of these varying customer demands, the electronic components industry has, since well before the semiconductor era, supplied products to a range of quality and reliability specifications; as many as half a dozen levels developed from the initial distinction between military and commercial parts. The lowest level has been for inexpensive consumer products such as toys and games, the highest for applications such as communications satellites, Failure rates for the most reliable devices can be more than a factor of a hundred below those for the least reliable,

Failures in Semiconductors

The time history of failures for a large population of semiconductor devices-as for manufactured products of many kinds—will normally follow a pattern like that in figure 39. Early in life, the failure rate tends to be high, with most of the failures caused by random manufacturing defects. The distinctions between quality and reliability y become rather arbitrary during these early stages, A strict quality standard, for example, might weed out parts that would otherwise fail during the infant

Figure 39.—Typical Failure History for Semiconductor Devices



SOURCE Off Ice of Technology Assessment

mortality period. "Burn-in" tests help detect infant mortality failures; during burn-in, ICs are cycled to high temperatures and exercised by computerized testing equipment.[23]

After the high failure rates early in life, failure frequency usually declines to a nominally constant value—the middle portion of the curve in figure 39. For semiconductor devices, this period typically spans hundreds of thousands, even millions of hours, during which the probability of failure is extremely low, Eventually, the curve may turn up again as devices "wear out" or otherwise deteriorate with age.

While semiconductor products do not wear mechanically, they are susceptible to degradation from environmental exposure, thermal cycling, and a variety of physical processes. Common causes of long-term failures in ICs include: loss of hermetic seal, with consequent damage from moisture or other environmental agents; thermal fatigue of the bond between the chip and its substrate or of the lead wire bonds; gradual thinning and cracking of metallized layers due to electromigration associated with high current densities (even though the currents in ICs are low, the small conducting paths result in high values of current density). Failure probabilities associated with particular mechanisms can be reduced by conservative design at both device and system levels, a common tactic in applications such as satellites or submarine cables,

Testing

Testing costs for ICs increase with levels of integration. Although 100 percent testing is common during the early steps in fabrication, manufacturers normally screen their final output by random sampling; that is, only a small fraction of the outgoing product is subjected to a full battery of tests. Many customers do their own screening of incoming parts. On the other hand, a toy manufacturer may not test incoming chips at all, cutting **costs** by relying on returns and complaints from the field to locate problems. Such an approach is favored where other parts are less likely to fail than the ICs.

Semiconductor products are normally screened and purchased to an *acceptable quality level* (AQL), a procedure much less expensive than 100 percent testing. From the standpoint of the purchaser, the AQL is the permissible fraction of *delivered* parts that can be defective—i.e., that escape detection during inspection and screening. A 1 percent AQL means that no more than one defective circuit out of every 100 is allowed, on the average, in an acceptable lot; statistical sampling methods are tailored to this requirement.

Figure **40** outlines the testing program adopted by a manufacturer of point-of-sale terminals for purchased ICs. Tests are conducted at many points prior to shipment because downstream failures cost much more to find and fix, Costs are even higher for field failures—both the direct expenses of warranty repairs and the possible costs in terms of damage to the firm's reputation. Table **48** illustrates the growth in costs of locating and repairing faulty components at successively later stages. The indirect and intangible costs can be much greater than the direct expenses.

Testing and Screening in Japan

When first qualifying a new vendor, Japanese purchasers normally test all incoming parts, With satisfactory experience, statistical sampling replaces 100 percent testing. If the defect fraction remains below 0.01 percent (100 defects per million parts) and downstream failures are rare, the purchaser may stop screening. Even when purchaser and supplier are unrelated firms, customers prefer to depend on their suppliers to guarantee quality levels. Japanese manufacturers do tend to rely rather extensively on in-process testing, aging, and burn-in—in part to minimize infant mortality failures.

Such practices differ from the arms-length relationships common in the United States. Perhaps because the major Japanese manufacturers of semiconductors are also the major users, they often appear to take the attitude that the objective of quality control is to deliver

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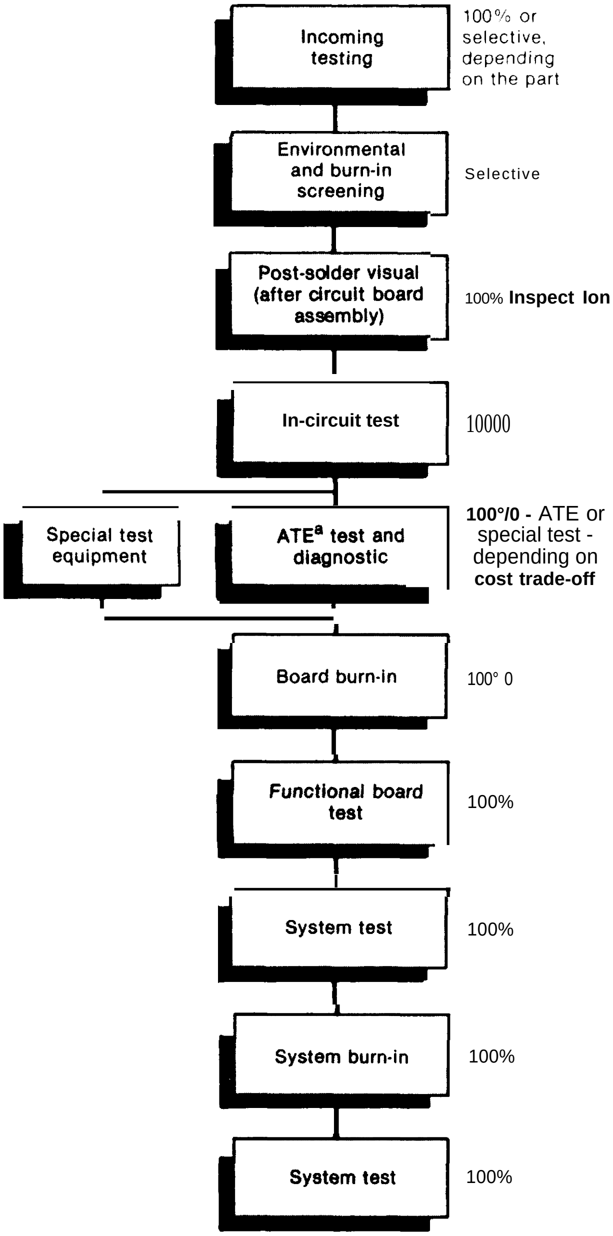
[23] Eleven percent of nearly 20,000 ICs tested for the 1977 Pioneer mission to Venus were rejected, many of these tests involving burn-in periods of 100 to 200 hours. The very high reject rate reflects the severity of the application. See "Quality and Reliability of Semiconductors and CTVs: United States v. Japan, " op. cit., p. 14.

Figure 40.—Testing Sequence for Point-of-Sale Terminals



aATE = Automatic Test Equipment

SOURCE Adapted from R Fleishman. R J Lever and R N Parente, Total Testing *Circuits Manufacturing,* November 1979, p 32

parts that meet their own in-house standards, A more common attitude in the United States has been that parts need only meet the customer's requirements; customers that demand high quality may get it, others receive less attention.

Table 48.—Typical Costs of Detecting and Repairing Faulty Components in an Electronic System

Point of detection	Direct cost	Intangible cost
Device level	Cost of device, if not refunded by manufacturer.	Minimized if more devices than needed are purchased initially.
Circuit board level	$5	Manufacturing process dislocated,
System level	$50	Shipment may be delayed, disrupted.
In the field. ., ...	$500	Customer upset,

SOURCE "Calls Volume Key to Testing Decision," Electronic News, Feb. 18, 1980, supplement p. 20.

Quality and Reliability Comparisons

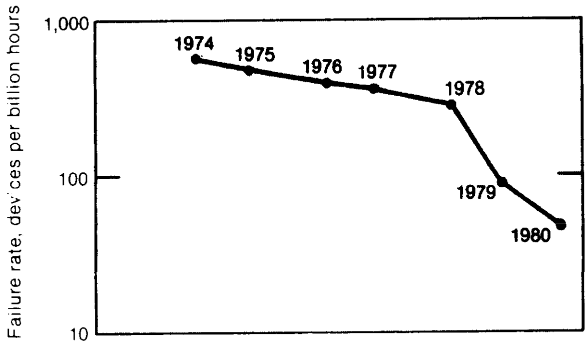
Although respective quality levels of ICs made in the United States and Japan have been debated for several years, there is little concrete data bearing directly on this matter. For a valid comparison, circuits from U.S. and Japanese firms should be tested under the following conditions:

1. The devices should be the same type and of similar designee. g., 4K dynamic RAMs, 8080 microprocessors.
2. Test procedures should be identical, the tests conducted at about the same time. (It is not possible to compare quality or reliability at the present moment. Quality comparisons always refer to some point in the past. And, while the most recent results are always desirable, quality and reliability are dynamic characteristics; they fluctuate with the vagaries of the manufacturing process,)
3. The ICs should be produced to the same purchase specifications in terms of AQL or other quality requirements, ideally for delivery to the same customer.

While it is no surprise that little of this kind of data has been made public, the unfortunate consequence was a series of public relation ploys obscuring the technical questions: Were there real differences in quality? If so, what were the reasons?

By any measure, *semiconductor quality and reliability have improved immensely over the years,* regardless of whether the devices have been produced in the United States, Japan, or Europe. As an example, figure 41 shows de-

Figure 41.— Reliability Trend for Analog Integrated Circuits



SOURCE G Peattie,'Quality Control for ICs *IEEE Spectrum,* October 1981 **D** 93

creases in failure rates for analog (linear) ICs as used in consumer electronic products. Other types of ICs show similar trends. Nonetheless, sources in the American electronics industry—both manufacturers and purchasers of semiconductors—agree that, during the mid to late 1970's, quality levels delivered by Japanese firms were superior to those delivered by U.S. firms. There is also broad agreement that quality levels delivered by American semiconductor firms have greatly improved since the publicity given the Japanese "quality advantage" during 1980.[24] The available data is summarized in appendix 6A. But at the same time that U.S. semiconductor firms have made rapid strides, Japanese manufacturers have also improved. While the gap has certainly narrowed, Japanese firms *on the average* may remain ahead in quality.

It is also important to recall that discussions and data on IC quality have centered on products sold in the merchant market. No data have been made public on quality levels attained by captive producers such as Western Electric or IBM. Captives account for about 40 percent of all ICs made in the United States (ch. 4); the quality and reliability attained by captive producers would, if available, be a useful indicator of the relative *technological* capability of the American industry.

The ranges in quality level included in appendix 6A, particularly table 6A-2, show a remarkable lack of consistency on the part of all vendors, Even the top 16K RAM suppliers exhibited a factor of five difference between best and worst lots. Much larger spreads were the rule, particularly for the American firms. This illustrates the danger in generalizing from limited samples of IC quality data. It also indicates the importance of a consistent and well-controlled manufacturing process, and the difficulty of maintaining that control.

Spokesmen for the U.S. semiconductor industry have sometimes claimed that Japanese firms create a false image of higher quality by sorting ICs and sending only the best to important customers like Hewlett-Packard—a practice that has been termed "quality targeting" or "quality dumping. " The claim is further made that this is a high-cost strategy, intended to "buy" U.S. market share—and that after their American competitors have been forced out, the Japanese will raise their prices and ship their normal product, which will be found to be poorer in quality .[25] Indeed, manufacturers in many industries and in many countries sometimes attempt such strategies. American semiconductor firms will sort ICs and ship higher quality lots to purchasers who demand them. However, as a widespread and general approach to marketing in the United States, quality dumping by the Japanese seems implausible. In order to ship higher quality lots to the United States, they would have to ship lower quality products to other customers—in either export or domestic markets—thus running the risk of jeopardizing those markets. It is difficult to believe that Japanese IC manufac-

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[24] Much of this publicity stemmed from a seminar entitled "Quality Control: Japan's Key to High Productivity," organized by the Electronic Industries Association of Japan and held in Washington, D. C., on Mar. 25, 1980. Data first released at that seminar appear in appendix table 6A-1, pt. A. A perspective common in much of the American merchant semiconductor industry at that time can be found in T. D. H inkelman, "The Economics of Quality: U.S. vs. Japan, " *An American Response to the Foreign Industrial Challenge in High Technology Industries,* Proceedings of the Semiconductor Industry Association Government Policy Conference, Monterey, Calif., June 18-19, 1980, M. Hodgson (cd.) (Palo Alto, Calif.: Worden Fraser Publisher. 1980), p. 85.

[25] T. D. Hinkelman, op. cit. See also "The Quality Goes On Before the (Japanese) Name Goes On, " *Rosen Electronics Letter,* Mar. 31, 1980, p. 1.

turers would do so in any concerted way, particularly at home.

It is clear from the data in appendix 6A that, at least until the recent past, Japanese large-scale ICs have had, *on the average,* both better quality and better reliability than comparable American parts. This does *not* mean that some products from some U.S. companies were not as good as or better than products from Japan. As the tables in appendix 6A indicate, the range in quality and reliability delivered by any firm is likely to be wide; this is intrinsic to the technology of semiconductor manufacturing, But as a generalization, the United States had fallen behind in both quality and reliability, It is also clear that the performance of American firms on these dimensions has greatly improved—in part because of the competitive pressures generated by the publicity given this issue. According to recent reports, the quality levels of 16K RAMs supplied by a number of American firms are now, on the average, about the same as those of Japanese devices.[26]

While this is a positive sign for the future, it does appear that Japanese firms devote more resources to analyzing field failures so as to find and eliminate their causes. In Japan, electronics firms have normally maintained captive service organizations which gather and analyze field service results, and feed them back to design and manufacturing departments. One American purchaser of Japanese semiconductor devices was reportedly quite surprised to find a team of engineers dispatched to explore the reasons for a batch of circuits with a defect rate of only 0.25 percent.[27]

In the future, *if American managers devote as much attention—and as many resources—to the quality and reliability of their products as do the managers of Japanese firms, there is no reason why U.S. firms should not keep pace with, or surpass, their overseas rivals on these dimensions of IC technology.*

Quality and Reliability of Color TVs

That Japanese TV manufacturers have achieved excellent quality and reliability, and largely succeeded in their marketing strategies, is self-evident. In order to bypass the franchised dealer networks that American manufacturers relied on, they had to forgo extensive service organizations. Failure by Japanese importers to maintain both the image and the reality of a reliable, trouble-free product would risk the largest market in the world. Most surveys continue to show the *reliability* of TVs produced by Japanese firms to be better, though differences in *quality* appear small.

Many of the TVs sold in the United States by Japanese firms are now assembled here. Quality levels achieved in the U.S. operations of both Sony and Quasar—the firm that Matsushita bought from Motorola in 1974—have received a good deal of publicity.[28] Such plants tend to combine features typical of Japanese and American manufacturing operations; see chapter 8 for a discussion of management styles and their effects. At least as important, TVs assembled in the United States by Japanese-owned firms contain large proportions of imported components. Based on the findings for semiconductor devices outlined in the previous section, imported components might be expected to exhibit somewhat higher levels of quality and/or reliability than similar parts from American suppliers.

Most of the information bearing on quality and reliability for TVs comes from sources like *Consumer Reports*. Several years ago this pub-

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[26] E. R. Hnatek, "Semiconductor Memory Update: DRAMs," *Computer Design,* January 1982, p. 109; "Faults Show Up in Japanese RAMs," *Electronics,* Jan. 13, 1982, p. 33; "In Semiconductors, Perfection Is the Goal," *Business Week,* Nov. 1, 1982, p. 72.

[27] "Quality and Reliability of Semiconductors and CTVs: U.S. v. Japan," op. cit., p. 57.

[28] On Sony, see "Statement of Sadami ('Chris' Wada, Assistant Vice president, Sony Corp. of America,' *Quality of Production and Improvement in the Workplace,* hearing, Subcommittee on Trade, Committee on Ways and Means, House of Representatives, Oct. 14, 1980, p. 62

At Quasar, quality levels improved rapidly after the Matsushita purchase; however, the baseline is deceptive in that Motorola devoted few resources to its TV operations for a number of years prior to the sale. This case is discussed in more detail in the appendix to ch. 8.

lication surveyed nearly 200,000 owners of 19-inch color TVs, the most popular size, sold during the period 1975-79. Nine of the fifteen brands for which the origins are known–all the Japanese makes but no others—were given reliability ratings of "better than average" based on the average cost of repairs during the 1979 calendar year. The remaining six brand names—for practical purposes, all the American brands—were rated "average" (one brand) or "worse than average" (five brands).[29] The *Consumer Reports* survey reflects reliabilities of sets sold during the period 1975-79 only. However, TV designs do not change rapidly; these trends should still be a reasonable indication of comparative reliability levels,

Similar but not identical reliability rankings come from a survey conducted by Trendex in the same year, 1979, but again covering TVs manufactured over a period of years.[30] Of the 12 brands included in this survey, TVs made by Japanese-owned firms filled four of the top five places in terms of reliability, The remaining Japanese brand ranked seventh, with the bottom five positions filled by American firms plus Magnavox.

Table 49 presents data from a survey of TV repair shops that point in a direction rather different from the consumer surveys discussed above. This table covers a smaller number of brands: three American (Zenith, RCA, and Sylvania—the latter at that time U.S.-owned, though since purchased by Philips); three Japanese (Sony, Quasar, and Panasonic—the latter two are Matsushita brand names); plus Magnavox. The repair shops rated the American brands generally superior on all three criteria—performance, reliability, and costs of repair. In particular, the largest-selling U.S. TVs—those made by Zenith and RCA—show up very well, with Zenith top-ranked in each category, In contrast, Zenith and RCA are rated "worse than average" in reliability by *Consumer Reports*. Because the *Consumer Reports* survey covered such large sample sizes—more than 40,000 owners of 19-inch Zenith sets, and 35,000 made by RCA—it must be given considerable weight. However, the data in table 49 are not restricted to any particular screen size, and might be more representative of each manufacturer's overall product line.

Table 49.— Rankings by Repair Shops of TV Receivers for Quality and Reliability

Rankings in terms of picture quality and other performance features:

1. Zenith
2. RCA
3. Sony
4. Sylvania
5. Quasar
6. Magnavox
7. Panasonic

Rankings in terms of reliability:

1. Zenith
2. Sony
3. RCA
4. Quasar
5. Sylvania
6. Panasonic
7. Magnavox

Rankings in terms of increasing costs of repair:

1. Zenith
2. RCA
3. Sylvania
4. Quasar
5. Magnavox
6. Sony

SOURCE "Quality and Reliability of Semiconductors and CTVs U.S. v. Japan, " report No, C972, prepared for OTA by Consultant Services Institute, Inc , under contract No 033-1170.0, p. 79, The survey, conducted during 1960, covered 60 repair shops in Chicago, Boston, and Northern New Jersey.

As is true for ICs, American manufacturers of TVs have clearly made considerable strides in improving quality and reliability—spurred by competition among themselves as well as with the Japanese, Consumer electronics firms now screen and burn-in components more thoroughly; they also burn-in complete circuit boards and assembled sets to weed out early failures. Automation has helped quality. Finally, American TV makers are using larger num-

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[29] "19-Inch Color TVs, " *Consumer Reports,* January 1981, p. 34. The nine brands in the "better than average" reliability category included TVs sold by Sears, most of which are made by Sanyo-some imported, some assembled in the United States. Other private brand merchandisers—e. g., Montgomery Ward, J. C. Penney–tend to purchase from both American and foreign suppliers, Excluding both the Wards and Penney TVs because of their uncertain origins, 15 brands remain. Of the 15, 5 are American, 9 are Japanese, and the other—Magnavox—is owned by Philips. As Magnavox is much more nearly independent of its parent than the American subsidiaries of Japanese firms, it has been considered a U.S. brand for purposes of this comparison.

[30] " Quality and Reliability of Semiconductors and CTVs: U.S. v. Japan, " op. cit., p. 78.

bers of imported components—mostly from Japan and other Asian countries. Imported components often cost less, but in at least some cases they have been chosen because of superior quality and/or reliability, Even picture tubes—which are bulkier and more difficult to ship than other components—are being imported in increasing numbers; one U.S. manufacturer stated that Japanese picture tubes had one-third the in-process failure rate of American-made tubes .31

Consumer perceptions created by and reflected in surveys like those discussed above can be extrapolated with some confidence into at least the near future. Furthermore, because TVs have a design life of 7 to 10 years, the surveys discussed above should do a good job of predicting the reliability of sets presently in use. *The weight of the evidence points toward an advantage in reliability for Japanese TV manufacturers during the* **1970's.** *Even if American manufacturers today are producing TVs as reliable as their Japanese competitors, the image of reliability that the Japanese have gained will persist for a number of years to come,* On the other hand, differences in *quality* among TVs appear to be small.[32]

Automation

Managers make decisions involving the automation of production processes largely on the basis of costs. Automation typically involves tradeoffs between labor cost and capital cost that depend on production volumes; mechanized production facilities also tend to lack flexibility, which raises the costs of adapting them to new product designs. Factors less directly related to costs include the impacts of automation on quality, and the possibility of mechanizing unusually dangerous, dirty, or onerous jobs.

Modern automated production systems usually rely on electronics, although electromechanical control systems were common until recently. Examples of automated processing include:[33]

- automatic machine tools, ranging from lathes and milling machines controlled by mechanical cams, to those that operate under computer control, to machining centers;
- automated gaging, inspection, and testing; examples include inspecting circuit boards by means of video image processing to check for solder runs or other visible defects, measuring the dimensions of machined parts, and determining the chemical composition of steel;
- mechanized systems for materials handling, ranging from computer-controlled conveyors to fully automated warehouses;
- process control systems incorporating sensors and processors that implement control algorithms based on feedback, feedforward, or some combination (see ch. 3, app. 3C, on industrial process control);
- use of computers in management or support functions such as scheduling of job flows, inventory control, or statistical quality control; and
- computer-aided design methods to aid in geometric modeling, in engineering anal-

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[31] Ibid, p. 80. Japanese-owned firms that assemble and sell TVs in the United States still import many components, but are gradually increasing value added here. Mitsubishi—which produces sets in the United States for sale under the MGA brand name—imports about 30 percent of their parts from a subsidiary in Singapore, and another 15 percent from Japan. Sony continues to bring in from Japan about 35 percent of the parts for their American-made sets. In general, the more critical components and subassemblies from a performance and quality standpoint are imported—e.g., circuit boards. Cabinets and nonelectronic parts are the first to be purchased domestically. See *Quality of Production and Improvement in the Workplace,* op. cit., p. 85.

[32] For example, "Small-Screen Color TV's, " *Consumer Reports,* January 1982, p. 17, where the distribution of brand ratings by set performance and quality shows no systematic differences among U .S. and foreign brands.

[33] See, in general, M. P. Groover, *Automation, Production Systems, and Computer-Aided Manufacturing* (Englewood Cliffs, N. J.: Prentice-Hall, 1980).

ysis, or in preparing design drawings or equivalent design information coded for automated production processes.

The earliest numerically controlled (NC) machine tools operated from instructions on a paper tape or similar storage medium, analogous to the cams and other electromechanical controls used for many years to automate manufacturing. The NC tape, however, could be prepared with the aid of a computer, and easily duplicated or modified, In the next stage, rather than following a sequence of instructions held in a read-only memory such as a paper tape, direct numerically controlled (DNC) and computer numerically controlled (CNC) machines were developed. These respond in real time to commands from the processor of a computer. As a result, control algorithms based on gaging or sensing of machining parameters can, at least in principle, be implemented. In a DNC system, one computer controls several machines; CNC machines operate under the control of a dedicated processor, typically a small minicomputer or a microcomputer.

Sophisticated control systems use information from sensors for regulating the process, typically by adjustments that keep measured parameters within predetermined bounds. For a machining operation, dimensions can be measured; for a wafer fabrication line in a semiconductor plant, possible control parameters include temperatures, pH of reagents, and current flows during ion bombardment, In contrast to such "closed loop" systems, in which information flows from the process back to the controller, systems in which there is no sensing and transmission of information, but which operate purely on preprogrammed instructions, are called "open loop, " A skilled machinist closes the loop just as does an automatic control system on a CNC lathe equipped for automatic gaging. But in fact, most NC machines still run on an open loop basis,

Electronic control systems make possible the automation of many processes that in earlier years were too difficult or too expensive to mechanize.[34] In essence, the flexibility gained through electronic controls makes automation cost effective in applications where production volumes are low. In the past, automation was practical only in continuous process industries such as food preparation and packaging, or in high-volume batch production industries like automobile manufacture. In the automobile industry, simple assembly operations, as well as machining, have been carried out by transfer lines linking a series of machines for many years; human operators have worked along the line performing tasks that were difficult or costly to mechanize.

Fixed and Flexible Automation

Automated production in either continuous process or batch industries can be thought of as spanning a range from "fixed" or "hard" automation to "flexible" or "programmable" automation, Fixed automation is exemplified by an automatic lathe in which the "instructions" are encoded in the profiles of cams. To set up the lathe for a different job, the cams must be changed, Designing and machining a new set of cams is a time-consuming job performed by skilled craftsmen, Conventional transfer lines are examples of fixed automation applied to a sequence of tasks, When an automobile manufacturer designs a new engine or transmission, the entire transfer line might have to be scrapped and replaced. Much the same is true if an electronics firm using such equipment wishes to introduce a new design for a printed circuit board, TV chassis, or computer terminal.

Until recently, automated production equipment with the flexibility to accommodate substantial variation in the design of the product was the exception rather than the rule.[35] Machines seldom adapt very well to perturbations

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[34] J. A. Alic, "Government Attitudes "reward Programmable Automation, " *proceedings of the Twenty-third International Machine Tool Design and Research Conference, 13.* J. Davies (cd,] [London: Macmillan, 1983), p. 521.

[35] Flexibility in the context of manufacturing systems carries a number of possible meanings; see, for example, D. Gerwin, "Do's and Don'ts of Computerized Manufacturing, " *Harvard Business Review,* March-April 1982, p. 107,

in the process—e.g., a part that comes down a conveyor sideways—much less to new product designs. When flexibility has been needed, manufacturing operations have depended on people. Engine lathes, which are operated entirely under manual control, are the flexible counterpart of the automatic lathe. A skilled machinist can make an amazing variety of different parts on an engine lathe, but the cost per part will be high.

One reason for the lack of flexibility characteristic of fixed automation is that new hardware—fixtures, tooling—is needed to accommodate a new design. A second reason is that the controls must be reprogrammed. A hardwired electronic control system—whether analog or digital—requires new circuitry every time the control logic is altered, This is costly and time-consuming, just as for an automatic lathe that requires a new set of cams. In recent years, computer control has become cost effective for replacing many mechanical or electromechanical control systems.

While the performance of a computer-based programmable controller—as a control system—will generally be superior to the alternatives, this is not necessarily the case for *hardware*. Often, flexibility in hardware trades off against performance, and perhaps capital cost as well. For example, a robot can be programed to weld together sections of pipe, but might not be as fast as a specially designed automatic welding machine—which might also produce better quality welds. However, the robot could be programed to do other tasks. In general, then, a flexible facility may be less efficient for making *any one product* than a dedicated, hard-automated manufacturing system.[36]

As flexible automation technologies incorporating computer-based control systems improve, an enormous pool of potential applications will open; the consequences will include, not only cost reductions and productivity improvements, but shifts in the composition of the factory work force. Skill mixes needed in manufacturing industries will change, and the total number of employment opportunities in the manufacturing sector of the U.S. economy may shrink even as total output increases. (Employment levels and work force composition are discussed in chapter 9.)

Automation in Electronics Manufacture

Reasons for Automating

Most applications of automation by U.S. electronics firms have been driven by costs; noncost factors have perhaps weighed more heavily for Japanese manufacturers. The industry in Japan has at times faced labor shortages; in addition, Japanese firms may sometimes have been motivated by potential quality improvements to automate earlier than their American counterparts.[37]

Table 50 presents the results of a 1979 survey in which Japanese electronics manufacturers were asked to list reasons for their decisions to automate. The most common response was to reduce costs, with quality improvements second; in contrast, a 1975 survey found labor shortages ranked at the top. Comparison of 1975 and 1979 results shows a rapid increase in automation by Japanese electronics manufacturers.[38]

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[36] Recent R&D work at Westinghouse illustrates a typical application of flexible manufacturing—here assembly, one of the most challenging tasks for automation. Westinghouse makes more than 450 different models of small electric motors, with an average lot size of 600; model changes average 13 per day. In such cases, labor-intensive manufacturing methods have generally been preferred. Fixed automation using transfer lines has been a real option only for long production runs of similar or identical products. For a description of the flexible assembly system under development, see R. G. Abraham, "APAS: Adaptable Programmable Assembly System," *Computer Vision and Sensor-Based Robots*, G. G. Dodd and L. Rossol (eds.) (New York: Plenum Press, 1979), p. 117.

Another example of flexible automation in assembly—this one already in use—is a machine developed in Japan by Nippondenso that can put together 288 different versions of an automobile dashboard indicator, The average lot size is 40, with 200 changeovers per day. See "British Government Finances Robotics Development," *West Europe Report: Science and Technology*, No. 70, Joint Publications Research Service JPRS 78820, Aug. 25, 1981, p. 14.

[37] K. Ito, E. Taira, S. Yagi, K. Iwamoto, and H. Tsukamoto, "The Progress of Automation and the Improvement of Reliability in Production of Color TV Receivers," *IEEE Transactions on Manufacturing Technology*, vol. MFT-3, December 1974, p. 55.

[38] "Quality and Reliability of Semiconductors and CTVs: United States v. Japan," op. cit., p. 47. Japanese consumer electronics firms reportedly spend about a third of their R&D dollars on man-

Table 50.—Reasons Given by Japanese Electronics Firms for Automating

Percent of firms surveyed[a]	Reasons for automating
84%	Reduction in manufacturing cost
69	Improvement in quality
43	Increase in production volume
43	Improvement in workplace conditions
32	Labor shortage

[a]Multiple responses were common.

SOURCE: *Nikkan Kogyo Shimbun,* May 1, 1979, and July 11, 1979, cited in "Quality and Reliability of Semiconductors and CTVS United States v. Japan, " report No. C972, prepared for OTA by Consultant Services Institute, Inc , under contract No 033-1170.0, p. 50.

Consumer Electronics

Manual assembly was at one time the rule for electronic products ranging from radios and TVs to computers. Components were first inserted and/or soldered into circuit boards, the boards then installed in a chassis, the assembly finally tested and adjusted. Component insertion was one of the first tasks to be mechanized. This is relatively easy for discrete components with axial leads, more difficult for ICs. Consumer electronics manufacturers first moved to automatic insertion of discrete parts; as ICs were designed into TVs, they were at first still inserted manually. By the end of the 1970's much of this work had been automated as well, using equipment roughly similar to that pictured in figure 42.

The spread of automation in the U.S. consumer electronics industry has been incremental. Firms automated at different times and for different reasons, depending in part on strategic responses to foreign competition. In most cases, the initial reaction, based on Japanese advantages in labor costs, centered on moving labor-intensive operations offshore rather than automating.

When American TV manufacturers did respond to competitive pressures by automating, cost was the driving force, quality and reliability improvements secondary. Meanwhile, the Japanese continued to take the initiative in automation, even though their labor costs remained lower. By 1976-77, 50 to 80 percent of all component insertion in Japanese TV factories had been mechanized.[39] Computer-controlled testing and inspection of components, subsystems such as circuit boards, and complete TVs also spread rapidly. Concurrently, chassis were redesigned to take advantage of the characteristics of automated production equipment. According to one study, labor productivity in the assembly of color TV receivers was a little greater in the United States than in Japan in 1970, but by 1977 productivity in Japan was more than twice that here–figure 43.[40]

Semiconductors

In the earlier years of the semiconductor industry, virtually all production operations—fabrication, assembly, inspection and testing—were labor-intensive. Among U.S. firms, the spread of automation may have been retarded by the widely publicized difficulties of Philco Corp., which invested heavily in automated manufacturing during the late 1950's only to see rapid changes in transistor technology render its equipment obsolete.[41] Philco later dropped out of the semiconductor business.

At present, semiconductor firms in all parts of the world are automating rapidly, not only in manufacturing but in computer-aided circuit design. A few companies—both American and foreign—have installed fully mechanized production lines, from wafer fabrication through inspection, testing, wire bonding, and packaging. The benefits include increased yields as

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ufacturing developments; see *Transfer of Technology in the Consumer Electronic Industry, Sectoral Study No. 2* (Paris: Organization for Economic Cooperation and Development, Sept. 14, 1979), p. 41. This percentage is probably a good deal higher than in the United States or Europe.

[39] For a description of some of the technology used by Mitsubishi, see T. R. Crossley, "Study Tour of Industrial Robots in Japan, " European Office of Aerospace Research and Development report No. EOARD-TR-80-3, London, August 1979, pp. 32-33. At the time of this visit, Mitsubishi was using robots of their own design for assembling printed circuit boards for TVs. The assembly line could be changed over for a different board configuration in 2 hours.

[40] I. C. Magaziner and T. M. Hout, *Japanese Industrial Policy* (London: Policy Studies Institute, 1980), p. 22. The data comes from work performed by the Boston Consulting Group.

[41] J. E. Tilton, *International Diffusion of Technology: The Case of Semiconductors* (Washington, D. C.: The Brookings Institution, 1971), p. 83.

Figure 42.—Automatic Installation of Integrated Circuits Onto Ceramic Substrate

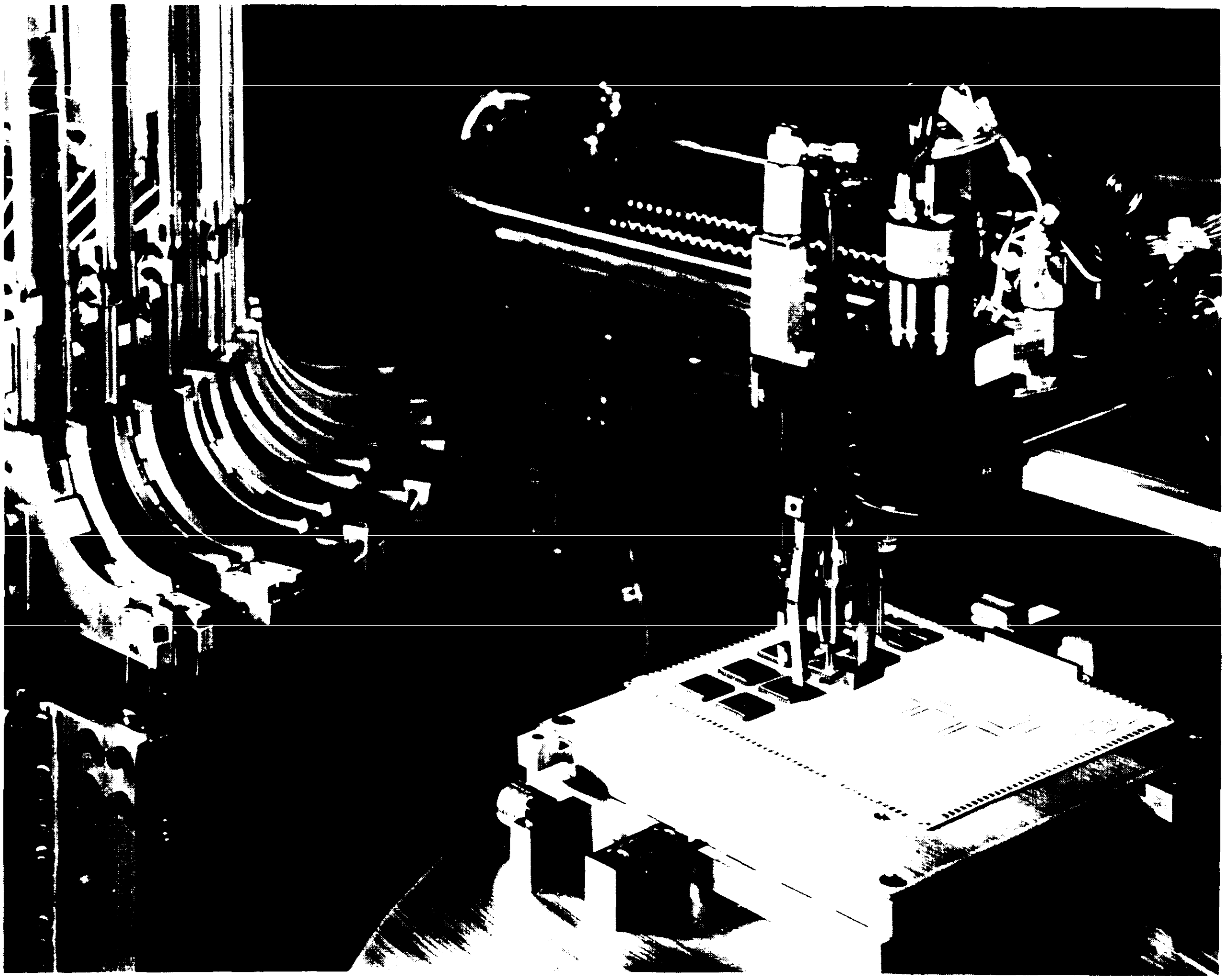

Photo credit Universal /instruments Corp

a result of better process control, Toshiba, for example, claims that its automated wafer fabrication facility has increased yields by 10 to 15 percent, and production rate by 20 to 40 percent; the control system, based on a central mainframe computer, includes 3 minicomputers and 74 microcomputers.[42]

Rates of Automation in the United States and Japan

While much of the evidence for the push toward automation in Japan is anecdotal, and quantitative data on relative extents of automation scarce, many commentators point to attitudes toward automation as an important difference between U.S. and Japanese manufacturers in both consumer electronics and semiconductors.[43] At the same time, it appears that the more integrated American semiconductor manufacturers—e.g., Western Electric, Texas Instruments, IBM—automated at a more rapid pace than smaller merchant firms. Japanese

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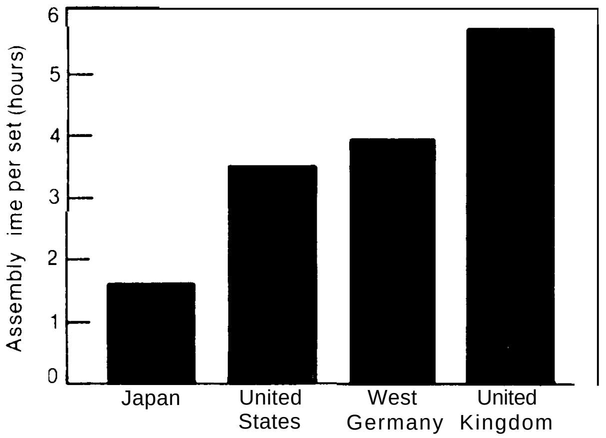
[42] "Toshiba Completes Fully Automated Production of IC's," *Japan Report*, Joint Publications Research Service JPRS 1./10264, Jan. 19, 1982, p. 85.

[43] R. H. Silin, *The Japanese Semicon doctor Industry: An Overview* (Hong Kong: Bank of American Asia Limited, January 1979), p. 124. See "The Drive for Quality and Reliability, Part 1," *Electronics*, May 19, 1981, for a discussion of the use of automation by Japanese IC manufacturers, especially p. 133.

Figure 43.—Average Labor Hours for Assembly of 21-Inch Color TV Receivers (1977)



SOURCE I C Magaziner and T M Hout, *Japanese Industrial Policy* (London. Policy Studies Institute, 1980), p 23. Data are from a client study performed by the Boston Consulting Group.

electronics companies do seem to have adopted robots more quickly than their American counterparts, Two to three times more robots are at work in Japanese factories than in the United States; about 40 percent of these have been installed in the factories of Japanese electronics and electrical equipment firms.[44] But again, a number of the larger American electronic companies are well known both for their R&D in robotics technology and for their applications of robots in manufacturing.

Some American electronics firms may have had difficulty in finding the capital needed for automation. The replacement of labor-intensive production operations by capital-intensive equipment aggravates the problems of financing expansion (ch. 7); a transfer line for inserting components in a circuit board can easily cost half a million dollars. In contrast, to their smaller American competitors, Japan's integrated electronics manufacturers can take advantage of internally generated funds—as well as somewhat lower costs for external capital—to invest in mechanized equipment. Furthermore, the Japanese Government has reportedly given preferential tax treatment for investments in production equipment that will improve the quality and reliability of Japanese goods, particularly those for export.[45] Such actions have probably affected the timing of investments more than the eventual extent of automation.

Although a few American semiconductor firms make some of their own manufacturing equipment—notably the larger, more highly integrated companies—most such equipment is designed and built by independent suppliers, In Japan, it is more common for electronics firms to design and fabricate their own. Matsushita, for example, meets 30 to 40 percent of its equipment needs internally.[46] Internal capability for equipment development can help speed automation.

As integration levels for ICs continue to increase, automation will become a necessity. Fine line widths and other requirements for very large-scale integration (VLSI) demand levels of cleanliness that are much easier to achieve if human intervention is minimized. More complex circuits can only be designed with computer-aided techniques, together with computer-aided drafting and mask generation; once built, such circuits can only be tested with computerized equipment. Better process control models—now limited by gaps in fundamental understanding of the physics of electron devices—will be needed to ensure the quality and reliability of VLSI circuits. Continued automation may reduce pressures for offshore

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[44] R. Ristelhueber, "Robotics-The Applications Gap, " *Electronic News*, Jan. 11, 1982, p. 60,

[45] " Quality and Reliability of Semiconductors and CTVs: United States v. Japan, " op. cit., p. 25.

[46] U. C. Lehner, "Japan Strives To Move From Fine Imitations to Its Own Inventions, " *Wall Street Journal*, Dec. 1, 1981, p. 1. Japanese firms continue to purchase a good deal of automated production equipment from American suppliers; as pointed out in ch. 4, about half the equipment used by Japanese semiconductor manufacturers comes from the United States, This percentage has been declining, however, with some observers predicting that Japan will produce 70 percent of its needs by 1985. Japanese firms are reportedly already designing and building fifth-generation automated wire bonders, while U.S. firms are still working with first or second generation machines; see "Pushing for Leadership in the World Market, " *Business Week*, Dec. 14, 1981, p. 61. In some cases—e.g., automated testing equipment—Japanese products have the reputation of being somewhat more reliable than those of American suppliers, largely because they are simpler, However, industry opinion generally holds that U.S. equipment is as good as or better than that made in Japan or in Europe, as well as being less expensive. See "Can Semiconductors Survive Big Business?" *Business Week*, Dec. 3, 1979, p. 81.

manufacturing because labor costs will become a smaller fraction of total manufacturing cost.

Robotics

Industrial robots comprise a subset of programmable automation technologies mimicking some of the attributes of the human work force, They are more flexible-in terms of ability to perform new tasks, or to carry out complex motion sequences-than other types of programmable equipment. Because advances in robotics depend to considerable extent on electronics and computer science they are discussed in some detail below. In the future, robots will be used to automate many of the operations in making electronics products now carried out by hand. In Japan, robots are already being used to produce more robots by a subsidiary of one of the major electronics companies—Fanuc, a part of the Fujitsu organization.[47]

The changing proportion of costs associated with electrical and mechanical components since the first industrial robots were introduced in the 1960's demonstrates the importance of electronics for this technology. A few years ago, about half the direct cost of making a robot was associated with the electronics, the other half with mechanical components. Now only about 15 percent of the costs go into electronics, largely because of the increases in computing power available with cheap ICs. Costs for the mechanical components have not changed greatly, but the total costs of robots have decreased, the mechanical parts now accounting for 85 percent of the total.

Technology

Industrial robots, those used for factory work, are machines that can move a manipulator, or end effecter, at the end of a chain of mechanical links, The end effecter may be a gripping device similar to fingers; alternatively, the end of the robot arm may carry a tool, welding torch, or nozzle for spraying paint. The simplest robots have only two or three degrees of freedom; an illustration of a two-degree-of-freedom system would be an "arm" that could only extend and rotate, as for tightening a bolt. The most sophisticated robots have seven or eight degrees of freedom, which allows them to reach around obstacles. Figure 44 shows a pair of typical robot designs.

While robots trace their descent from more primitive manipulators having little flexibility—e.g., with position and sequencing con-

Figure 44.—Two Approaches to the Design of Industrial Robots

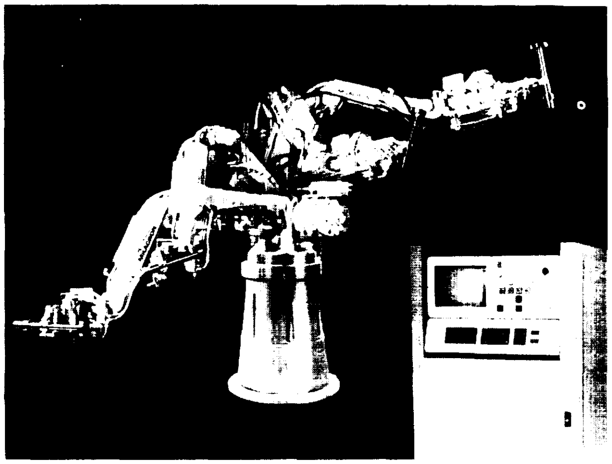

Photo credit Cincinnati Milacron

(a) This robot emulates the human arm

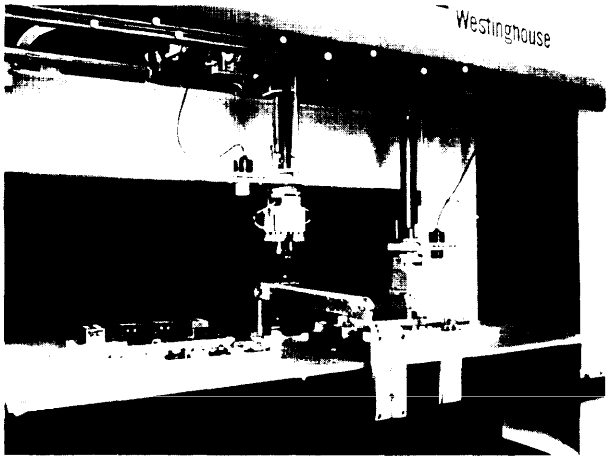

Photo credit Westinghouse

(b) This robot moves rectilinearly

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[47] N. Usui, "Untended Machines Build Machines,' *American Machinist*, June 1981, p. 142,

trolled by limit switches—state-of-the-art designs now operate under computer control, often a microcomputer. In routine production applications, the robot is commonly "taught" a sequence of motions by a human operator, who leads the arm through these motions while they are stored in memory. The machine can then repeat them on command. Although satisfactory for simple applications like spray painting or some forms of welding, off-line programing—in which the instruction sequence is developed independently and loaded into the computer when needed—is a major R&D goal.

Virtually all robots still operate with relatively primitive open loop control systems.[48] This is one of the factors limiting operating speeds, as well as the accuracy with which the end effector can be positioned, Current-generation robots are also burdened by complex and expensive actuators that tend to restrict performance. At some future time, one robot may be able to throw a part across the factory floor to another, but this is far in the future. Making robots "smart' '-i.e., with the ability to gather and process substantial amounts of information, then make decisions based on that information—is a related problem. Few robots can yet make even simple decisions.

As such examples indicate, robotics technology depends on computer technology. While computer firms like IBM, Digital Equipment Corp., and Texas Instruments are expected to enter the market for robots—and Fujitsu and Hitachi are already two of the leading producers in Japan—many of the robots in current production come from machine tool builders. In the United States, for instance, Cincinnati Milacron has a substantial share of the market.

From the perspective of the machine tool industry–whether the portion that builds metal-cutting equipment or the manufacturers of hard-automated assembly equipment such as transfer lines—robots trace their descent mostly from NC machines. In fact, much of the technology in the control systems of current-generation robots is similar to that for DNC and CNC machine tools. Companies that intend to compete in the design and manufacture of future generations of robots will need a broader range of technical capability; those moving into programmable automation from other high-technology fields may have the advantage, particularly firms with experience in automatic controls and the modeling of complex mechanical systems,

Robots in Manufacturing

Robots are usually installed in factories where they can cut costs (compared to human workers) and increase labor productivity—the same motives that drive other capital investments. In many early installations of robots, human workers were replaced on a one-for-one basis, a substitution facilitated by the robot's ability to emulate the human arm. In comparing the costs of robots to those for human workers, one-for-one replacement has often been assumed, This is potentially misleading because a more thorough redesign of the production facility means that some robots may each replace several people, while in other cases several robots might be needed to do the work of one person. A cost analysis comparing robots and people must also take account of the number of shifts planned for the facility, maintenance and repair costs, depreciation, and energy consumption. A robot may use a hundred times as much energy as a human worker. Generally speaking, when production volumes are small, human operators will still be the least cost alternative because of the expenses associated with setting up and programing the robot—figure 45, Moreover, at sufficiently high production volumes, fixed automation will be cheaper because there is no need to trade off performance for flexibility. In general, robots tend to be the low-cost alternative for annual production volumes of roughly 300,000 to 3 million units.[49]

The plot in figure 46 has been well publicized by Unimation, one of the largest robot manufacturers in the United States. It compares the

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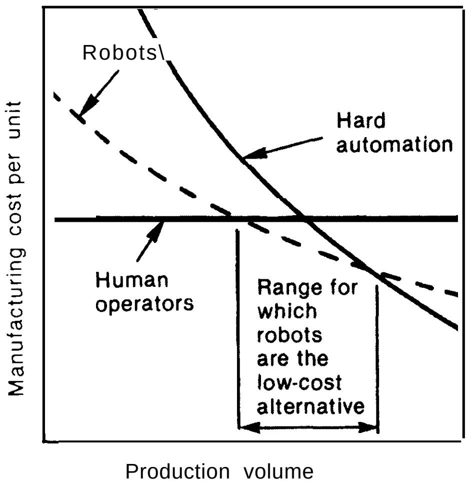
[48] "Government Attitudes Toward Programmable Automation, " op. cit. Much of the material that follows is drawn from this paper.

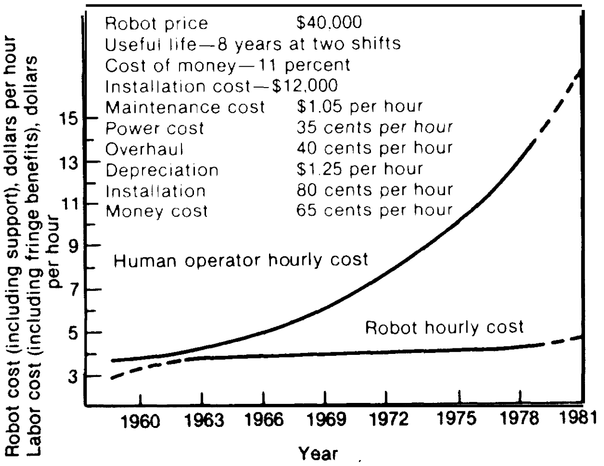
[49] R. Allan, "Busy Robots Spur Productivity, " *IEEE Spectrum,* September 1979, p. 31.

Figure 45.— Manufacturing Costs for Robots, Hard Automation, and Human Operators as a Function of Production Volume



SOURCE Off Ice of Technology Assessment

Figure 46.—Cost Comparison for Human Operator and Robot Assuming One-for-One Replacement and Two-Shift Operation in the Automobile Industry



SOURCE R Allan, "Busy Robots Spur Productivity," *IEEE Spectrum*, September 1979, p 31

costs for one of their robots with the costs of wages plus fringe benefits for an autoworker, assuming the robot to be a direct replacement, According to figure 46, hourly costs for industrial robots have gone up only slightly since their introduction in the 1960's, a period over which wages and fringe benefits for autoworkers increased sharply. Note that installation of the robot is included, but not the engineering costs for the application. For a new installation, development costs, including programing and general debugging, can easily total twice the purchase price of the robot.

In electronics, robots can contribute to quality and reliability by minimizing mechanical damage to delicate parts—which also cuts direct costs—and by helping improve cleanliness. The latter is particularly important for large-scale ICs, where "clean rooms" with levels of dust and other contaminants reduced to very low levels are required. Because people bring contaminants into the production area with them, automation helps raise yields and reduce fabrication costs.

Beyond the now routine applications like spray painting and welding lies a great deal of scope for robots that extend or improve on human capabilities, Some of these robots will be larger than those currently on the market, others smaller. While a few robots now available can handle loads in the range of 500 to 2,000 lb, most are designed with lifting capacities in the range of 50 to 200 lb. Until recently, robots intended for low loads (e. g., under 10 lb) and precision work have been rare. Limitations on precision and repeatability have placed severe constraints on potential applications.[50]

Robots and Jobs

Despite the fact that robots are simply one type of flexible automation, with roots in a number of familiar manufacturing methods—and that automation itself is as old as the industrial revolution—it is as difficult for many people to be dispassionate and objective about robots as it is for them to regard nuclear power as just another means of generating electrici-

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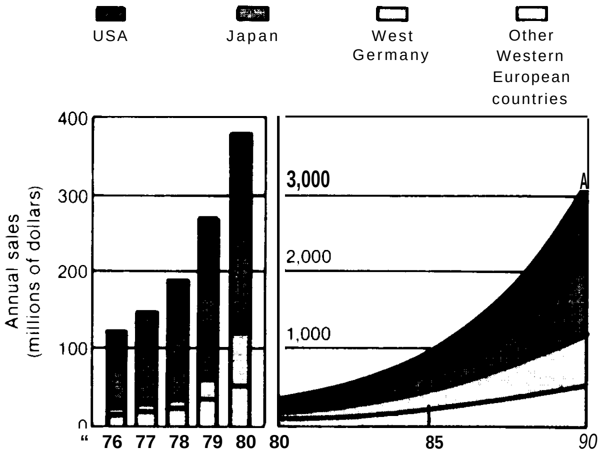
[50] Electronics firms need robots with high accuracy because the small and delicate parts used in electronic equipment are so easily damaged. Nippon Electric Co. [N EC) has recently described a machine with a load capability of about 5 lb and a claimed positioning accuracy of 0.00016 inches, an order of magnitude better than previous high-precision robots. NEC plans to use it in circuit board assembly, as well as wire bonding for ICs. See R. Neff, "Robot Moves by Micrometers, " *Electronics*, Apr. 7, 1981, p. 84.

ty. The entire set of technologies for automating manufacturing and services poses very real threats to the employment opportunities and current job skills of a large segment of the U.S. labor force, as discussed in chapter 9. But it is the whole family that is the proper focus of attention. While it is too early to predict the full range of impacts of computerized manufacturing, it is likely that—as with most instances of major technological change—these will come relatively slowly and in piecemeal fashion. Just as these impacts are likely to be random and incremental, many will be unexpected—and to the extent that they are, people and institutions will be unprepared for them.

Market Growth

If the effects of programmable automation will not become visible overnight, this is in part simply a result of time scales for production and installation; *rates* of increase will be high, but total penetration will mount rather slowly. Figure 47 gives estimates for worldwide robot sales through 1990, According to this projection, the market will exceed $3 billion by the end of the decade, an increase of nearly 10 times over the 1980 level. Other estimates range both higher and lower. To set these figures in perspective, note first that spending for capital equipment in U.S. manufacturing industries is currently $80 billion to $85 billion per year, and second that during the 1980's expenditures on robots are expected to remain well under 10 percent of total expenditures just on automated equipment.[51] Again, from a job displacement viewpoint, all types of automation must be considered.

Figure 47.—Worldwide Annual Sales of Robots, Past and Projected



SOURCE E Heer Robots in Modern Industry *Astronautics & Aeronautics,* September 1981 p 52

Figure 48 illustrates the growth in sales by application expected in Japan over the period 1980-90. While many of the robots sold in 1980 were for use in casting, metal forming (i. e., forging and stamping), and painting, the projections in the figure indicate that these applications will be far outstripped by assembly, welding, loading and unloading of machine tools, and inspection, Some observers predict even more rapid market growth in the United States than figure 48 shows for Japan,

When markets grow this rapidly, a good deal of technical and market volatility can be expected, with many opportunities for entrepreneurial firms pursuing innovative technologies. While there are no guarantees that robot manufacturing will follow a path similar to semiconductors, it would not be surprising to see startups in the United Stated challenging established leaders like Unimation and Cincinnati Milacron. The multidisciplinary demands of advanced robots—both hardware (microelectronics, kinematics and mechanical design, instrumentation) and software (artificial intelligence and computer engineering, automatic control theory, the production engineering skills needed to integrate robots into the workplace)—create conditions favoring innovation and fresh thinking. New companies may emerge to lead this industry into the third generation of robotics, just as Unimation—originally a startup and now owned by a larger corporation—led the first and second generations,

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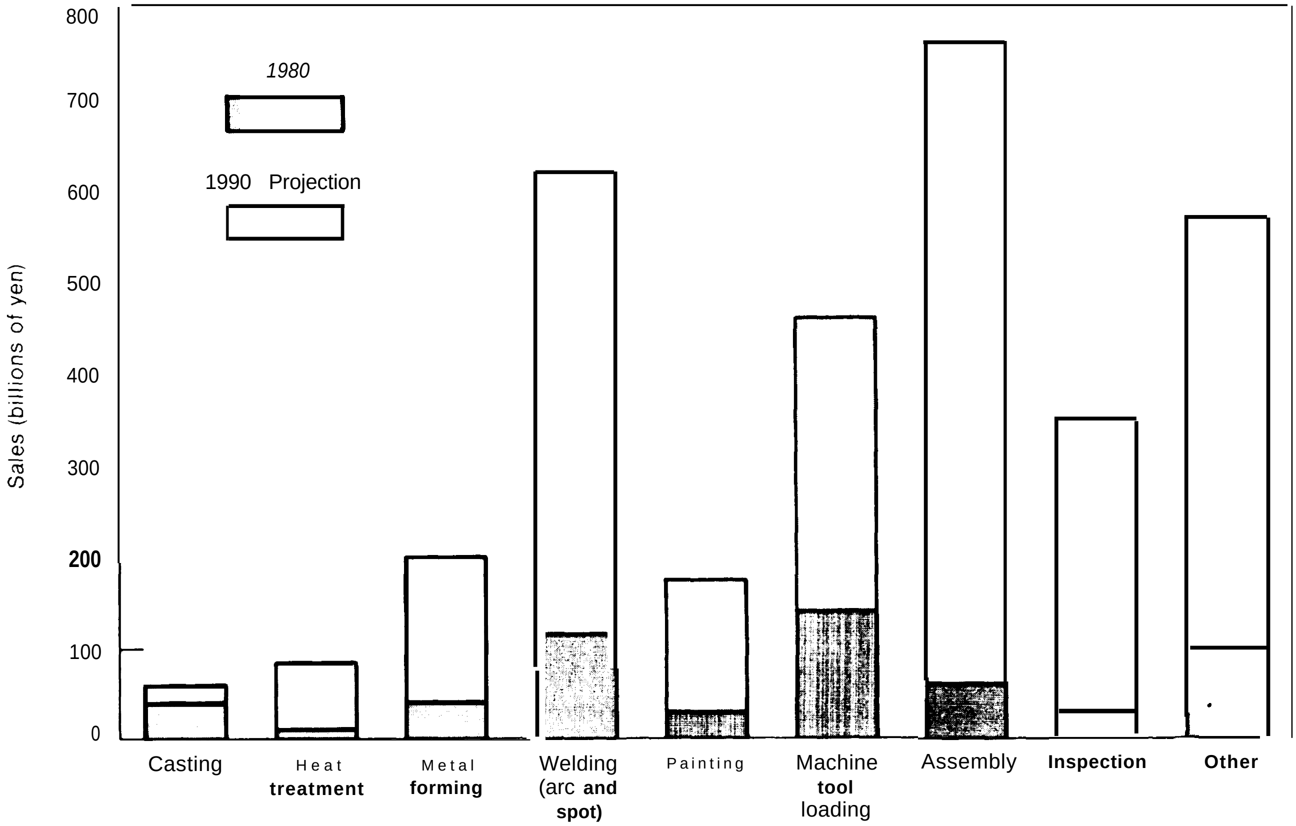
[51] J. T. Woodward, E. P. Seskin, and J. S. Landefeld, "Plant and Equipment Expenditures, the Four Quarters of 1982," Survey *of Current Business,* September 1982, p. 35 (capital equipment spending); "Industrial Robotics, " *Emerging Issues in Science and Technology, 1981* (Washington, D, C.: National Science Foundation, June 1982), p. 28 (robotics as fraction of spending on automation).

Figure 48.—Robot Sales in Japan by Application



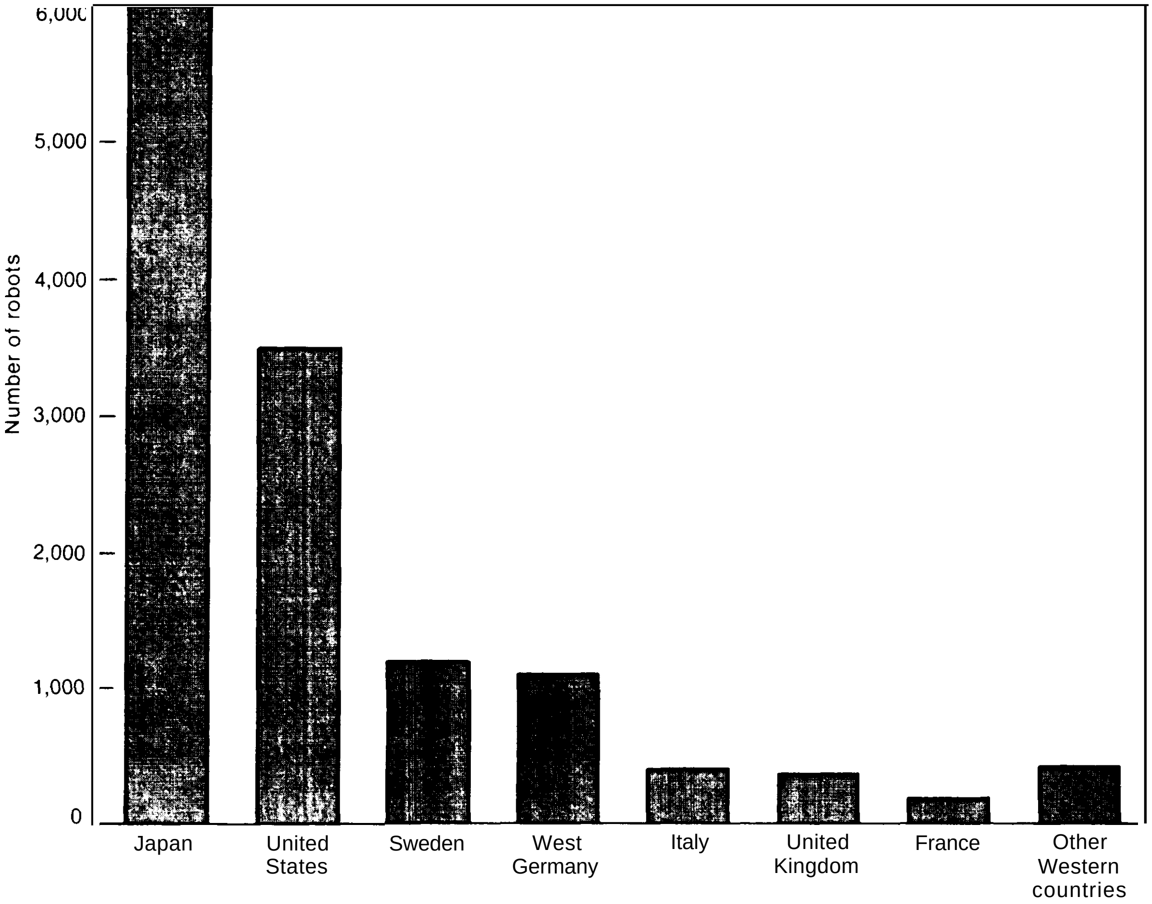
SOURCE Based on data in Robot Industry to Grow Rapidly in 1981," *Japan Report*, Joint Publications Research Service JPRS L/9744, May 19 1981 p 33

Japanese firms are applying robots in manufacturing more intensively than their competitors in other countries—figure 49. Although most observers feel that the United States still leads in the relevant technologies, there are more firms building robots in Japan—130 to 150, perhaps five times the number here—and, indications that Japan may be ahead in learning to apply robots in typical factory environments. As figure 47 indicated, future robot installations in Japan are expected to at least match those in the United States.

Using Robots

While the critical technical problems in the further development of robots center around modeling and control, the critical implementation problems for even the existing robots center on integrating them into the production process. More than half the costs of typical batch manufacturing operations are associated with scheduling and otherwise managing the flow of production—i.e., with software, broadly speaking. These management and production control costs involve: getting the right parts, materials, and supplies to the right place at the right time; seeing that shop floor personnel have the information (now including computer programs) they need; and ensuring that machinery is available and in good repair when scheduled for use. Tasks involving production planning and machine scheduling, job flows, inventory control, and the related routing and coordinating functions might seem straightforward, but in fact they are extraordinarily complex; experience shows them to be among the most critical factors in controlling manufacturing costs. Computer-aided manufacturing holds a great deal of promise for reducing at

Figure 49.— Estimated Numbers of Robots in Use, 1980



SOURCE: 'CAM An International Comparison, " *American Machinist*, November 1981, p. 214

least some of these costs—e.g., those associated with materials handling, control of the inventory of tools, jigs, and fixtures, routing of parts—but only when appropriately integrated into the production environment. Integration will require a great deal of rethinking at both the design and manufacturing stages—rethinking for which cheap computing power is necessary but hardly sufficient. The potential benefits in terms of productivity are huge, but no one anywhere in the world knows at present how to realize them,

Computer-integrated manufacturing will affect the cost structures of many industries; as labor productivity improves, fixed costs will increase relative to variable costs. Engineering and software development expenses will rise compared to blue collar labor costs. Flexibility will make small-batch production more attractive; product differentiation and product customization will become relatively less expensive. The result will be far-reaching changes in the product and marketing strategies of manufacturing companies throughout the world.

International Trends

As has happened in so many other industries, Japanese firms–which began to manufacture robots by importing technology from the United States and Europe—are now quite capable of advancing the state of the art on their own. Currently, robotics technology is flowing between the United States and Japan in both

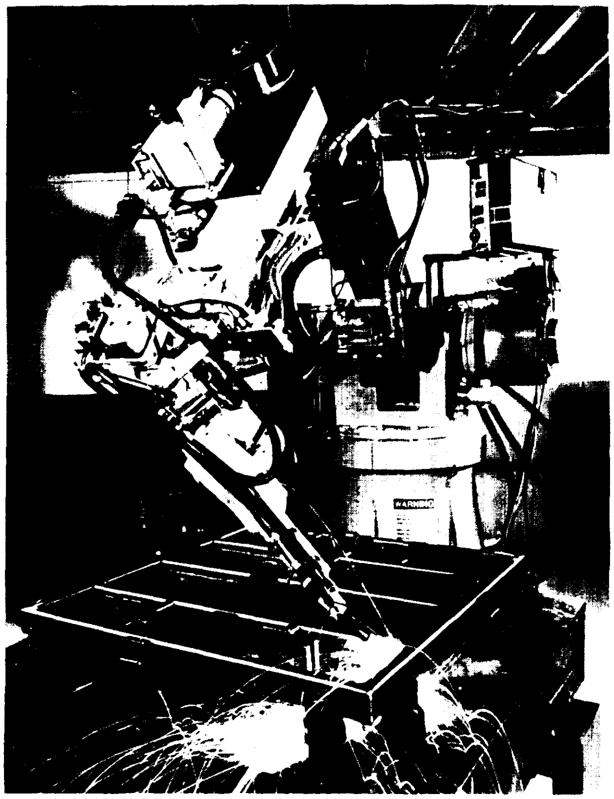


Photo credit Cincinnati Milacron

Robot welding frame assembly for computer

directions; General Electric, for example, has begun to build robots under license from Hitachi. While fewer than 5 percent of the robots produced in Japan during 1980 were exported [imports were comparably small), Japan expects to export 15 to 20 percent of its robot production by 1985.[52]

Again as in other industries, the Japanese Government—via the Ministry of International Trade and Industry (MITI)—has designed programs to encourage and support builders of robots. A number of Western European governments are following suit. MITI sponsored several manufacturing-oriented R&D programs which encompassed robotics during the 1970's. One of the agency's first steps to support the robotics industry itself was the establishment of a leasing program. The Japan Robot Leasing Company, Ltd. (JAROL), incorporated in 1980, is owned 70 percent by 24 robot manufacturers and 30 percent by 10 insurance companies. About 60 percent of JAROL's capital has been borrowed from the Japan Development Bank and from commercial banks. The consortium uses this capital to purchase robots, which are then leased, primarily to smaller firms.[53] While the program is similar to that operated by the Japan Electronic Computer Corp. for financing computers, JAROL does more than just lease equipment; its engineering staff provides assistance in installing and programing robots. Among its other initiatives, the Japanese Government has also granted an extra 13 percent depreciation allowance to purchasers of advanced types of robots, while smaller firms that buy robots for modernization or to automate hazardous jobs can take advantage of low-interest loans.[54]

Much more ambitious is MITI's plan for a joint R&D program aimed at making robots smarter.[55] This effort, with a proposed annual funding level of about 30 billion yen (roughly $135 million), will be organized much like other government-sponsored R&D programs in Japan, About 10 companies are expected to be involved, plus the Electrotechnical Laboratory of the Agency for Industrial Science and Technology, Major thrusts planned over the 7-year schedule beginning in 1982 include:

- improved sensory capabilities—e.g., pattern recognition, force/torque sensors;
- control algorithms incorporating true adaptive or "intelligent" behavior which would allow the robot to operate more-or-less au-

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[52] M. Kanabayashi, " In March of the Robots, Japan's Machines Race Ahead of America' s," *Wall Street Journal,* Nov. 24, 1981, p. 1.

[53] Y. Machida, "Industrial Robot in Japan, I, *TCB* Research, Long-Term Credit Bank of Japan, March/April 1981, p. 4.

[54] The special depreciation provisi apply t robot purchased between 1980 and 1983 that are computer (controlled, have six or more degrees of freedom, and meet specified standards for positioning accuracy, The added 13 percent depreciation in the first year means that a total of 53 percent can be written off (assuming the 5-year, double declining balance depreciation procedure that is normal in Japan). See "Robotics: They Are Smart and Never Need a Tea-B reak, " *Far Eastern Economic Review*, Dec, 4, 1981, p. 70.

[55] "MITI To Launch 7-Year Project To Develop Intelligent Robot," *Japan Report,* Joint Publications Research Service JPRS 1,/10125, Nov. 18, 1981, p. 31.

tonomously, making decisions based on sensory data it receives from the operating environment; and

- improved mechanical design, including manipulators and mobility, the latter very much a controls problem as well.

The program is in part a sequel to previous MITI-sponsored work on remote control devices for maintaining and repairing the radioactive portions of nuclear powerplants. However, the robot program will be much broader.

Summary and Conclusions

In the past, Japanese electronics firms making both TV receivers and ICs—notably memory chips for the merchant market—have emphasized quality and reliability more heavily than their counterparts in the United States. This does not mean that the best performing American firms may not have had quality and reliability as good as the Japanese, or that captive manufacturers in the United States may not have been as good or better than IC makers anywhere, It does mean that specific types of products—color TVs and dynamic RAMs—have, in the past, been produced to higher average levels of quality and reliability in Japan. The picture at present is less certain—indeed, reliability cannot be estimated until products are well along in their service lives. It is plain that American firms have made major efforts to improve quality and reliability—with considerable success. But it is not obvious that they have caught–much less surpassed—the Japanese, who have been improving their own performance at the same time.

Japanese manufacturers may have succeeded in creating *perceptions* of quality and reliability outstripping any actual performance margins, particularly for color TVs; certainly the strategies of Japanese electronics firms have parallels in other industries—e.g., cameras or automobiles—where the emphasis placed on both the image and the reality of quality had an important role in the penetration of U.S. markets. For American firms to match this image demands top management attention,

While the Japanese stress on quality begins with management and appears to permeate organizations from the top down, quality assurance has often been an orphan in the United States. Quality control personnel here have been viewed as obstacles to production; they have had integral roles in neither design nor manufacturing. Japanese firms learned many of the basic techniques of quality control from American engineers, but they have gone a step beyond conventional practice in much of the rest of the world by, for instance, making individual workers responsible for the quality of their own efforts.

Electronics firms in Japan also invest more heavily in employee training. At all levels—assembly workers, engineers and designers, foremen and supervisors, sales and management—employees of American electronics firms tend, on average, to be less knowledgeable concerning quality and reliability than their counterparts in Japan. Although many of the recognized authorities in these fields are Americans, expertise is not spread as widely here as in Japan. Moreover, U.S. electronics manufacturers may still to some extent be paying lip service to quality and reliability, Over time, the depth of their commitments will become more apparent. In particular, it takes time to design quality and reliability into a product line.

In general, Japanese electronics manufacturers also appear to do a better job of managing the interface between design and production. Moreover, the characteristically close working relationships between vendors and purchasers in Japan's electronics industry evidently yields benefits in quality and reliability. Production equipment made in Japan does not, however, appear superior to that available here; indeed, Japanese electronics firms continue to purchase a good deal of manufacturing equipment from U.S. suppliers.

Japanese companies automated the production of TV receivers and other consumer electronic products earlier than most American firms. Extensive applications of robots—in electronics and other industries—will help the Japanese increase manufacturing productivity still further, and will also improve quality and reliability. At present, robots remain a small subset of automated production equipment with limited impact, but they will be a key part of future manufacturing facilities. And, while robots will spread rather slowly through industry in both the United States and Japan–with unpredictable effects, as for any new technology—the cumulative impacts of these and other types of factory automation will be massive, affecting productivity and competitiveness, the skill mix in the work force, and the total number of job opportunities in the economy, Computer-integrated manufacturing will shift corporate strategies in many industries toward greater product differentiation, Japanese companies can be expected to apply computerized manufacturing technologies at least as fast as American firms, wherever there are benefits in terms of cost, quality, worker safety, or product design and marketing.

Appendix 6A—Quality and Reliability Comparisons for Integrated Circuits

This appendix summarizes the data that have been made public concerning quality and reliability levels of chips supplied by American and Japanese firms to the merchant market. The most widely noted comparisons have come from Hewlett-Packard Corp., a U.S. firm that purchases large numbers of semiconductors on the merchant market, and also manufactures ICs for internal use.

Quality Levels

As indicated in table 6A-1, part A, at the end of 1979 the quality levels of Hewlett-Packard’s U.S. suppliers were poor relative to Japanese firms. While Hewlett-Packard had an obvious interest in pressing their suppliers to provide high quality, this data is not just another case of a purchaser playing its vendors off against one another; the semiconductor industry has generally accepted Hewlett-Packard’s test results as valid, although offering a variety of explanations for the relatively poor showings by domestic manufacturers.

The data in table 6A-1 are all for 16K RAMs; indeed, most of the public discussion of quality has focused on RAMs, because they are bought in large quantities by many customers and have become a locus of international competition. Part C of the table shows that American suppliers of 16K RAMs dramatically improved their quality and reliability y during 1980, but that they continued to trail Japanese firms. Improvements by Japanese suppliers over the time period covered in the table were negligible. Note that failure rate after burn-in-parts B and C of the table—is essentially an indication of infant mortality failures, and thus more closely associated with quality than with reliability’. Needless to say, conclusions based on such results should be generalized only with care; the table refers solely to circuits purchased by Hewlett-Packard, and differences from shipment to shipment even from a single manufacturer can be large.

Table 6A-2 presents data gathered for OTA on quality levels for RAMs, 4K as well as 16K. As for the first set of the Hewlett-Packard data, the Japanese 16K RAMs were superior by a large margin. The 4K RAM data—though limited to only one Japanese vendor—are quite different, showing the American-made devices to be superior.

Along with quantitative data on RAMS such as that in tables 6A-I and 6A-2, purchasers of ICs surveyed by OTA’s contractor sometimes provided more general comments. One purchaser. for instance, included the following comparison:

Origin	*Percent of ICs rejected on incoming inspection*
Japan	0-3.0%
United States	0.5-15.0
Western Europe	1.0-5.0

Table 6A-1.—Hewlett-Packard Data on 16K Random Access Memory (RAM) Circuits

A. ***Reported March 1980.***

Country of manufacture		Percent failing incoming inspection	Field failure rate (o/o per thousand hours)	H-P composite qualitv index[a]
Japan-	I[b]	0	0.010 "/0	89.9
	2	0	0.019	87.2
	3	0	0.012	87.2
United States-	1	0.190/0	0.090 "/0	86.1
	2	0.11	0.059	63.3
	3	0.19	0.267	48,1

[a] This index is based on 10 equally weighted factors, of which incoming inspection and field failure rates are two; the others include such things as cost and delivery schedules

[b] Evidently, the three suppliers (not necessarily in order) were Fujitsu, Hitachi, and NEC, American suppliers (again not in order) Intel, Mostek, and Texas Instruments. See "The Quality Goes On Before the (Japanese) Names Goes On, " *Rosen Electronics Letter,* Mar 31, 1980, p 1

SOURCE: R W Anderson, "The Japanese Success Formula Quality Equals the Competitive Edge, " Verbatim Record, Seminar *on Quality Control Japan Key to High Product/vi(y, Washington, D C,* Mar *25, 1980, p 40*

B. Reported November 1980.

Country of manufacture		Failure rate after burn-in	
Japan-	1	0.05 "/0	
	2	0.10	
	3	0.12	Average = 0.17°/oa
	4	0.35	
	5	0.25	
United States-	1	0,60	
	2	0.50	
	3	1.20	Average = 0.75%[a]
	4	0.70	

[a] Averages are not weighted by numbers of circuits from each manufacturer.

SOURCE: B LeBoss, "U S Reject Rate Still Trails Japanese," *Electronics,* Nov 6, 1960

C. Reported April 1981.

Country of manufacture		Failure rate after burn-in: First half 1980		Failure rate after burn-in: Second half 1980	
Japan-	1	0.060/0		0.04	
	2	0.13	Average = 0.25%[a]	0.13	Average = 0.24%[a]
	3	0.40		0.40	
	4	0.40		0.40	
United States-	1	0.60		0.35	
	2	1.20	Average = 0.97%[a]	0.20	Average = 0.35%[a]
	3	1.10		0.50	

[a] Averages are not weighted by numbers of circuits frOm each manufacturer.

SOURCE: R W Anderson, *Seminar on* Management, *Productivity and Reindustrializat /on* East *Meets West*, Washington, D.C , Apr 2, 1981.

Consistent with such patterns, an independent testing firm noted that rejection rates following screening and burn-in were twice as high (about 4 percent) for American-made ICs as for Japanese (1 to 2 percent). End users of ICs generally reported similar results, several noting that they no longer felt it necessary to screen or burn in Japanese circuits.[1]

Reliability Levels

While screening and other tests can locate defective circuits and 'measure quality, determinations of *reliability* must await field experience; long-term

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[1] See, for example, J. Lyman, "The Drive for Quality and Reliability, Part I," op. cit., where an executive of the American minicomputer firm Data General is quoted as follows: "The best U.S. devices are about the equivalent of average Japanese products, Good Japanese lots run at a rejection rate of about 0.03 percent, whereas a good U.S. lot shows about 0.3 percent . . That's why the only RAMs we are not burning in are Japanese ones, " Other information in this paragraph is based on "Quality and Reliability of Semiconductors and CTVS: U.S. v, Japan, " op. cit., pp. 74-76.

Table 6A-2.–Quality Levels of Japanese and U.S. Random Access Memory (RAM) Circuits

		Percent rejected on Incoming inspection		
Country of manufacture		Average		Range
A. *16K RAMs*				
Japan-	1	0.30 ”/0		0.1-0.5%
	2	0.53	**Average = 0.87°/0** [a]	**0-1.8**
	3	1 77		0.1-5.0
United States-	**1**	0.70 %		0-2.7
	2	0.85	Average 1.7 %	o-4.7
	3	1,07		0-6.2
	4	411		0-12.4
B. 4K RAMs				
Japan-	1	1.07 “/’0		0-5,3
United States-	1	0.32 0/0		0-2.0
	2	**0,41**	Average o 53 ”/0	O-24.5
	3	**0.87**		0.1-1.1

[a] Averages are not weighted by numbers of circuits from each manufacturer

SOURCE Quality and Reliability of Semiconductors and CTVs United States v Japan report prepared for OTA by Consultant Services Institute Inc under contract No 033 1170 p 72

tests are very expensive, and burn-in failures more properly ascribed to quality problems. Field failure data assembled by Hewlett-Packard for 16K RAMs were included in table 6A-1, part A. Table 6A-3 contains the remainder of the reliability data available to OTA. Consistent with the Hewlett-Packard results, this shows the reliability of Japanese 16K RAMs to have been markedly better than American products.

Soft Errors

Failure modes for ICs can be divided into "hard" and "soft" failures. Hard failures are repeatable and final: the device no longer functions properly. In contrast, soft failures are random and nonrepeatable. Alpha radiation can cause soft errors in RAM circuits, a problem that was not appreciated until densities reached 16K. The radiation—emitted at low levels from ceramics and other materials used in packaging ICs—sometimes causes a bit stored in a memory cell to switch from "0" to "1" or vice versa.[2] The result is a soft error that appears when the contents of that cell are next recalled.

Table 6A-3.— Reliability Levels of Japanese and U.S. Random Access Memory (RAM) Circuits

Country of manufacture		**Field failure rate (% Per thousand hours)**	
A. 16K RAMs			
Japan-	1	**0 0062°/0**	
	2	**0.0263**	**Average . 0 027‘/oa**
	3	**0.0507**	
United States-	**1**	**00167**	
	2	**0.0687**	
	3	**0.0889**	**Average O.125%** [a]
	4	0.107	
	5	0.1268	
	6	0.3421	
B. 4K RAMs			
Japan-	1	0 “/0	
United States-	1	0.0524	
	2	0.0526	
	3	0.1018	
C. ***1K RAMs***			
Japan-	1	0.07560/o	
United States-	1	0.0667	

[a] Averages are weighted by numbers of chips from each manufacturer

SOURCE "Quality and Reliability of Semiconductors and CTVs United States v Japan report prepared for OTA by Consultant Services Institute Inc , under contract No 03311700, p 72

The frequency of soft errors caused by alpha radiation can be reduced by a number of techniques, which Japanese manufacturers evidently implemented more rapidly than American firms—perhaps because Japanese semiconductor firms were more willing to accept the extra costs. One purchaser of 64K RAMS reported soft failure rates of *10-8* per hour for circuits from *two* Japanese manufacturers; the rates for the products of a pair of American firms were 10^{-3} and 10^{-6} failures per hour.[3]

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[2] T. C. May, "Soft Errors in VLSI: Present and Future," *IEEE Transactions on Components, Hybrids, and Manufacturing Technology*, vol CHMT-2, December 1979, p. 377.

[3] "Quality and Reliability of Semiconductors and CTVs: U.S. v. Japan," op. cit., p. 73. Several years ago, the alpha-induced soft error rate for Fujitsu's 16K RAM was reported to be three orders of magnitude better than that of Mostek's device. The differences were attributed to the designs of the circuits. See J. G. Posa, "Dynamic RAMs: What to Expect Next," *Electronics*, May 22, 1980, p. 119. The resistance of Mostek's 16K RAM to alpha radiation has since been greatly improved, and U.S. firms in general have adopted measures that substantially reduce sensitivity to alpha particles.

CHAPTER 7

Financing: Its Role in Competitiveness in Electronics

Contents

List of Tables

List of Figures

CHAPTER 7

Financing: Its Role in Competitiveness in Electronics

Overview

Declines, real or imagined, in U.S. competitiveness in electronics have been ascribed at various times and by various people to such causes as: unfair competitive tactics by foreign firms, trade barriers that keep American products out of overseas markets, government subsidies in other countries, and costs of capital that are lower than in the United States. Low-cost investment funds are said to be available in countries like Japan for reasons ranging from higher rates of consumer savings to allocations of capital by governments or direct subsidies.

This chapter deals with only this last set of possible causes—those related to corporate financing. Although limited in scope, the discussion has clear implications for other facets of competitiveness. For example, financing costs could be lower where a protected home market reduces risk and provides a stable foundation for international operations. Government subsidies might be indirectly channeled through financial markets as implicit or explicit loan guarantees, as well as in more obvious forms such as grants for research and development or tax havens encouraging regional development.

In mature industrial economies, a vast and varied network of channels links companies seeking funds with individuals and organizations that have moneys to lend or otherwise invest. The capital markets where transactions between those seeking and those providing funds take place accommodate both direct and indirect investments, for short time periods and for long. Among the direct and long-term methods that corporations use to raise capital are sales of stock (equity), where the purchasers acquire an ownership position, and sales of corporate bonds. purchasers of bonds have no ownership relation with the issuing company, but receive a fixed rate of return, as well as possible capital gains (or losses). * Shareholders accept a variable rate of return in the form of dividends, as well as changes in the value of the stock depending on the success of the company. Both stocks and bonds are traded in active secondary markets in the United States and many other industrialized nations. In general, holders of debt—of which bonds are only one type—have first claim on the residual assets of a corporation in the event of liquidation; the claims of stockholders are subordinate.

Highly developed capital markets such as those in the United States also provide indirect financing mechanisms—i.e., one or more financial intermediaries are interposed between the investor and the final recipient of funds. Banks are the most common intermediaries. Investors deposit moneys—for instance, in ordinary savings accounts—which the banks then lend to businesses. Other financial institutions function in generally similar fashion—e.g., the postal savings system in Japan, an important channel for capital that ultimately helps finance Japanese industry. Investment banks, insurance companies, and pension and retirement funds are other examples of financial intermediaries.

The fundamental questions in this chapter deal with costs of capital faced by electronics firms in various parts of the world. Spokesmen for American companies have often compared

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*Several types of corporate bonds exist. Straight bonds carry a fixed interest rate, but their market price varies with economic conditions. For example, if interest rates fall, the value of straight bonds may rise. Convertible bonds allow holders to convert to common stock at a specified price; thus capital gains are possible if the price of the company's stock rises during the period of convertibility.

their costs for investment funds—whether debt (bank loans, bonds) or equity (primarily stock issues)—unfavorably with costs in other countries. In particular, costs of capital in Japan are often said to be as little as half those in the United States. Some observers also claim that the pool of funds potentially available for investment in the U.S. industry is too small.

Such concerns are particularly relevant for the rapidly growing, high-technology portions of the American electronics industry, Firms whose business centers on semiconductors, computers (including software), and even the more rapidly expanding portions of consumer electronics (e.g., electronic games) can find themselves with markets outstripping their ability to finance expansion.

Problems in securing funds for rapid expansion—not only of production, but of R&D and product development—are compounded by the rapidly increasing capital intensity of some portions of the electronics industry. Semiconductor manufacture is a prime example; capital costs are going up rapidly, not only because of escalating design cost as circuits become more complex, but also because new generations of production equipment are much more expensive (ch. 3). Given the predilection of U.S. firms, in electronics as in other parts of American industry, for relying on internally generated funds—i.e., retained earnings and depreciation—whenever possible, financial managers have often been hard pressed to secure funds for growth.

Because the chapter centers on costs of capital, interest rates and the mechanisms by which they are determined become one of the fundamental bases of comparison. The cost to the borrower of acquiring funds is the interest rate on the loan or bond. Costs of equity, following conventional practice, can be related to costs of debt. In countries with well-developed capital markets and modest levels of government intervention—as in the United States—market-determined interest rates are the primary competitive mechanism for allocations of investment funds, Industrial firms obtain funds by entering capital markets in competition with other borrowers.

The interest rate thus serves a critical function in the economy—that of the price for borrowed funds. This price serves to allocate funds so that the pool of available capital goes first to the most productive investments. The mechanism is as follows. Managers of profit-seeking enterprises make investment decisions by comparing their costs in acquiring funds with the expected profits from the uses of these funds—i.e., with the returns on alternative investments. These projects might be new manufacturing facilities, R&D programs, or the acquisition of other corporations. If the anticipated returns are greater than the costs of obtaining funds, then the investment might be made using money generated within the enterprise—e.g., from retained earnings—or from outside capital markets. In either case, the interest rate is the primary factor in determining the cost of financing the project. For example, if market interest rates are high, a corporation might choose to invest in securities rather than in its own business, In general, less attractive investment projects will be postponed when interest rates rise, the market serving to allocate funds to other uses both within the firm and among various companies seeking financing in the capital market,

The market-driven process described does not always function ideally, but as a rule interest rates allocate funds quite efficiently. Still, governments can act in various ways to influence investment decisions—either on a case-by-case basis or by favoring some sectors of the economy over others. Outright subsidies and loan guarantees are two of the more obvious and common tools, Less visible and less direct policies are also possible; some of these are explored in the discussion of financing practices in Japan later in the chapter, Where governments intervene in capital markets, one consequence can be higher interest rates for all borrowers except those favored by the government.

To explore international differences in sources of funding and their costs, this chapter compares the structure of financial markets in the United States and Japan, together with typical financing practices of electronics firms.

More limited discussions of France and West Germany follow. The objective is to understand the effects of financing patterns on competitiveness in the international marketplace, where governments may try to complement corporate strategies or to implement national strategies.

Sources of Funds and Financial Leverage in the United States and Japan

Many executives in the U.S. electronics industry believe the firms they manage to be constrained in efforts to defend or expand international markets by relative costs of financing, and in some cases also by shortages of capital. The electronics industry is not alone in this concern. Other American industries, especially those facing intensified international competition, voice the same complaint, more especially if they feel threatened by the Japanese. The argument has been articulated best—and empirically supported in most detail—by the U.S. semiconductor industry, largely because its rate of expansion and changing technical character place extraordinary demands on the financing capabilities of independent merchant firms. The semiconductor industry's position with regard to financing is summarized below; to the extent possible the argument will be generalized to other sectors of electronics—i.e., computers and consumer products.

The basic contention of the semiconductor industry is straightforward, and for the most part directed toward the industry's primary foreign competitor, Japan: the ability of Japanese electronics firms to gain market position against American companies over the past few years, both in the United States and abroad, has been eased by cheap capital. (The meanings that attach to cost of capital will become clearer below.)

For one reason or another, in this view, Japanese corporations in many industries enjoy costs of capital markedly lower than their American counterparts, and from this source alone gain competitive advantage; Japanese companies would be able, in principle, to manufacture products at lower costs and market them at lower prices. At times, U.S. firms have also associated low-priced products with "unfair" practices in international trade (see ch. 11). Certainly, a broad range of business tactics—whether or not fair within the accepted framework of international trade—are easier to implement if capital is inexpensive.

The U.S. semiconductor industry has also asserted that favorable access to funds has enabled Japanese manufacturers to add capacity in advance of market demand—indeed, to create excess capacity even in times of recession—a "luxury" decidedly unavailable to American firms. As a consequence, when the economy improves, the Japanese are better placed to quickly move into expanding markets, while their competitors here struggle to build capacity and catch up. Finally, it is alleged, ample supplies of cheap capital allow Japanese corporations to spend lavishly on the advanced R&D so necessary in this rapidly changing field. Lower costs of capital, together with full control over their domestic market, are viewed as primary underpinnings of Japan's global strategy.

What are the perceived reasons for these lower capital costs? Two main causes are frequently cited, along with related structural features of the financial system in Japan: 1) the distinctly different capital structures of Japanese electronics companies; and, 2) the very high rate of savings within the Japanese economy. For structural reasons, Japanese firms can tap relatively large amounts of nonequity funds, primarily bank loans (bond markets in Japan are still relatively undeveloped). American corporations, in contrast, rely much more heavily on reinvestments of internally generated revenues to finance growth. Nonequity funds, it is claimed, tend to be less costly.

The second source of Japanese advantage—high savings–by increasing the pool of funds available to be lent, should depress interest rates. This would have the effect of making all types of investment capital less expensive compared to countries where savings are a smaller proportion of gross national product. Savings rates are discussed in more detail in a later section; household savings in Japan run at about 20 percent of income—nearly four times the rate in the United States. There is little agreement on why the savings rates in different countries vary so much, and in particular why that in Japan is so high and that in the United States so low, Variations in the average proclivity of individuals in different countries to save under otherwise similar circumstances appear to be a factor; so do the extent of social welfare programs and differing tax structures.

Combined, these two sources of financial advantage are said to give Japanese electronics firms capital costs barely half those of their American competitors—in 1980, about 9 percent compared to 15 to 18 percent for U.S. semiconductor firms.[1] Such a result, if true, has implications for competitiveness in many other industries.

The conclusions of the Chase Financial Policy study cited above are summarized in table 51. According to Chase's calculations, the typical Japanese manufacturer of semiconductors enjoys substantially lower costs of capital than merchant firms in this country, Only Matsushita (table 51) incurs financing costs larger than *any* of the U.S. companies, at least for the time period examined. Nonetheless, the *range* in capital costs faced by firms in either country is relatively large,

Table 51 .—Costs of Capital for U.S. and Japanese Semiconductor Manufacturers as Calculated by Chase Financial Policy

	Weighted averages of debt and equity costs as of June 4, 1980[a]
U.S. **companies** (calculations in dollars)	
Advanced Micro Devices	17.7%
Fairchild Camera and Instrument[b]	15.5
Intel	16.8
Intersil[c]	21.1
Mostek[d]	16.7
Motorola	13.8
National Semiconductor	17.4
Texas Instruments	16.5
Japanese companies (calculations in yen)	
Fujitsu	8.80/0
Hitachi	12.1
Matsushita Electric	17.1
Mitsubishi Electric	7.7
Nippon Electric Co. (N EC)	7.7
Toshiba	7.7

[a] In terms of required overall rate of return on invested capital
[b] Subsequently acquired by Schlumberger
[c] Subsequently acquired by General Electric.
[d] Subsequently acquired by United Technologies.

SOURCE "U. S and Japanese Semiconductor Industries A Financial Comparison, " Chase Financial Policy for the Semiconductor Industry Association, June 9, 1960, tables 4 and 9, pp 5,3 and 7,6

There are two major reasons for the wide divergences in capital costs in table 51. First, borrowing costs used in the calculations for Japanese firms were lower than rates for American companies, The second primary source of difference lies in the dissimilar capital structures of corporations in the two countries—the greater use of debt by Japanese firms, principally in the form of bank loans (most American firms with substantial debt carry this in the form of bonds),

If Japanese firms use substantially more debt than U.S. companies—as they do—and if debt financing is less costly than equity—as the computational method used by Chase assumes—then a total cost derived from a weighted average of the two sources must favor Japan, This

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[1] "U.S. **and Japanese Semiconductor Industries:** A Financial Comparison," Chase Financial Policy for the Semiconductor Industry Association, June 9, 1980, p. 2.5. The most thorough discussion so far of the impact of corporate financial structure on relative costs of capital, this report seeks to quantify Japanese and U.S. financing costs with considerable care to identifying the sources of the differences.

A more recent analysis comparing industry as a whole in the United States and Japan finds average costs of capital for 1981 to be 16.6 percent here versus 9.2 percent in Japan. See, "A Historical Comparison of the Cost of Financial Capital in France, the Federal Republic of Germany, Japan, and the United States, " Department of Commerce, April 1983. In this report, no attempt was made to adjust for inflationary expectations, nor were the sources of the difference explored in any detail.

would imply cost advantages for Japanese companies, not only in electronics but in any industry making similar use of leverage.

Internal and External Financing

Table 52 illustrates something of the range in international differences in corporate finance. Japanese capital structures are heavily weighted toward external financing. Japanese corporations, on the average, received less than half their capital from internal sources—i.e., from depreciation and reinvested profits. And, while Japan is at the high end in use of external capital, the United States is at the low end, relying much more heavily on internally generated funds.

The category of external finance includes both loans—which in all five countries are extended primarily by banks—and securities. The two major categories of securities are bonds (like loans, debt) and stocks, representing equity holdings.[2] Note that Japanese firms rely much more heavily on loans than securities (either loans or equity) for their external funding; in general, companies in Japan employ much higher financial leverage than do American corporations (leverage can be defined in several ways, perhaps the most common being the ratio of debt to equity in a firm's capitalization). Table 53 compares debt/equity ratios for U.S. and Japanese electronics companies. The reasons that corporations in Japan make greater use of financial leverage—and the consequences—are taken up later.

The conclusions of the Chase study concerning the impact of debt financing on capital costs in Japan are grounded in well-accepted methods of calculation, The cost of capital for a particular investment can be estimated using the relative proportions of the company's sources of capital as weights in the computation for the investment. For example, if a company pays 15 percent interest on debt instruments, and its risk-adjusted cost of equity (explained below) is 20 percent–and if the debt-equity ratio is 1,0—then the firm's overall cost of capital would be 17% percent, The returns expected from a given investment can then be compared to this estimated cost of capital, The computational method is deceptively simple and—except for various subtleties involved in determining the appropriate interest rate for debt and the risk measures for equity—can be applied in straightforward fashion.

All other things equal, then, Japanese firms would enjoy clear financial advantages from their greater relative amounts of debt (higher leverage) so long as the interest rate on debt is less than the risk-adjusted cost of equity—the normal case. Several questions follow: If financial leverage lowers costs of capital, why don't U.S. firms emulate the Japanese by using more debt in their capital structures? Wouldn't stockholders benefit from this choice by earning higher returns? There are also potential tax benefits: since corporations can deduct interest paid on debt as an expense, but not dividends paid to stockholders, would not greater use of debt decrease Federal tax obligations and in-

Table 52.—internal and External Sources of Corporate Financing[a]

	Internal finance (reinvested profits, depreciation)	External finance			Ratio of internal to external finance
		Loans	Securities[b]	Total	
United States	69.40/o ‘	12.40/o	18.20/o	30.60/o	2.27
Japan ... , ...	40.0	49.0	11,0	60.0	0.67
United Kingdom. ., ...	51.4	10.3	38,3	48.6	1.06
West Germany	63.1	29.6	7.3	36.9	1.71
France	65.0	27,4	7.6	35.0	1.86

[a] 1966-70. These patterns have probably not changed greatly.

[b] Corporate securities are mostly stocks and bonds

SOURCE Y Suzuki, *Money and Banking in Contemporary Japan* (New Haven, Corm Yale University Press, 1980), p 14

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[2] For a standard introduction to corporate finance, see J. C. Van Home, *Fundamentals of Financial Management, 4th* ed. (Englewood Cliffs, N.J.: Prentice-Hall, 1980).

Table 53.—Total Debt-to-Equity Ratios for Selected U.S. and Japanese Electronics Firms

	1975	1979
United States		
Advanced Micro Devices	81%	8%
Control Data Corp. (CDC)	38	20
Digital Equipment Corp. (DEC)	30	32
General Electric	41	25
Honeywell	65	32
IBM	4	17
Intel	0	0
Motorola	28	30
National Semiconductor	25	37
RCA	106	125
Texas Instruments	14	21
Japan[a]		
Fujitsu	200%	190%
Hitachi	160	96
Matsushita Electric	14	16
Mitsubishi Electric	370	270
Nippon Electric Co. (NEC)	350	400

[a] The financial data for Hitachi, Matsushita, and Toshiba—as used by chase Financial Policy—includes affiliated trading companies among the consolidated subsidiaries, while that for Fujitsu, Mitsubishi Electric, and NEC does not See the Chase Financial Policy report cited in the source note below, p. 61

SOURCES: United Statea — Derived from annual reports; also “Financial Issues in the Competitiveness of the U S. Electronics Industry, ” report prepared for OTA by L. W. Bergman & Co. under contract No. 033.1550.0, pp 52, 56 Japan-Derived from data in “U S. and Japanese Semiconductor Industries’ A Financial Comparison, ” Chase Financial Policy for the Semiconductor Industry Association, June 9, 1960, Appendix Japanese Semiconductor Companies, Financial Statements and Supporting Schedules.

crease aftertax profits? If so, isn’t this another reason to encourage U.S. electronics firms to increase their leverage? (Japanese tax treatment of interest payments is similar to U.S. law in this respect.) At this point, the layperson might think that Japanese firms have simply taken advantage of financing choices also open to American companies,

Risk

The answers to the questions above, and the key to understanding the U.S. electronics industry’s unhappiness with Japanese financing practices, relate to a second aspect of financial decisionmaking—risk. Investment decisions inevitably involve risks for those who supply funds—whether external funds or internal—because there can be no certainty that future cash flows will be sufficient to compensate investors. In essence, the risks borne by investors are of two types. First, cash flows are variable—more so in some types of businesses than others. In one year, the funds remaining after expenses—hence available for distribution to shareholders or for retention in the enterprise—may be plentiful; in another, such moneys may be scarce or nonexistent. Stockholders are generally believed to desire stable earnings from year to year, accepting greater *variability* in rate of return only if compensated by a higher *average* return.

In contrast to stockholders, who share in the ownership of the firm, creditors merely lend it funds; they generally have first claim on cash flow, as well as on the assets of a firm, and receive a “guaranteed” rate of return—i.e., the interest rate on bonds or other debt instruments. While creditors seldom share in the first type of risk—variability in returns—they may sometimes choose to subordinate their claims rather than force a firm into bankruptcy. In the recent example of Braniff International, the airline’s creditors several times allowed payments of both principal and interest to be deferred before Braniff finally entered bankruptcy.

The Braniff case illustrates the second type of risk—loss of all or part of the investment itself, as well as loss of revenues from interest payments or distributions of profits. This is a risk borne by both owners and creditors. But because creditors have first claim, they are more likely to recover at least part of their investment in the event of business failure. This is the reason interest rates on debt are generally lower than the risk-adjusted cost of stockholders’ equity: holders of debt face lower risks because they have first claim on assets. At the same time, they must accept a nominally fixed rate of return—generally lower than that accruing to shareholders. (In fact, the effective rate of return on bonds is not necessarily fixed, as pointed out earlier, but this is not important here.)

The discussion above is necessarily schematic, and corporations can avail themselves of other methods of financing, which fit into the subordination ordering in various ways. But as a general rule, common stockholders come last–i.e., can recover their assets only after all other creditors and investors have been paid. This subordinated status makes shareholders sensitive to the degree of leverage employed by the firm; their exposure to risk increases with higher leverage. Not only does more debt in the firm's capital structure tend to increase the variability of returns to shareholders, but added debt worsens their position in the event of a forced liquidation. Typically, common stockholders must be compensated through higher returns–which can include capital appreciation—before they will accept the risk inherent in greater leverage.

As a consequence, adding more debt will not necessarily lower a firm's cost of capital.[3] Indeed, neglecting tax effects, the *choice of debt-equity ratio, over rather wide ranges, should have little, if any, impact on capital costs*. Even assuming no increase in interest rate as a firm borrows more—which is not very realistic—the lower costs of debt are generally offset by the higher required returns to common shareholders as leverage increases. Several cautions must be added. While this conclusion is commonly accepted as applying for U.S. capital markets, it is not clear that it always holds in the same way in other countries. Furthermore, taxes do matter, and the fact that interest payments lower a company's tax bill usually would argue for adding to the proportion of debt in a firm's capital structure. But at some point more debt will be accompanied by higher interest rates, since the debt itself becomes increasingly risky for potential holders.

With all of this said, how is it possible that Japanese companies can, on the average, employ debt-equity ratios markedly higher than American firms, without seeming to bear higher costs of both debt and equity? The usual response holds that the Japanese financial system differs from that in the United States, and forces that tend to raise the cost of capital as leverage increases are absent in Japan (or function differently than they do here), This implies one or more of the following:

1. Japanese investors exhibit risk aversion behaviors markedly different from their counterparts in the United States,
2. Some Japanese investors are accepting risks for which they receive less compensation—for whatever reason—than they desire.
3. Some classes of borrowers in Japan pay premiums for funds, these premiums counterbalancing the low rates available to other borrowers—or, alternatively, some potential borrowers cannot get funds at all because of capital rationing.
4. Some risks which private investors in the United States must bear are, in one way or another, reduced for private investors in Japan.

Each of these four possibilities will be briefly examined.

Risk Aversion Behaviors

Financial and business risks must be absorbed within any system that operates to transfer funds from savers to commercial borrowers. The presumption is that people have an aversion to risk and, if they are to accept such risks, they must be compensated by interest payments, capital appreciation, or dividends on shares. Still, it is not necessarily true that all people—or all economies—will exhibit identical patterns of risk aversion. Japanese investors, for example, might demand less remuneration for a *given* level of risk than Americans, (It is also possible that the Japanese are less reluctant to postpone consumption—a possible explanation for the higher savings rate mentioned earlier, with its tendency to force down interest levels.)

Compensation for Risk

The second possibility suggested above was that some individual or institutional investors in Japan might be compelled to accept less compensation than they desire—i.e., less than they would receive in a capital market that functioned differently. It does appear that Japanese banks—which provide much of the capitalization for electronics firms through loans—are accepting what are essentially quasi-equity positions. That is, by the standards of countries like the United States, *banks in Japan are accepting the greater risks normally asso-*

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[3] Ibid., ch. 18.

ciated with equity. While banks can diversify these risks by maintaining a portfolio of corporate loans, to the extent that such risks are systematic, diversification will be ineffective ("systematic risk" is simply that which cannot be reduced by diversification), The question remains: Why do banks in Japan accept financial risks that would not be acceptable elsewhere in the world? This question is taken up later in the chapter.

Preferential Treatment of Selected Borrowers

Some observers assert that "target" industries in Japan are selected to receive bank loans at interest rates well below market levels.[4] This would imply, in the normal circumstance, that other borrowers will pay higher than market rates; still other potential borrowers might not be able to secure funds at all. The bias is usually alleged to favor large firms at the expense of the far greater number of small establishments in Japan, and to favor growth industries —even though such industries may, in the shorter term, offer rates of return both lower and more variable than alternative investments, In general, both semiconductors and computers would be classed as rapid growth, long payout industries—in Japan as well as in the United States,

If some borrowers are, in fact, favored with lower than market interest rates in Japan, this question follows: Why doesn't competition among lenders force Japanese banks to allocate resources to the firms and industries promising the greatest returns, as in the United States?

Subsidization of Risk

The foregoing question is often answered, at least in part, by appeal to the fourth point—namely, that on some loans Japanese banks can shift part of the risk to other parties. In particular, for loans to companies whose activities are deemed to further national interests, the Japanese Government may effectively guarantee the loan, at least to the extent of providing protection against bankruptcy, Some observers, indeed, suggest that many loans by Japanese banks are simply government loans passed through the banking system. In this view, some of the "normal" risks of debt financing are absorbed by the government rather than the banks; interest charges below market rates reflect government subsidization.

As with the other points raised above, the question of whether and to what extent the Japanese Government subsidizes risk can be answered, at least in part, by empirical evidence. While the actual functioning of the country's financial system is taken up in a later section, the Japanese economy is no different from others in that capital is a scarce resource allocated by various mechanisms among an enormous variety of investments. If the government or the banking community chooses to step in by selecting target sectors to receive capital at rates that were directly or indirectly subsidized, the consequences are quite predictable. The target sectors would gain at the expense of the rest of the economy—for which credit would normally have to be rationed. In other words, no country can subsidize all industrial sectors simultaneously—although manufacturing might be favored over agriculture, or the private sector over the public. In fact, there is no question that capital was allocated by the Japanese Government during the earlier postwar period; what is not so clear is whether more than remnants of these policies remain.

Price Inflation and Banking Practices

One question that even the more sophisticated analyses, such as the Chase study mentioned above, have not adequately addressed

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[4] L. C. Thurow, for example, has claimed that Japanese inroads into U.S. and world semiconductor markets are financed with funds provided by the government-owned Bank of Japan: "But the Japanese are entering this industry with massive amounts of debt capital ultimately lent by the Bank of Japan, Their aim is to jump directly into large-scale, capital-intensive techniques of production; proceed rapidly down the learning curve; sell at prices lower than those of the rest of the world; and capture most, if not all, of the market. If American industry limits its investments to those that can be financed by retained earnings, they will simply be driven out of the semiconductor industry. " See, "Prepared Statement of Dr. Lester C. Thurow," *Productivity in the American Economy,* hearings, Task Force on Economic Policy and Productivity, Committee on the Budget, House of Representatives, Jan. 12, 13, and 15, 1982, p. 34.

is the impact of inflation on international financial comparisons, The effects are too complex to fully review here, but differing inflation rates among the world's economies are a major factor in apparent differences in costs of capital. The reason is that observed market interest rates depend in part on expectations by investors with respect to price inflation. If expectations differ between a pair of countries, then market interest rates will diverge from this cause alone. But to the extent that the divergence in interest rates simply reflects the underlying inflation rates in the two economies, differences in costs of capital based on these interest rates are not "real. " only a difference in costs of capital after adjustments for inflation would confer advantages in international competition.

The difficulty is that future inflation can only be projected; the presumption is that the market mechanisms which set interest rates take such projections into account. Interest levels enter the calculation of capital costs for U.S. and Japanese electronics firms in table 51 in at least two ways: 1) through the cost of equity computation, which is based on a "riskless" interest rate; and, 2) in the choice of interest rate for the cost of debt. The riskless interest rate applies to investments for which the risk borne by the lender can be considered negligible, at least in comparison to the risks of equity. Government notes, bonds, or bills are typical examples of "riskless" investments.

The riskless rates applied by Chase Financial policy were: 10.2 percent for the United States, derived from the June 1980 Treasury bond rate; and 9.0 percent for Japan, the yield on the most widely traded debenture (a type of bond) on the Japanese market–lo-year issues of Nippon Telegraph and Telephone Public Corp. (NTT). The analysis takes the degree of risk for these instruments to be, if not zero, at least small and comparable in the two countries. *

These two interest rates do not differ by much; indeed, their closeness accounts for part of the cost advantages calculated for the much more heavily leveraged Japanese companies. But are they close in real, rather than nominal, terms? The answer depends entirely on long-term inflationary expectations—expectations which were probably considerably higher in the United States than in Japan during 1980. * The nominal interest rate differential favoring the Japanese might well reverse, and favor the United States, could the real rates be compared.

Differences in banking practices between the two countries also affect the true costs of capital. For instance, banks in Japan typically demand that greater compensating balances be kept on deposit against corporate loans.[5] Because the firm pays more for the funds it has borrowed than it receives on its deposits, this practice raises the effective interest cost of the loan, Large compensating balances mean that the usual measure of financial leverage—debt-equity ratio—overstates the true degree of leverage.

These observations on the effects of inflation and compensating balances emphasize the complexity of cost of capital comparisons as applied to funds from external sources. They do not confirm or deny the general trends in table 51, though perhaps throwing doubt on the magnitude of the differences resulting from the Chase analysis.

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* NT”r **debentures may actually carry somewhat greater risks, depending on whether the Japanese Government backs such** issues. If NTT debentures are in fact riskier, the effect would be to *decrease* the risk-free rate in Japan, and hence the risk-adjusted cost of capital.

*The Chase study from which table 51 comes did attempt to compensate for varying inflationary expectations. The Japanese cost of capital in yen was converted to a dollar cost using the difference between the two interest rates cited above, said to represent "the premium investors require for receiving interest and principal payments in U.S. dollars rather than yen" (p.7.7). But by implying that the 1.2 **percentage point difference represents dissimilar inflationary expectations, this procedure amounts to assuming that the riskless rates** in the two countries, expressed in dollars, *are equal.* This seems unlikely; it would imply that the capital market in Japan is both efficient and perfectly linked to that in the United States, neither of which is true. It is more reasonable to assume that differences in inflationary expectations were considerably larger than 1.2 percent in mid-1980.

[5] Y. Suzuki, *Money and Banking in Contemporary Japan* (New Haven, Corm.: Yale University Press, **1980)**, p. **50.** Japanese firms often keep 25 percent or more of borrowed funds deposited with lending banks. Furthermore, banks are more likely to lend to firms that are already large depositors. In the United States, compensating balances have typically been in the range of io to 20 percent, but this requirement is increasingly being replaced by an explicit fee. The fee arrangements generally result in lower borrowing costs. See "The Perilous Hunt for Financing, " *Business Week*, Mar. **1,** 1982, p. 44.

Effects of Financial Leverage on Tax Payments

While the Japanese Government might support electronics firms through a variety of capital and other subsidies, the study by Chase Financial Policy summarized in table 51 is based solely on a leverage argument—i.e., on the advantages of debt as a source of corporate financing. In the absence of other sources of financial advantage, leverage provides lower capital costs primarily through its effects on corporate tax payments. Although these are not trivial, the tax advantages that accrue to Japanese firms as a result of high debt-equity ratios reduce their costs of capital by only a few percentage points—probably less than 2—compared to American firms. The reasons are outlined below.

In order to isolate the effects on cost of capital stemming from tax shields on debt, assume that interest rates in the United States and Japan are the same–say 10 percent–but that corporate tax rates differ. For purposes of illustration, use the nominal tax rates in the two countries—48 percent for the United States, 40 percent for Japan.[6] For leverage, assume a ratio of total debt to total capital equal to 0.67 for Japan and 0.17 for the the United States. * As a result of the tax shield created by leveraging, costs of capital would be lowered by:

Japan . . . . 0.67 (0.4) (0.1) = 0.0268
United States .0.17 (0.48) (0.1) = 0.00816
Subtracting gives . . . .0.01864 or 1.864°/0

That is, the tax shield created by greater leverage would give Japanese firms a cost of capital advantage of about 1.9 percentage points compared to firms in the United States.

In fact, this example overstates the advantage because the median figure (0,67) for Japanese firms ignores the impact of absolute size, Hitachi and Matsushita—which have less than median leverage—are much larger than the others; Nippon Electric Co. (NEC), which has the highest debt-to-capital ratio—0.80—is considerably smaller. When the debt-to-capital values are weighted by total assets, the debt-to-(total) capital ratio for the Japanese companies is 0,52, a result that is considerably affected by Matsushita, which had negligible leverage. Using this figure for Japan, along with the leverage value that Chase suggests in their study as a desirable target value for American firms desiring to reduce their costs of capital–0.33--the comparison becomes:

Japan . . . . 0.52 (0.4) (0.1) = 0.208
United States .0.33 (0.48] (0.1) = 0.01584
Subtracting gives . ...0.00496 or 0.496°/0

These two changes reduce the cost of capital advantage of the Japanese firms from 1.9 percentage points to only half a point. This second comparison is not necessarily either more or less meaningful than the first; the lesson is that tax advantages are quite sensitive to small changes in leverage. The computation is far less sensitive to the tax rate itself.

These examples show that, while the use of leverage does lower a firm's cost of capital, the effects are relatively small. A cost of capital lower by 2 percentage points might translate to manufacturing costs lower by 1 percentage point—not very significant. The difference that does result can be regarded as an implicit financial subsidy from the Japanese Government via the tax system. (The question of special tax provisions for certain industries is independent.)

Risk Absorption in Japan

As mentioned earlier, Japan's banking system absorbs risks normally assumed by shareholders in the United States—in particular, the risks of high leverage in Japanese electronics companies. The first question is whether, in

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[6] This is the nominal rate for retained income in Japan; distributed profits are taxed at 30 percent. While nominal rates suffice for illustration, they bear little resemblance to the taxes that corporations actually pay after deductions, credits, depreciation allowances, etc. The "effective" tax rates in the two countries in the late 1970's—total corporate taxes paid divided by total corporate profits—were about 37 percent in the United States, 29 percent in Japan. See H. Gourevitch, A. Wilson, and D. Culp, *7'ax Rates in Major industrial Countries: A Brief Comparison,* Congressional Research Service report No. 80-224 E, Dec. 15, 1980, p. 8.

*The *0.67* figure is used at several points in the summary of the Chase Financial Policy study —e.g., p. 2.7. It is essentially the median figure for Japanese semiconductor manufacturers. Medians for U.S. semiconductor firms in the years examined by Chase were 0.16 to 0.18 (p. 2.2).

fact, the risks of bankruptcy, reorganization, and business failure are increased by the greater use of financial leverage in Japan. If so, the frequency of failures—especially during economic downturns—should be higher than in countries like the United States where, on the average, leverage is much lower. Indeed, bankruptcies in Japan have risen to rather high levels in times of general economic downturn. In 1977, for example, Japanese enterprises failed in record numbers.[7] The rate of bankruptcy that year was four times greater than the comparable U.S. figure, and these failures involved corporate liabilities of over $16 billion, more than five times the 1977 level in the United States. While 1977 remains the peak year in terms of both number of business failures and total liabilities, in every year since 1976 Japan has experienced more than 15,000 bankruptcies (excluding small businesses) with total liabilities exceeding 2 trillion yen (roughly $10 billion).[8] Although bankruptcies in electronics have been infrequent—in part because growth rates and cash flows have remained high, allowing firms to service their debt—risk is clearly present.

In the Japanese financial system, these risks tend to be shifted to the banking community. Banks assume quasi-equity positions by accepting debt in highly leveraged firms. If a company finds itself in financial difficulty, the banks are literally forced to take action aimed at reorganization. The alternative is to proceed with bankruptcy. When large corporations have faced trouble, the choice, not surprisingly, has often been restructuring—sometimes accompanied by infusions of even more funds, Typically the banks have forced a complete reassessment of corporate strategy; not infrequently the ailing firm's executives have been replaced by a bank-appointed managerial team.

Sometimes observers in the United States conclude that these interventions by Japanese banks serve to reduce risks to businesses, or risks to the banks, or both. To believe this implies believing that bankers are on the average wiser than managers of industrial corporations. In fact, these interventions do not lessen financial risks, but are *caused* by the much greater exposure of the banks. Such interventions are less common in the United States because American banks do not provide as great a fraction of corporate financing.

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[7] G. R. Saxonhouse, "Industrial Restructuring in Japan," *Journal of Japanese Studies*, vol. 5, 1978, p. **273.** Elsewhere Saxonhouse states: "Debt-equity ratios which are four or five times the American level result in bankruptcy rates which are also four or five times the American level. Large *Japanese* firms do go bankrupt. In recent years Japan has had two close to $1 billion in liabilities bankruptcies" See "Statement of Gary R. Saxonhouse Before the House Foreign Affairs Committee, Subcommittee Asian and Pacific Affairs and Subcommittee on International Economic Policy and Trade," Oct. **1, 1980.**

[8] Only firms with liabilities of more than 10 million yen are included Figures for 1968 through *1980* can be found in "Japan **1981** —An International Comparison, " *Japan Report,* Joint Publications Research Service JPRS 1,/10760, Aug. *24, 1982,* p. 7, those for 1981 **in 'corporate Failures** in Japan Last Year Fell 1.5% to 17,610, " *Wall Street Journal,* Jan, 15, 1982, p. 28.

Other Factors in Costs of Financing

Size and Diversification

Many of the leading international competitors in electronics are large, diversified companies (ch. 4). This is the case for American corporations like GE or IBM, European manufacturers like Philips or Siemens, and many Japanese electronics firms. But other U.S. entrants in world markets, notably the merchant semiconductor firms, remain much smaller. These firms, have generally depended more heavily on one or a few product lines than their competitors in Japan. Size and diversification affect capital costs quite directly, with the advantages going to big companies with broad product lines. Such firms can absorb and spread risks more effectively.

Lenders look to a stable pattern of financial returns as one indicator of security for their own repayment. Diversified companies exhibit more stability, hence lenders are willing to supply funds at lower rates of interest. Large diversified firms are also, on average, evaluated as better risks by bond rating companies like Moody's or Standard & Poor's. Texas Instruments taps a lower cost bond market than, say, Advanced Micro Devices; IBM lower than Digital Equipment Corp.; GE lower than Zenith. The conclusion is: *costs of capital will be higher for U.S. as opposed to foreign electronics companies when the American firms are significantly smaller and less diversified.*

There is a great deal of variation in the sizes of firms within the electronics industries of the United States, Japan, and the European countries. Nevertheless, in Japan and Europe it is primarily larger companies that are active on a world basis, more the exception than the rule for companies the size of Nixdorf (West Germany) or Oki Electric (Japan) to be strong international competitors, In the United States, the situations of companies like Mostek, Fairchild, or Intersil have changed dramatically as a result of their acquisitions by much larger concerns. Still, the United States remains unique in the number of relatively small electronics firms that seek to compete worldwide, including many of the new startups making semiconductor and computer products.

In Japan, the evidence suggests that the government and banking system—as in a number of other countries—overtly discriminate among borrowers on the basis of size.[9] But even if foreign capital markets were identical in every respect to American markets, and operated with no more government intervention than in this country, the larger average size of the major foreign competitors—particularly in semiconductors—would give them at least a small relative advantage.

On the other hand, larger semiconductor and computer firms in the United States clearly have *not* reaped great benefits from their own ability to tap somewhat lower cost sources of external capital. Thus, one can question how important such differences might be internationally. Over the years, fast-growing and profitable small- and medium-sized firms have coexisted with the giants of the U.S. industry—indeed have often outstripped them; size and diversity did not appear to give RCA or GE much help in computers or semiconductors. In dynamic, technologically advancing industries, other competitive forces far outweigh small differences in interest rates on bonds or bank loans,

Savings Rates[10]

As mentioned earlier, international differences in savings rates could affect relative costs of capital, Within a closed economy, a high rate of savings creating an ample supply of investment funds will tend to depress interest rates. Given the international linkages among capital markets, this simple argument is not by itself sufficient to relate savings levels to interest rates, but may still have weight. For reasons that are poorly understood, the savings rate in Japan has been extraordinarily high for many years, Table 54 gives data on household savings for the 1976-79 period; the figures for all five countries have remained fairly constant over the past two decades. High savings rates have characterized both the corporate and household sectors in Japan, but it is personal savings that have been most surprising in view of interest rates that have been below prevail-

Table 54.—Household Savings Rates in Several Industrial Countries

	Average savings rate, 1976-79[a]
United States	5.80/o
Japan	21.1
West Germany	13.4
France	13.5
United Kingdom ., ...	8.3

[a] Percentage of household disposable income saved.

SOURCE: K. Sate, "Why Have the Japanese Saved So Much? On Determinants of Japanese Household Saving, " presented at Japan Economic Seminar, Washington, D. C., Jan 23, 1982, p 1

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[9] R. E. Caves and M. Uekusa, *Industrial Organization in Japan* (Washington, D. C.: Brookings Institution, 1976), pp. 37-38.

[10] For a general introduction to savings rates, see C. Elwell, *Investment and Saving: The Requisites for Economic Growth,* Congressional Research Service report No. 81-207 E, Nov. 15, 1981.

ing rates of inflation—as shown later (see table 64)—and have also been significantly lower for savings accounts than for alternative investments such as bonds.[11] Despite this, Japanese households carry the largest portion of their savings as cash or deposits; the contrast with behavior in the United States—illustrated in table 55—is striking. Householders in Japan keep a substantially lower portion of their assets in corporate stocks.

This extraordinarily high savings rate–half again as much as in France or West Germany, and nearly four times that in the United States (table 54)–when combined with closely controlled savings institutions, is often said to produce artificially low interest rates on loans to Japanese businesses. The argument is essentially on the supply side: low interest yet abundant sources of capital have allowed Japanese corporations to expand rapidly while maintaining low prices, especially in export markets. As one consequence of rapid growth, the companies would enjoy economies of scale, along with modern, highly productive manufacturing facilities, Past this point, low capital costs would be less of an advantage, but Japan's firms could by then compete comfortably on other grounds.

Numerous variations on this theme have been propounded, many stemming from the Japanese Government's well-known low interest, high growth strategy in the earlier postwar years. Some observers go so far as to imply that no resource allocation problems exist in Japan because of a virtual glut in investment funds.[12] Often such assertions are linked with the target industry argument mentioned earlier. If true, this would mean that Japan's chosen industries enjoy low financial costs for reasons entirely apart from their high debt-equity ratios.

Table 55.—Distribution of Household Assets in the United States and Japan, 1978

	United States	Japan
Cash, plus demand and savings deposits	39.20/o	68.70/o
Bonds	9.6	8.1
Stocks, including mutual funds	23.5	10.0
Life insurance	5.6	12.6
Other[a]	22.1	0.6
	100.0"/0	100,00/0

[a] For the United States includes money market and pension funds—the latter accounting for the major portion of this category, for Japan, consists mostly of company savings plans

SOURCE Adapted from E Lincoln, "Financial Markets in Japan, " Council Report No 47, United States-Japan Trade Council, Dec 19, 1980, p 9

But capital markets should not be viewed from only one side. In this case, there are potential impacts on the demand side as well as the supply side. Growth affects both the demand for funds and the supply, Businessmen foresee abundant sales opportunities in expanding economies and invest to meet the new demand. This places heavy pressures on capital markets. On the supply side of these markets, individual consumers may experience rapid growth in real income but adjust their consumption habits more slowly—meanwhile saving their unspent income. Thus, a case can be made that Japan's high savings rate is a consequence rather than a cause of rapid economic growth—i.e., that income growth has outstripped consumption.

In fact, neither demand-side nor supply-side perspectives tell the whole story; both are needed. In Japan, inflation-adjusted interest rates on savings have recently been comparable to rates in the United States—table 56. This table compares rates of return available on long-term government bonds in both countries (a rather arbitrary choice) to the respective inflation rates, the difference being "real" rate of return. As the table shows, since 1978 investors in Japan have received higher real returns than those in the United Sates. This suggests *that artificially depressed interest rates have not recently been a source of abnormally low*

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[11] See, for example, H, C, Wallich and M. 1. Wallich, "Banking and Finance, " *Asia New Giant,* H. Patrick and H. Rosovsky (eds.) [Washington, D.C.: Brookings Institution, 1976), pp. 260-261.

[12] Response of W. Rapp, *Technology Trade,* hearings, Committee on Science and Technology, Committee on interstate and Foreign Commerce, and Subcommittee on International Trade, Investment and Monetary Policy of the Committee on Banking, Finance and Urban Affairs, House of Representatives, and House Task Force on industrial innovation, June 24, 25, 26, 1980, p. 421. Rapp stated, "The Japanese have basically solved that problem by generating too much capital, so that they are actually wasting it to a certain degree now, so it is overkill. They don't really have a capital allocation problem now,

Table 56. —inflation-Adjusted Rates of Return in the United States and Japan

	United States			Japan		
	Long-term government rate	Inflation rate[a]	Real rate of return	Government bond rate	Inflation rate[a]	Real rate of return
1975 .., ...	8.20/o	9.20/o	– 1 .0 "/0	9.20/o	11 .9 "/0	–2.70/o
1976	7.9	5.8	2.1	8.7	9.3	–0.6
1977	7.7	6.5	1.2	7.3	8.1	–0.8
1978	8.5	7.5	1.0	6.1	3.8	2.3
1979	9.3	11.3	–2.0	7.7	3.6	4.1
1980	11.4	13.5	– 2.1	9.2	8.0	1.2
1981	13.7	10.4	3.3	8.7	4.9	3.8

[a] Based on consumer Price indexes.

SOURCE Based on data from International *Financial Statistics*, International Monetary Fund, various Issues.

costs of capital for Japanese electronics firms, In other words, there is little evidence of any across-the-board supply-side stimulus that might stem from an ability by Japan's Government to persuade people to save even at relatively unattractive interest rates. As the table demonstrates, corporate (and recently government) demands for funds have driven up interest rates in Japan much as in other developed economies.

This does not dispense with the possibility that the Japanese Government intervenes in capital markets to subsidize target industries. Certain industries—or firms—could be favored by government repayment guarantees to lending banks, effectively transferring the risk of default from the commercial banking system to the public at large. Alternatively, the Bank of Japan could be encouraged to rediscount bank loans at favorable rates. Finally, through the postal savings system the government itself takes in about a third of all savings deposits.[13] These funds could be channeled to favored industries at interest rates largely determined by government fiat,

It is quite true that in early post-World War II Japan, allocations of investment funds were more a function of administrative control than relative interest rates; favored industries had access to funds at subsidized rates of interest, while personal savers and small businesses bore the brunt of the costs. This point is taken up later, when the overall structure of the Japanese financial system is described in more detail. Still, this practice seems largely to have disappeared; government capital allocations do not *now* seem to provide borrowers in Japan with a notable edge over U.S. competitors. Government financial institutions accounted for about 30 percent of all corporate loans in 1950, but as of the end of 1980 their share had fallen to 13 percent; during the 1970's, loans from government institutions accounted for only about 5 percent of total capital flowing into Japanese industry.[14] The percentage is even lower in the electrical machinery sector, which includes electronics; here, government institutions accounted for only 8,2 percent of outstanding loans as of December 1980, Nonetheless, some observers continue to hold that the Japanese Government effectively socializes the risk of corporate borrowing.[15]

Costs of Capital for Electronics Firms in the United States and Japan: Summary

It does seem clear that Japanese electronics manufacturers can get external capital at somewhat lower rates than their counterparts in the United States. But at present, this capital cost advantage, in inflation-adjusted terms, appears

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[13] *The Japanese Financial System* (Tokyo: The Bank of Japan, 1978), p. 22.

[14] E. Lincoln, "The Japanese Government's Role in Business Financing, " *JEI Report,* Japan Economic Institute, Washington, D. C., Jan. 8, 1982, p. 12.

[15] E. Sakakibara, R. Feldman, and Y. Harada, The *Japanese Financial System in Comparative Perspective,* Joint Economic Committee, Mar. 12, 1982, p. 26. The authors reach no conclusions about the effects on interest rates or cost of capital, however.

Photo credit GCA Corp

Wafer processing equipment for making integrated circuits

to be small—certainly less than 5 percentage points. The sources of this advantage are multiple: government policies in Japan that have the effect of subsidizing interest rates for favored investments no doubt continue to account for a good deal of the margin. Except for the tax-shielding effects of their higher leverage, Japanese electronics companies do not have access to cheaper capital because of the preference for bank loans in their capital structures. While greater leverage transfers business risks to the banking system, it does not allow the Japanese to avoid risks.

A difference in financing costs of 2 or 3 percentage points is nontrivial but will not drastically alter the market postures of competing firms. For purposes of comparison, assume a sales-to-capital ratio of 2—within the typical range for much of the electronics industry—and a 3 percentage point difference in capital costs. Moreover, assume that this 3 percentage point margin applies for the total investment in a production facility—which is unlikely. Even then, the result would be a potential manufacturing cost difference of about 1½ percent, and might translate into a price difference of the same magnitude. Smaller capital cost differences would reduce this advantage commensurately.

Such a 2 or 3 percentage point advantage in capital costs represents an average over many firms in both Japan and the United States. The difference in *average* costs of capital in the two countries is smaller than the differences in capital costs among competing electronics firms *within* either country. Although table 51 does not accurately portray cost of capital differences between the two countries, it will illustrate this point if taken as representative of firm-to-firm differentials. The range in costs of capital for the eight U.S. semiconductor firms listed in the table is 7 percentage points, that for the six Japanese manufacturers nearly 10 percentage points. The interfirm differences—and the resulting competitive advantages or handicaps—are much larger than OTA's estimate of the average differential between the two countries.

Relative *availability* of capital for electronics firms in the United States and Japan has greater potential impact. Favored Japanese electronics firms seem to have little difficulty in acquiring funds for expansion and modernization. In contrast, some U.S. companies—particularly the smaller ones—believe themselves subject to capital constraints. That is, they may find themselves unable to raise as much capital as they would like at any reasonable cost.

Capital availability is a subject left to a later section, but note one major difference between electronics and other American industries that make this same complaint. Some domestic steel companies, for instance, have had difficulty attracting external funding because of their inability to convince prospective investors of the industry's potential for growth and future profits. While a few segments of electronics face similarly limited prospects, the financing problems faced by most U.S. entrants are more closely related to the large amounts of new capital—particularly compared to existing net worth—required to maintain their share in a rapidly expanding worldwide market. In semiconductor manufacturing, rising capital intensity compounds the difficulty. These matters, concerned more with the dynamics of growth than with absolute costs of capital, are taken up below. The next section extends the comparative treatment of financing to several other countries, while carrying forward the U. S.-Japan comparison,

Financial Structure: An International Comparison

Many countries are attempting to build competitive electronics industries because they believe them essential for a growing and healthy economy. Government assistance, often financial, has flowed to electronics companies: Great Britain provides explicit subsidies; France has combined subsidies with trade protection. A number of the rapidly developing countries are following suit, as outlined in chapter 10. Still, Japan remains the primary competitor in electronics, and its financial system is treated in much more detail than that of France or West Germany, the two other countries examined below, The focus on semiconductors continues because U.S. firms in this part of the industry have faced the most pronounced financing problems,

Funding rapid expansion is a challenge that semiconductor companies share with manufacturers of small computers and peripherals, software firms, and new entrants in other portions of the industry; Atari, the manufacturer of video games, has reputedly been the fastest growing technology-based company in history, while one firm making game cartridges saw its sales grow 1,000 percent (to $50 million) during 1981.[16] In order to remain competitive, firms in such markets must be able to finance growth at rates that are literally explosive,

United States

Sources of financing for American electronics companies vary depending largely on their size, extent of diversification, and maturity. New corporate startups have been frequent during the industry's postwar history–not only in semiconductors and computers, but in many other product lines. Hewlett-Packard—a diversified manufacturer of test and laboratory equipment, calculators and computers, and a leader in integrated circuit (IC) technology through its captive operations—got its start just before the war in a garage in Palo Alto, Calif.[17] In many respects typical of the firms that later gave this region the name Silicon Valley, the company's founders began by designing its first product themselves—an audio oscillator supplied to Walt Disney Studios for the production *Fantasia*.

Venture Capital

Businesses typically draw on far different sources of funds in their early stages of development than later, progressing through a fairly predictable sequence as they grow and mature. This progression, which illuminates some of the unique characteristics of U.S. capital markets, is rather different from that in other countries, For purposes of illustration, consider a startup firm with origins like those of Hewlett-Packard or the many semiconductor manufacturers that sprang up during the 1960's. Often these enterprises were formed by small groups of engineers and managers spinning off from a somewhat older company with the aid of funds from the venture capital market. The process is not unique to the semiconductor industry: Control Data Corp. was founded in 1958 by a group of ex-Univac employees. While startups had become rare by the mid-1970's,

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[16] L. Wailer, "Home Video-Game Sales are Dazzling," *Electronics*, Jan, 27, 1982, p. 78.

[17] "At War, " *Electronics*, Apr. 17, 1980, p. 203.

many new ventures in microelectronics, computer peripherals, and software have been established since 1980.[18]

Where rapid growth creates expectations of high returns, capitalization for new companies often comes from specialized financiers who provide equity funds to the venture capital market. Along with electronics, biotechnology is a current example. In such cases, ownership is typically shared among venture capital organizations and the founders of the firm. Stock options have been a common means of attracting talented individuals to startups, and have been used to build handsome compensation packages for key executives or technical specialists without cutting too deeply into cash flow,

Annual returns of 25 to 50 percent over a period of perhaps 5 years are typical goals of institutional venture capital organizations. In the past, wealthy individuals or families sometimes founded private corporations for seeking new and risky—but potentially highly profitable—investments. Today, corporate venture capital organizations are also prominent—subsidiaries of larger companies seeking to diversify. Corporate venture funding is more likely to go toward second- or third-round financing of young companies than to new startups, and investments tend to be larger than those of independent venture capital organizations. Sometimes eventual ownership is an objective; in other cases corporate venture capitalists are simply seeking capital appreciation. Occasionally the funding organization provides capital largely to gain proprietary technology. This has been the apparent goal of investments in U.S. electronics firms by a number of foreign companies. Both Siemens (West Germany) and Fujitsu (Japan) have invested in this way. Siemens owns 20 percent of Advanced Micro Devices, Fujitsu 26 percent of Amdahl, a leader in technology for large computers.

An alternative source of venture funding, the Small Business Investment Co. (SBIC), was created by the Small Business Investment Act of 1958, Although most SBICs concentrate on neighborhood businesses, a few have national outlooks. Venture capital partnerships and funds have also blossomed in recent years; the U.S. venture capital industry now includes about 600 firms and should continue to expand as a consequence of new ERISA (Employee Retirement Income Security Act of 1974) rules allowing "prudent" participation of pension funds in venture activities.[19] In rare circumstances funds can be raised through public stock offerings, but this avenue is more likely to be available later in development.

Venture capital markets are highly cyclical. One influence has been taxation of capital gains. In general, high taxes on capital gains discourage potential investors. Table 57 summarizes the results of a study prepared for the National Venture Capital Association, together with more recent data that bears on this point. The maximum tax on capital gains in the United States was reduced from 49 percent to less than 30 percent in 1978. Although total venture investments rose dramatically, such trends do not prove a cause-and-effect relationship. They do suggest that the tax revision was a powerful contributing factor in the upswing.

At the same time, a variety of other forces affect the ups and downs of venture funding. The cyclicality reflects the confidence of potential investors on the supply side and of potential entrepreneurs on the demand side concerning prospects for the economy and the propitiousness of risky new undertakings. The timing of startups depends on more than economic conditions. Venture organizations look carefully at the abilities of a new firm's leaders; both capitalists and managers look for "technological windows" that offer unusual oppor-

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[18] Numerous examples can be found in J. W. Verity, "StartuP Fever is Spreading," and R. Emmett, "Venture Market Mysteries," *Datamation*, September 1982, pp. 180 and 194.

estimate of the industry breakdown is as follows: private venture capital firms, 200 to 250; SBICs, 300 or more; corporate venture capital organizations, about 50. See J. A. Timmons and D. E, Gumpert, "Discard Many Old Rules About Getting Venture Capital," *Harvard Business Review*, January-February 1982, p. 152.

Table 57.—Aggregate U.S. Venture Investment Activity (millions of dollars)

	New commitments	Higher round investments (prior commitments)	Totals
1977			
Amount	**$56**	**$28**	**.$84**
Number of investments	**126**	**126**	**252**
1978			
Amount	**$92**	$31	$123
Number of investments	196	150	346
197P			
Amount	$145	$65	$210
Number of investments	290	248	538
1980			
Amount	NA	NA	$657
1981			
Amount	$500	$900	$1,400

NA = not available.

[a] 1979 data annualized from first 6 months Data taken from 55 respondents. To OTA's knowledge, no fully comparable data on venture investments for later years are available

SOURCES 1977-79—"Financial Issues in the Competitiveness of the U S. Electronics Industry, " report prepared for OTA by L W Bergman & Co. under contract No. 033-1550.0, p 9, quoting from "Survey of Venture Capital Investment, 1977-1 979, " prepared for the National Venture Capital Association by D J. Brophy and P L Schaefer of the University of Michigan *1960 —Government-Industry* **Cooperation** *Can* **Enhance the** *Venture Capital Process,* GAO/AFMD-82-35 **(Washington, D.C : General Accounting Office, Aug 12, 1982),** P. 3.1981 **–J. W Dizard, "Do We** Have Too Many Venture Capitalists?" Fortune, Oct. 4, 1962, p 106.

tunities. Some of the upsurge in investments in table 57 is related to booming interest in applications of microprocessors; of the new venture capital deals nationally since 1979, perhaps half have been in electronics or closely related fields.[20] At the peak of the most recent cycle—i.e., mid-1981—many observers of venture capital markets concluded that entrepreneurs were having an easy time finding startup funds; some claimed that the supply of venture capital considerably exceeded demand during 1981, and that poor risks were being financed.[21] In more normal times, potential startups may face a long and arduous search for capital,

Table 57 will serve to illustrate another point: *venture capital makes only a small contribution to the overall funding needs of American industry*. Annual venture financing at something over $1 billion, and a total pool of venture capital of perhaps $5 billion to $6 billion, pales alongside other sources of capital for U.S. business and industry: bank loans, $230 billion; other short-term debt, $250 billion; corporate bonds, $490 billion; commercial mortgages, $280 billion; equities, $1,3 trillion.[22]

Costs of Entry

Although a substantial fraction of new venture investments continue to flow into electronics, in some segments of the industry entry costs are becoming prohibitive. Among the exceptions are firms able to generate cash flows in other lines of business, NCR is an example: an established manufacturer of computers and other business equipment, the firm had made ICs exclusively for internal consumption. In 1981 NCR announced plans to produce semicustom logic circuits and certain kinds of memory chips to be sold on the outside, becoming one of the few new entrants in the merchant market contemplating a fairly broad product line.[23] The reason is straightforward. Costs for establishing a new semiconductor

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[20] "Financial Issues in the Competitiveness of the U.S. Electronics Industry, " report prepared for OTA by L. W. Bergman & Co. under contract No. 033-1550.0, p. 12; "Startup Fever is Spreading, " op. cit.

[21] See, for example, A. Pollack, "Few Places for Venture Capital: Funds Outpace Investment Opportunities, " New *York Times,* June 17, 1981, p. D1; J. Levine, "Once Again, It's A Buyer's Market," *Venture,* June 1982, p. 80.

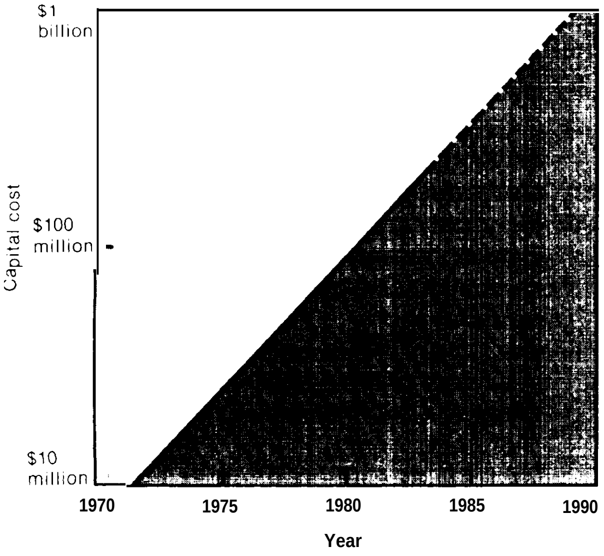
[22] " The Perilous Hunt for Financing, " op. cit. The estimates are totals outstanding at the end of 1981.

[23] "A Surprise NCR Leap Into the Chip Market, " *Business Week,* July 13, 1981, p. 22.

firm have risen by a factor of 10 over the past decade; as figure 50 indicates, the end is not in sight. The rapid increases in capital intensity shown in the figure stem largely from the more expensive production equipment required for current-generation ICs (ch. 3, especially table 2).

Rising entry costs are one reason why the 1980-83 group of semiconductor startups have picked narrow market niches rather than attempting to compete in a broad range of products, Examples include: custom chips, or in some cases just design services; specialized device families such as linear ICs or programmable logic arrays; and, in one case, gallium arsenide circuits. While entry via niche markets is the usual pattern in this and other industries, none of the semiconductor startups appear to be aiming at the mass-produced memory or microprocessor markets; the most recent new entrant to attempt this was Inmos, established in 1978 with the aid of $90 million in direct investment by the British Government.[24]

Figure 50.— Increase in Capital Costs for High-Volume Integrated Circuit Production Line



SOURCE R W Broderson Signal Processing Using MOS VLSI Technology *VLS/ Electronics Microstructure Science*, VOl 2, N G Einspruch (ed) (New York Academic Press 1981) p 206

Entry barriers can be higher still in mainframe computers, where the new firms in recent years have entered with plug-compatible machines—Amdahl, Magnuson, in 1981 Trilogy. The one exception during the 1970's was Cray, established with venture funding to build specialized supercomputers. An added hurdle stems from the preference by many customers for leasing rather than purchasing large computers. Financing leases is a severe strain on smaller companies; lease cancellations were one of the immediate reasons that Itel, a conglomerate that had entered the plug-compatible mainframe business, declared bankruptcy in 1981.

Leasing has been a major part of IBM's strategy in mainframes; competing firms—none of which has assets near IBM's—face a major constraint in financing leases.[25] Not only are they limited by their smaller size in securing funds at rates comparable to IBM's cost of capital, but the risks of competing with IBM are large and well known—Itel's failure presumably adding to the concerns of potential lenders. Without a source of particular advantage such as Amdahl or Cray get from their reputations as technological leaders, cost and availability of capital will remain formidable barriers for entry into the mainframe computer market.

Entry costs are also daunting at the high performance end of the minicomputer industry, though firms such as Prime (1972) and Tandem (1974) did begin operations during the past decade. The microcomputer segment has still seemed attractive; the entry of IBM into the personal computer market at the end of 1981 has not seemed to dampen the enthusiasm of prospective entrepreneurs and venture capitalists.

Early Growth

In the startup stage, equity capital from venture or other sources goes to purchase or lease plant and equipment and cover the initial expenses of developing, manufacturing, and marketing the first products. Later, more familiar

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[24] "UK Board to Cut Stake in Inmost" *Electronic News*, Mar. 29, **1982, p.** 54. The National Enterprise Board, which has had considerable autonomy to fund British industry (ch. 10), provided 50 million pounds, with Inmos receiving an equal amount in loan guarantees and grants for specific projects.

[25] J. T. Soma, *The Computer Industry* (Lexington, Mass.: Lexington Books, 1976), p. 41.

financial markets can be tapped, External financing is critical at this stage; the company may be growing rapidly, with production outstripping sales as inventories build and distribution channels are filled. New firms often operate below their break-even points for a number of years, and cash flow problems are common,

Once sales have begun, local banks will normally provide short-term loans up to about 80 percent of net receivables, this amount being rolled over—i.e., the loans rewritten at prevailing interest rates—every 3 months or so. Longer term financing may come from incremental venture capital commitments; many venture organizations prefer to participate in second- or third-round financing because they can better evaluate a company's prospects once it has products to show. While at this stage limited public offerings may also be possible, stock sales to the general public have been less common in electronics than in other industries. Many electronics manufacturers have been able to finance quite rapid growth through retained earnings and employee stock option and purchase plans. Indeed, the managers of electronics companies started by individual entrepreneurs or small groups have often shunned external equity markets to avoid stock dilution and the loss of close control.

When sales reach annual levels in the vicinity of $10 million, credit lines typically become more regularized, Revolving credit and term loans provide short-term financing. In addition, banks will generally extend lease credit for capital equipment—particularly helpful in electronics because it reduces the pressure to raise funds for purchasing equipment at a time when long-term investment requirements are expanding rapidly. Because capital equipment can quickly become obsolete, staying at the forefront of the technology can strain resources. On the other hand, for firms with adequate cash flows, rapid obsolescence means short writeoff cycles and tax savings from depreciation.

In any case, firms with growth patterns that take them beyond the $10 million level find capital more abundant and less costly. At this point, electronics companies exhibit financing patterns that depend on the preferences of owners and managers, as well as opportunities in relevant capital markets, Some firms offer new equity shares to the public; others issue shares but limit purchases to their own executives or employees. Some sell bonds, often in addition to equity, to add leverage to the capital structure. But while financing patterns differ, they share a characteristic common to most of U.S. industry: American electronics firms typically attempt to finance expansion internally, even when this delays dividends indefinitely. Only if self-generated sources prove inadequate do companies enter external markets.

Internal and External Sources of Funds

Table 58 illustrates the extent to which American semiconductor firms rely on internal funds—i.e., depreciation and retained earnings. When the companies listed in table 58 have resorted to external financing, this has ranged from virtually all capital stock (Intel) to substantial amounts of debt (National).

Although both new and established firms in the U.S. electronics industry will no doubt wish to continue relying on internal funds, a number of factors converging during the early 1980's foretell financial dilemmas for some companies. Among those common at least to manufacturers of semiconductors are:

1. *Growth in unit sales* over the coming years may exceed even the rapid rates of the previous decade,
2. Revenue *growth* will continue to trail growth in unit sales as manufacturing costs and sales prices decline. Historically, semiconductor prices are driven rapidly downward as costs fall because of learning curve phenomena. The sharp drops in memory chip prices during 1981—when 16K RAM (random access memory) prices fell from $4 each to about $1–are symptomatic.
3. *Capital intensity* will continue to rise because new production equipment—e.g., for fine-line lithography—is much more expensive than in the past.

Table 58.—internally Generated Funds as a Percent of Total Capital From All Sources

Year	Texas Instruments	National Semiconductor	Intel	Advanced Micro Devices
1974	890/o	760/o	890/o	93%
1976	79	82	79	96
1978	87	97	87	67
1980	65	60	46	71

[a]Fiscal year

SOURCES 1974-78—"Financial Issues in the Competitiveness of the U S Electronics Industry, " report prepared for OTA by L W Bergman & Co under contract No 033.05500, p 31 1980—Annual reports

4. **Engineering and design** *costs* are also escalating, due to the increasing complexity of ICs.
5. *Global competition,* particularly from the Japanese, is becoming more intense, and will be based on low prices to an even greater extent than in the past. Although forward pricing in anticipation of learning economies has been characteristic even of competition among domestic firms, pressures from the rapidly expanding Japanese industry may cut still further into sales revenues.
6. Competition is also forcing companies to pay more attention to quality and reliability, requiring *costly test equipment.* As IC designs increase in complexity, testing procedures become more time-consuming and expensive.

Figure 51, comparing capital spending rates in the United States and Japan over the past few years, illustrates the rise in capital intensity. Capital spending in both countries fell sharply in 1975 when the market for semiconductors slumped; since that time, the U.S. trend has been steadily upward. Japanese spending rates have been higher because they have been adding capacity faster.

While capital spending in the United States averaged around 10 percent of sales during the 1970's, rates in the last 3 years have been significantly greater (fig. 51). Continued increase will be difficult for many merchant firms without substantial outside funding. Capital needs of U.S. semiconductor manufacturers during the current decade will probably be in the range of $30 billion, with some industry sources expecting considerably higher figures. Such estimates compare with capital expenditures totaling $4.5 billion during the 1970's.[26]

The changing character of semiconductor production and marketing is not unique. Smaller American manufacturers of computers, as well as peripherals, are confronting more intense foreign competition at a time when developing technologies are placing severe demands on their financing capabilities. New firms are entering markets for peripherals such as terminals and disk drives designed to be compatible with the products of established companies, Microcomputer applications of all sorts are on the rise. Computer software is one of the most rapidly growing portions of the industry, New entrants have often depended on venture capital for their original financing, and—again like semiconductor manufacturers—followed growth patterns relying on internally generated funds supplemented with limited amounts of debt,

Parallels exist even in consumer electronics. A good deal of the production of established products—radios, televisions, audio equipment—has moved abroad, taken by Far Eastern

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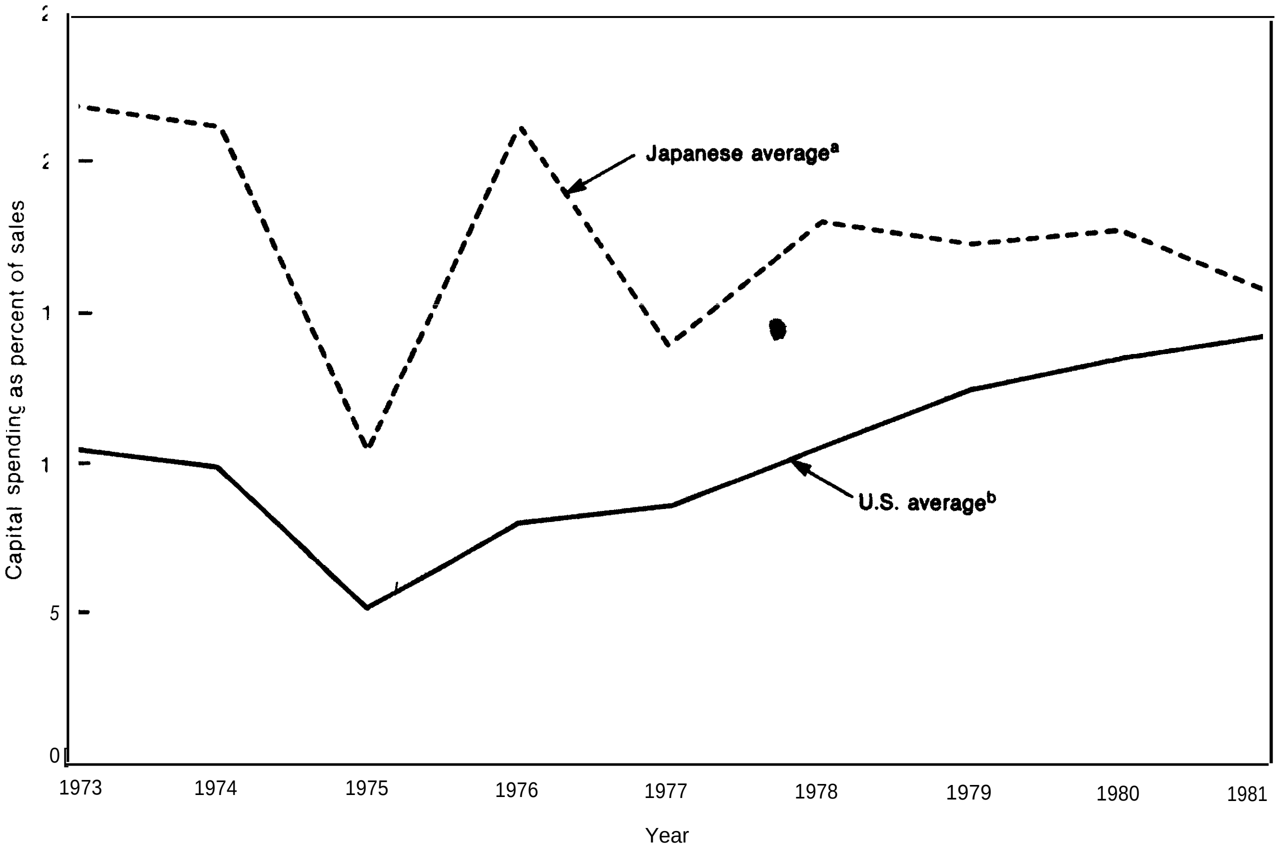
[26] "Hungry for Capital to Sustain the Boom, " *Business Week.* June 1, 1981, p. 74. J. F. Bucy of Texas Instruments has estimated spending at $25 billion to $35 billion for the decade of the 1980's, while G. Moore of Intel places the figure much higher, in the range of **$65** billion. An estimate of $30 billion results if sales are projected through *1990* **based on** the t re d ce 1975 (c 4), with capital spending assumed to remain at 13.7 percent of sales, the average over the past 3 years. Spending rates may rise—some predictions point to 15 percent of sales in coming years (see E. Williams, "Electronic Components, " *Financial Times,* Mar, 5, **1982, sec.** I I 1, p. I)—but the total is much more sensitive to the sales projection than to the capital spending rate.

Figure 51.— Rates of Capital Spending by U.S. and Japanese Semiconductor Firms



[a] Integrated circuits only, 1973-1979; weighted of 12 manufacturers 1973-1979, 11 manufacturers 1980, 1981

[b] 1973-1980: Weighted averages for 11 U S merchant semiconductor manufacturers; 1981 estimated

SOURCES United States— 1973.1977, Bureau of Census; 1978-1981, Department of Commerce and Semiconductor Industry Association Japan —1973. I 979, *Japan fact Book '80* (Tokyo Dempa Publications, 1980), p 203; 1980, 1981, *Japan Economic Journal.*

competitors or transferred offshore by U.S. companies. But the broader market for consumer electronics remains dynamic, as the example of video games showed, Along with video cassette and disk players, as well as home computers, these are precursors of an array of electronics-based innovations for personal and home use to be introduced over the next two decades. Many of these products will be high-technology items made possible by advances elsewhere in the industry. Some may come from small companies organized by entrepreneurs with strong technical backgrounds, as has happened with semiconductors, microcomputers, and software. Unquestionably, fierce competition from abroad will continue in consumer products; financing could become a problem here too if small firms need to support rapid expansion.

Financing Startups and Growth in the Coming Decade

But why should future financing be troublesome for an industry which—by all indications—can expect expanding markets overseas as well as at home? Not all observers believe the problems will be that great; those who do generally point to a pair of related concerns:

1. It may not be possible to finance growth from internal sources in the proportions common in earlier years, thus requiring

greater dependence on external sources of capital.

2. Costs of external funds will be high, and may place U.S. firms at a disadvantage compared to competitors in Japan, The profit levels required may be difficult for American firms to reach.

The first point deals with the continuing ability of electronics companies to fund growth internally, To expand sales, manufacturers must either purchase assets that are more productive or use existing assets more effectively. To supplement assets, funds must come from one or more of the following sources: moneys accumulated through corporate operations (retained earnings plus depreciation); capital generated by the sale of additional stock; or borrowings of one type or another.

As discussed previously, borrowing without parallel increases in equity alters a firm's leverage, This, in turn, tends to increase the variability of returns to equity, increasing the risks to owners. In countries like the United States, where capital markets are relatively competitive, managements choosing higher leverage eventually confront two problems: 1) common stockholders become increasingly sensitive to their risk positions, and make adjustments that tend to depress stock prices; and 2) lenders also may object, ultimately refusing to supply additional debt. As capital intensity increases, financial managers face an intricate set of decisions,

The important relationships can be expressed as follows:

$$\frac{\text{Net profit}}{\text{Value of equity}} = \frac{\text{Value of sales}}{\text{Total value of assets}} \times \frac{\text{Total value of assets}}{\text{Value of equity}} \times \frac{\text{Net profit}}{\text{Value of sales}}$$

This expression is simply an identity. The first term on the right-hand side, asset turnover, is a broad measure of asset productivity. Defined as the ratio of sales to total assets, it indicates the efficiency with which a company utilizes its assets to generate revenues, and depends on such factors as the firm's capital intensity and the degree of competition characterizing its markets. The second term—the ratio of assets to equity—is one way of measuring a firm's leverage, an alternative to debt-equity ratio, Profitability, the third, depends on many factors: product mix, competition, and labor productivity, to mention just a few,

Industry analysts tend to focus on the asset turnover ratio, which may fall as a consequence of expensive capital equipment (this should, however, improve productivity). Thus to preserve existing returns to equity, firms will either have to adopt higher leverage ratios or somehow improve profits on sales. Given the constraints likely to be exercised by the U.S. financial community, there are clear boundaries to the first option—i.e., to increasing the relative proportions of debt in a firm's capitalization. The second possibility—greater profitability—will be equally problematic if international and domestic competition continues to be stiff.

There is a second difficulty. In the identity above, note that if each term were to be held constant, growth would have to involve a balanced expansion of debt and equity. But the left-hand side of the equation dictates that, if a given increase in equity is to be financed internally—i.e., through retained earnings—there must be a proportionate increase in aftertax returns to equity (profits). (This assumes that electronics companies use aftertax earnings to fund growth instead of paying dividends, a policy followed by most of the rapidly growing companies during the 1970's.) Thus, growth must be accompanied by an increase in profits.

There is no requirement that new capital be restricted to funds generated internally. Firms could tap markets for both equity and additional debt. Managements, however, often object to stock offerings on the grounds that new issues are "expensive." Aside from the costs of floating the offering, before the current boom executives commonly cited what they perceived as low price-earnings (P-E) ratios in security markets. From the perspective of management, selling new stock under such conditions would have provided too little capital compared to their expectations of future growth, earnings, and presumably dividend payments. P-E ratios of 2 or 3 for electronics stocks were cited as indications of "unrealistic" rate of return requirements—as implying that the market was demanding returns in the range of 33 to 50 percent. New equity issues, in this view, should be delayed until the market returned to more normal conditions—i.e., until stock prices and P-E ratios rise.

Whether or not this makes sense depends in part on how stockholders are perceived. To those who believe that equity holders are, in fact, *owners* of the corporation—and if existing stockholders have first rights in the purchase of new issues—then stock prices may appear too low to management but the firm's "loss" is exactly offset by the "gains" of these stockholders. That is, existing owners would be able to buy new stock "cheaply." The existing owners would be unaffected by variations in the issue price based on market conditions. On the other hand, equity may be viewed as effectively another form of subordinated debt—in reality separated from any control. In this case, managers would perceive equity as "borrowing" and its costs would be evaluated like any other debt in cost of capital calculations. Statements on the high cost of equity by managements of electronics firms often seem to point toward this second belief.[27]

Then to the second point above: Will external funding be available at a cost manufacturers are willing and able—in the face of competitive pressures—to pay? At the moment, the availability of funding does not appear to be a limiting factor, but this could change as firms increase their leverage. Lending institutions typically establish standards on levels of debt considered prudent—guidelines that depend on liquidity and the variability of cash flows to the borrowing firm. Effective limits on debt, therefore, differ from company to company. Even if some companies can borrow what they need, the total volume of funds required by the U.S. electronics industry seems so high that others will almost certainly need new equity.

While equity from venture capital sources has been more freely available since the 1978 revision of capital gains tax rates, most of the firms needing capital will be well beyond this stage. Nor is it likely that such sources could provide enough money; the venture capital market is far too small. Still, there remain portions of the electronics industry where initial capital requirements are less than in semiconductor manufacturing–e.g., computer software, specialized industrial equipment—and where startups should find capital relatively abundant. Considering the effective reductions in corporate income taxes resulting from the Economic Recovery Tax Act of 1981, the total venture capital pool should continue to expand,

Even so, many observers predict that the cost of funds will be too high, From this perspective, investments may simply not promise adequate rewards; American companies in parts of the industry that face mounting competition from abroad may have difficulty in attracting funds from wary lenders with numerous alternatives, some offering better prospects for safety and high returns. Finally, some commentators believe that the total supply of investment capital in the United States is smaller than it could or should be because of a variety of disincentives affecting savings and investment built into the American tax system.[28] While the capital market will certainly supply funds in an amount equal to total demand at some set of interest rates, such observers believe that supply constraints artificially force these rates to levels too high compared to other countries,

Several of these matters are at the heart of economic policy debates still before Congress; the capital formation question, in particular, has been widely discussed for years, and has not been resolved by the tax policy changes instituted in 1981,[29] The issues are often complex and technical. As a consequence, the discussion below concentrates on matters that are particularly relevant to electronics.

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[27] For similar arguments applied to the Japanese case, see Wallich and Wallich, op. cit., pp. 268-269.

[28] For a typical commentary, see A. Sloan and C. Miles, "Showdown at Capital Gap," *Forbes*, Jan. 7, 1980, p. 38.

[29] See, for example, *Capital Formation*, hearings, Joint Economic Committee, Congress of the United States, June 9, 1976.

Capital Supplies and Financing Costs for the U.S. Electronics Industry

As mentioned previously, American electronics firms—with some prominent exceptions—tend to be smaller than their major international competitors. And, in part because their lack of diversification results in sharper swings in cash flow, small companies confront higher financing costs than large integrated manufacturers, Therefore, on the basis of company size alone, U.S. electronics producers are likely to face higher costs of capital than many of their competitors in Western Europe or Japan.

The semiconductor industry again provides a ready example. Table 59 lists total assets for a sample of U.S. and Japanese companies. While Japan's semiconductor manufacturers are substantially larger than the typical American merchant suppliers, several of the U.S. firms already have been acquired by much bigger companies. Intersil may look puny compared to Hitachi or NEC, but this is hardly true of its new owner, GE. It is quite possible that further rationalizations of this type will continue, perhaps in part to assure continued funding for expansion, although many of the currently attractive candidates for purchase have now been acquired. Finally, as table 59 also notes, the two largest captive manufacturers in the United States, IBM and Western Electric, have assets much *larger* than the Japanese producers.

For U.S. companies that are not affiliated with larger firms, the question of differential funding costs remains. Based on the usual assumptions concerning prudent amounts of leverage as discussed earlier, the difference in debt financing costs between a firm the size of Intel (table 59) and companies like Motorola or Texas Instruments probably averages about 1.2 percentage points (in fact, as table 51 illustrates, the firm-to-firm differences at any point in time clearly depend on many factors beyond size). All else equal, Japanese firms making semiconductors would probably have about the same advantage as a result of their size and diversity, But, because debt accounts for only a fraction of a company's capitalization, the impact of this difference in interest rates is smaller, and other forces are likely to weigh heavier in the competitive balance. After all, the American firms included in table 59 were formed, grew, and flourished even though their capital costs were greater than such competitors as RCA, GE, and GTE, all of whom entered the semiconductor market in its early years.

The related question—whether interest rates in the United States have been driven to excessive levels by supply constraints—is too involved to cover in any detail. It is true, for example, that interest rates to corporate borrowers are lower in Japan for equivalent proportions of debt (to the extent that equivalence can be ascertain. But such comparisons, based on different currencies, can easily mis-

Table 59.—Assets of U.S. and Japanese Semiconductor Manufacturers

	‘Total assets ‘ (millions of dollars)	
	1979	1980
U.S. merchant firms		
Advanced Micro Devices	$109	$165
American Microsystems .,	80	81a
Intel	500	767
Intersil . . .	83	98[b]
Mostek	161	—[c]
Motorola ., .,	1,904	2,112
National Semiconductor ., ., ...	385	561
Texas Instruments . .	1,908	2,414
U.S. captive producers		
IBM	$24,530	$26,703
Western Electric[d] ., ...	7,126	8,048
Japanese companies		
Fujitsu	**$2,030**	$2,380
Hitachi ., ..., .	**6,790**	7,450
Matsushita Electric .	**5,190**	5,640
Mitsubishi Electric	**4,490**	4,910
Nippon Electric Co (N EC)	3,110	3,560
Toshiba . . .	6,180	6,450

[a] Acquired in early 1982 by Gould, which had 1980 assets of $1 6 billion

[b] As of September 1980; in early 1981 Intersil was purchased by General Electric G E s 1980 assets were $185 billion

[c] Acquired in 1980 by United Technologies 1980 assets $73 billion

[d] Assets for Western Electric only does not nclude assets of AT&T Bell operating companies or other AT&T subsidiaries

‘Asset figures do not include affiliates Conversions from yen to dollars based on exchange rates from Economic *Report of the President* (Washington D C February 1982) p 345 1979 218 yen per dollar 1980 226 yen per dollar

SOURCES U.S. firms —Annual reports Japanese firms - *Japan Company Handbook* (Tokyo Toyo Keizai Shinposha/The Oriental Economist 1979 1981) lead. In part, they reflect differing inflationary expectations as mirrored in interest rates. Adjustments for inflationary expectations are problematical; to some extent, it might be possible to make such adjustments based on patterns of variation in the exchange rate. But a variety of factors other than inflationary expectations affect foreign exchange markets, especially in the short run, and the gyrations of the yen against the dollar in recent years have generated a wholly independent source of controversy.[30]

The inflationary trends reflected in high U.S. interest rates can themselves deter new investment, in electronics and in other sectors of the economy. Inflation adds to uncertainty in the cash flows that can be anticipated from investments; these mount as investment horizons recede. *High rates of price inflation tend to discourage longer term commitments; instead, they favor investments with relatively quick payoffs.* American managers—in electronics as in other industries—have been charged with ignoring long-term growth opportunities while concentrating on the short run. Part of this hesitancy to commit resources is tied to uncertainties created by price inflation and the attendant impact on interest rates. That is, differences in short-term compared to long-term managerial behavior between American and Japanese corporations may not be caused by differences in capital availability, or by differences in real interest rates, so much as by uncertainties associated with high and *variable* rates of interest and inflation.

The United States has not had a great deal of success in controlling inflation over the past few years; while current economic policies may help to keep down the inflation rate, adjustments in expectations often lag well behind. Can the electronics industry expect to benefit more directly from the changes in U.S. tax law adopted in 1981? After all, many of these changes—cuts in personal income taxes as well as effective reductions in corporate taxes—were directed at enlarging the supply of funds for investment. Unfortunately, increasing capital supplies—which all else equal will decrease the costs of investment—tends to be more easily said than done, al For instance, tax changes that affect both supply and demand for funds may leave interest rates unchanged. Under this circumstance, neither the availability nor the cost of funds for American electronics firms would change.

In part because of these complicating factors, it is not yet clear what the net effects of the Economic Recovery Tax Act of 1981 on aggregate capital formation will be, much less the differential impacts on various sectors of the economy. Thus far, there is scant evidence of broad positive effects on capital investment in industry; many observers are skeptical that the revisions to U.S. tax law will have much effect on levels of personal savings, which they feel are central to freeing up new investment for industry.[32] Internationally, even before the more rapid depreciation schedules and other reductions in corporate taxes enacted in 1981, the United States had in place tax policies that, according to at least some analyses, favored capital investment more strongly than taxation in Japan and most of the European nations .[33]

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[30] See, for example, P. Hartland-Thunberg, ''Value of Yen Fuels [J. S.-Japan Gap: Exchange Rate, Not Quality, Makes Imports a Better Buy, " Los *Angeles Times,* Apr. 29, 1982, Spokesmen for American business often blame competitive problems on an undervalued making Japanese imports cheap in the U.S. market.

[31] Over the postwar period, investment levels as a fraction of the country's gross national product have fluctuated markedly from year to year, but with no evidence of any long-term trend either up or down. See J. J. Enzler, W. E. Conrad, and L. Johnson, "Public Policy and Capital Formation, " *Federal Reserve Bulletin,* October 1981, p. 749. For an excellent summary of international differences in capital formation, see V. C. Price, "Capital Formation and Investment Policy," *Western Economies in Transition: Structural Change and Adjustment Policies in Industrial Countries,* I. Leveson and J. W. Wheeler (eds.) (Boulder, Colo.: Westview Press, 1979), p. 185.

[32] K. W. Arenson, "The Low U. S. Rate of Savings, " *New York Times,* Dec. *22, 1981, p.* 1)1.

[33] G. F. Kopits, "Tax Provisions to Boost Capital Formation Vary Widely in Industrial Nations, " *Tax Notes, Nov.* 17, 1980, p. 955. The effects of international differences in taxation on competitiveness are extraordinarily complicated. The same difficulties that apply to other international comparisons are at work, compounded by the complexities of the tax codes in each country, Effective rates of taxation can be compared in a number of different ways, with results that depend on factors such as projected inflation rates. Even when the tax differences themselves are carefully analyzed, the problem of relating the

At the same time, a number of nations use financial subsidies other than tax incentives more actively than the United States to support certain of their industries .34

Regardless of effects on overall supplies of capital, the accelerated depreciation schedules implemented by the 1981 Tax Act seem likely to place electronics firms at a disadvantage relative to other industries with which electronics competes for funds. More rapid depreciation lowers tax obligations and increases cash flows from new investments. Faster depreciation raises profits for projects that were formerly marginal or unattractive; the result should be to increase the overall demand for investment funds and the overall rate of investment in industry. For most industries depreciation is more rapid under the new law—but not necessarily for electronics.

The 1981 Tax Act permits equipment such as that used in production or R&D to be depreciated over either a 3- or a 5-year period. Formerly, production equipment was depreciated at rates at least nominally related to actual obsolescence. All equipment used for R&D can now be written off over 3 years; so can any equipment that could, under the old law, be depreciated in 4 years or less. All *other* equipment is now eligible for a 5-year writeoff. [35]

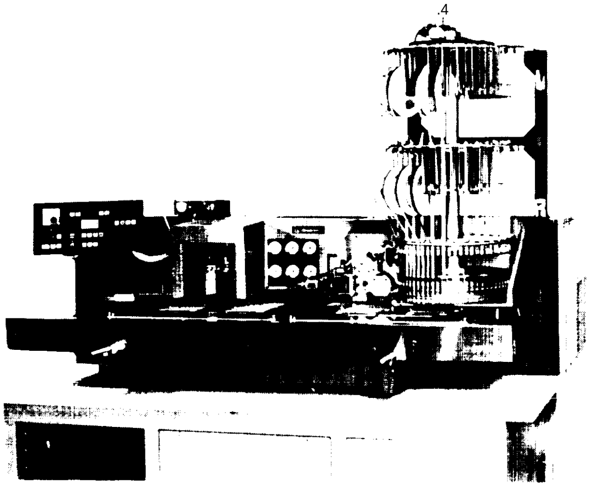

Photo credit Universal Instruments

Automated machinery for electronics assembly

Although electronics firms probably purchase little equipment with useful lives less than 3 years, this is nonetheless now the minimum depreciation period. To the extent that a company was formerly able to write off some of its equipment more quickly, it may suffer a reduction in cash flow. While this should be no more than a minor factor, the new depreciation procedures will place some electronics manufacturers—indeed, firms in any industry where technological change results in rapid obsolescence—at a disadvantage with respect to industries that reap *greater* benefits from the new depreciation schedules. The latter tend to be industries where technological change is slower, and equipment has a long useful life. Steel and other heavy industries are examples. [36]

Focusing on levels of domestic savings can also lead to underestimates of impacts flowing from international financial markets. Nations need no longer rely on domestic savings for investment; international capital movements are large and continuing to grow. For the United States, these long-term capital flows, both portfolio and direct investment, have been negative for many years—i.e., the flow of funds out of the United States has exceeded the inward flow.[37] This implies that rates of return are

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effects of tax policy to economic performance remains. See, for example, *Tax Rates Major Industrial Countries: A Brief Comparison*, op. cit.

[34] J. Mutti, *Taxes, Subsidies and Competitiveness Internationally* (Washington, D.C.: NPA Committee on Changing International Realities, January 1982).

[35] Economic Recovery Tax Act of 1981, title II, subtitle A, sec. 201. Also see P. Oosterhuis, "High Technology Industry and Tax Policy in the 1980s," *National Journal*, Jan. 1, 1983, p. 46.

[36] The only analyses of differential impacts across industries that have been published are on a highly aggregated basis; thus it is not clear how electronics—much less particular portions of the industry—will fare. The "machinery and instruments" category, within which the electronics industry falls, is one of the least favored sectors under the new depreciation methods. See *Economic Report of the President* (Washington, D.C., February 1982), pp. 122-125, particularly table 5-7; also J. G. Gravelle, "Effects of the Accelerated Cost Recovery System by Asset Type," Congressional Research Service, Aug. 31, 1981.

[37] Although direct investment of U.S. funds overseas is still running at two to three times the level of foreign investment in the United States, foreign holdings of U.S. securities roughly balance American holdings of foreign securities. See *Statistical Abstract of the United States, 1982-83*, 103rd ed. (Washington, D.C.: Department of Commerce, December 1982), p. 823.

higher overseas than at home, Therefore generating more savings in the United States will not necessarily increase the rate of domestic capital formation; funds may flow abroad instead, At the same time, were the cause of high interest rates in the United States simply a shortage of funds for capital investment, money should quickly flow here from abroad. International capital markets operate quite efficiently under such circumstances.

Japan

To what extent have Japanese electronics firms been aided by the unique structure of the country's capital markets, a factor that has been claimed to give Japan's corporations advantages in international competition?

Postwar Trends in the Japanese Financial System

Japan's financial system has changed more than most over the past 35 years, and the country's markets and financial institutions are now far removed from their grossly underdeveloped state in the early postwar period. The transformation of the Japanese financial system has paralleled, first, the reconstruction of Japan's economy, and, following that, the country's dramatic industrial expansion. The yen has become a major international currency, while Tokyo-only partly by governmental design--is emerging as a world banking center.

Given the speed with which the Japanese financial system has evolved, it is easy to be misled by images from the past. Yet the future, even more than the present, should be the real concern; effects on international competitiveness are functions of the dynamics of change in financial markets in the United States, Japan, and elsewhere. Insight into competitive trends depends on these dynamics.

Because systemic changes in Japan have been evolutionary rather than revolutionary, elements of validity often remain in descriptions of financial institutions that are otherwise outdated. For example, some discussions imply that government, the Bank of Japan, the commercial banking system, and various industrial sectors are all hierarchically linked, with control over resource allocation vested in the Ministry of Finance. Although hardly the case today, this is probably a fair—if simplistic—representation of the situation two or three decades ago. And even now, at the level of individual investment decisions, the Japanese system responds much more directly to the wishes of government than does that in the United States. But if government guidance still exists, it is a far weaker force now than 20 years ago, and the investment climate in Japan much more fluid.

Now to more concrete questions: Why do Japanese corporations utilize much greater proportions of bank debt in their financial structures than firms in the United States or Western Europe? (Leverage in European electronics firms tends to be greater than for American companies but less than that of Japanese.) The answer lies partly in the historical development of industrial groupings in Japan, most of which contain one or more banks.[38] Japanese manufacturing companies for many years have depended much more heavily on close working relationships with banks—even to the extent of participation by banks in management decisions-than have firms in the United States or Europe (West Germany is a partial exception, as discussed below). In other parts of the world, banks generally enter the picture only if reorganization follows bankruptcy, whereas in

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[38] These groups, called *zaibatsu* before World II, function something like holding companies. For general background, see R.E. Caves M. Uekusa, *Industrial Organization in Japan*, op. cit., ch. 4; also, *Industrial Groupings in Japan*, revised ed. 1980-81 (Tokyo: Dodwell Marketing Consultants, July 1980).

As an illustration, consider the Hitachi group. It consists of nearly 500 firms; as of 1977, Hitachi, Ltd. held majority shares in 40, and minority shares-typically in the 20 to 50 percent range-—in the remainder [J. Gresser, *High Technology and Japanese Industrial Policy: A Strategy for U.S. Policymakers*, Subcommittee on Trade, Committee on Ways and Means, House of Representatives, Oct. 1, 1980, p. 2]. While many of the affiliates make electrical and electronics products—and Hitachi, Ltd. is the largest electrical and electronics firm in Japan—others produce nonelectrical machinery, transportation equipment, chemicals, and primary metals. Members of the group are linked with the Dai-Ichi Kangyo Bank, the Fuji Bank, and the Sanwa Bank, as well as the Industrial Bank of Japan (*Industrial Groupings In Japan*, pp. 120- 121).

Japan-even with the weakening of the industrial groups following the postwar disbanding of the *zaibatsu—banks* have continued to influence managerial direction for firms that are financially healthy as well as those in trouble. This close relationship within the industrial group is one reason Japanese banks are willing to absorb risks more like those of shareholders. Lead banks, it is said, frequently subordinate their credits voluntarily. That is, the banks act much like holders of equity, and defer to others lower in the hierarchy of claims on assets when economic conditions dictate. What appears to Americans an oppressive debt load, may not be so from the perspective of a borrower in Japan.

The close relationship between banks and electronics companies in Japan is only part of the story. Following World War II, Japan's capital markets were undeveloped, with viable public markets for neither corporate debt nor equity. Financial intermediation was carried out almost entirely through the banking system. Of necessity, industrial expansion had to be financed by channeling funds through commercial banks.[39] Moreover, it was not an accident that alternative financing methods did not develop more rapidly as Japan progressed economically. The government could conveniently guide the economy through the commercial banking system. Government decisions to foster economic growth by extending credit to industry at the expense of consumer credit and infrastructural development were implemented in this way. Today, the extent of government influence over the lending decisions of major commercial banks in Japan remains considerably greater than that exercised by Western governments, France excepted (while West German banks have a good deal of leverage over corporate managements, the government influence on the banking community is much less than in France, as discussed later in the chapter). The lack of alternative sources of financing for Japanese companies enhanced the government's ability to direct economic growth; "window guidance" and a variety of other industrial policy tools would have been weaker instruments if corporations had been able to look elsewhere for capital.

Reliance on External Funding

Although debt-equity ratios have decreased considerably in recent years, as shown in figure 52, Japanese electronics companies remain heavily leveraged. And, because banks are so deeply involved, even the definition of leverage must be adapted to the Japanese case. In the United States, the usual indicators of leverage are based on the *long-term* debt in a company's capital structure—i.e., obligations that mature after 10 or more years, most of which are bonds. Leverage can then be defined as the ratio of the value of this long-term debt to the value of the firm's equity, or to its total capitalization, In Japan, as the figure indicates, such a ratio would be misleading because much of a typical firm's capital comes from *short-term* bank loans. Table 60, which lists sources of external funds for Japanese and American corporations, shows that companies in Japan have depended much more heavily on loans from financial intermediaries, mostly banks, than on bonds. Bonds are issued by American firms at nearly 10 times the rate in Japan, although in recent years these patterns have been changing somewhat. U.S. industry has been relying to an increasing extent on short-term bank loans—probably because uncertainty concerning future rates of inflation makes corporations wary of floating bond issues at recent interest levels.[40] In neither country have stock issues been a major source of capital; still, American firms have relied more heavily on new equity than their counterparts in Japan.

Financing patterns exhibited by electronics companies in Japan differ, but not greatly, from those for Japanese industry as a whole. Electronics firms have financed growth with internal funds to a greater than average extent, Table 61 compares leveraging for electronics companies in Japan and the United States. Nei-

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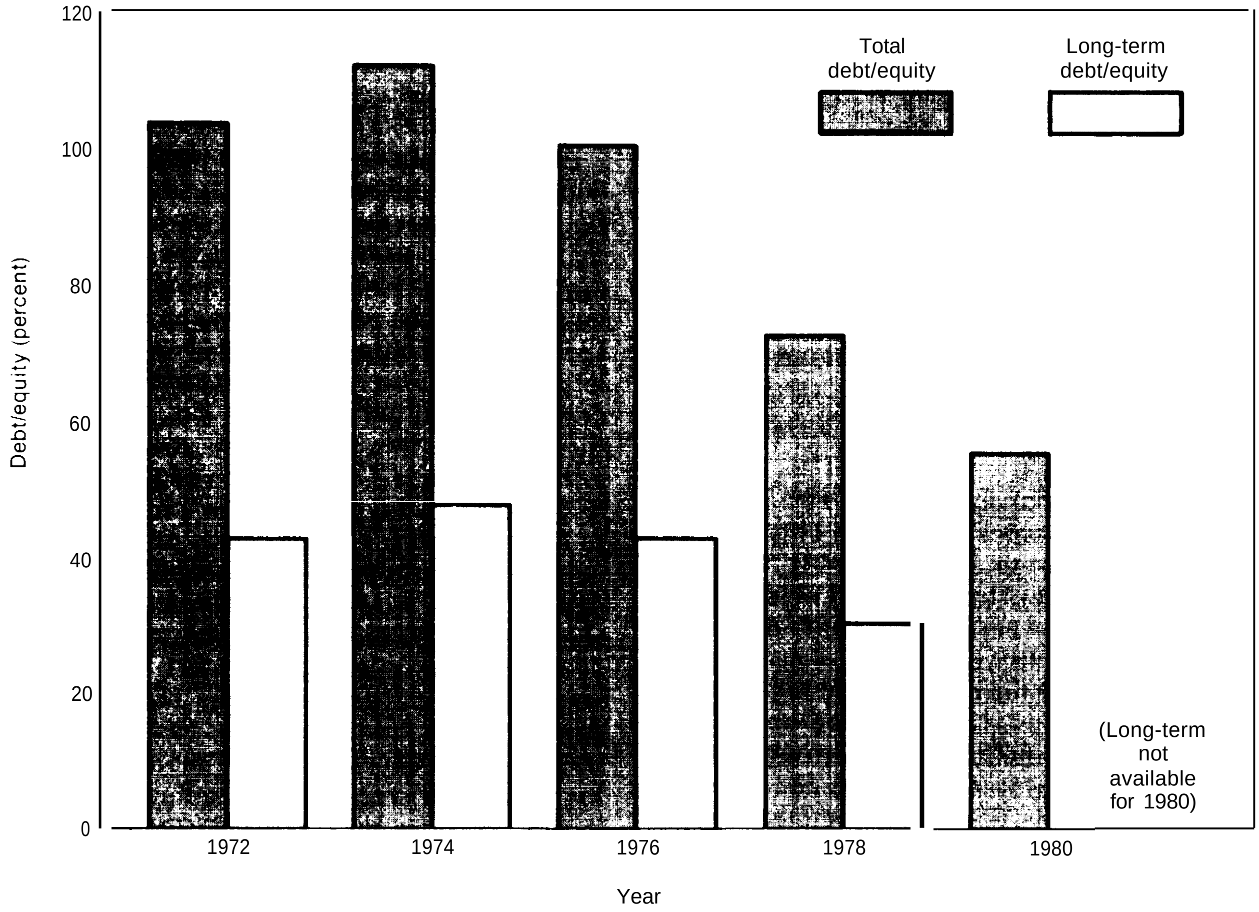
[39] G. Ackley and H. Ishi, "Fiscal, Monetary, and Related Policies,' " *Asia New Giant,* op. cit., p. 153.

[40] '' The Perilous Hunt for Financing, " op. cit.

Figure 52.—Debt-Equity Ratios for Japanese Electrical/Electronics Firms[a]



[a]Averages for 75 firms in 1972, 85 firms in 1974-78, 14 firms in 1980

SOURCES. 1972 -78—"Financial Issues in the Competitiveness of the U S. Electronics Industry," report prepared for OTA by L W Bergman & Co under contract No 033-15500, p 171
1980-Derived from data in *Japan Company Handbook* (Tokyo. Toyo Keizai Shinposha/The Oriental Economist, 1981).

Table 60.—Sources of External Financing for U.S. and Japanese Corporations

	Proportions by source, 1965-72	
	United States	Japan
Loans from banks and financial intermediaries.	51%	890/o
Bond issues	37	4
Stock issues	12	7
	100 "/0	100 "/0

SOURCE T Maruyama, "Financing Japanese Business, " *The Conference Board Record,* May 1976, p 47

ther the six Japanese electronics firms, nor, except for RCA, the seven in the United States stray too far from the patterns typical of each country. As the table shows, the Japanese companies have depended much more heavily on external capital—a point that has been emphasized previously (table 52). The heavy reliance on both short- and long-term debt in Japan's electronics industry contrasts sharply with U.S. semiconductor firms. Electronics companies in Japan utilize very large absolute

Table 61 .—Short" and Long-Term Debt as a Percent of Total Capitalization for U.S. and Japanese Electronics Firms

	All Japanese industry, 1975	Six Japanese electronics companies, 1979[a]	Weighted average of four U.S. semiconductor manufacturers, 1979[b]	Individual U S. companies, 1979 DEC	IBM	RCA
Short-term debt	34.2 %	*38.0%*	8.1 0/0	0.8%	5 3° 0	18.40,
Long-term debt	37.5	29.0	12,7	231	90	372
Total debt	71 7	67,0	208	24.0	144	556
Shareholder's equity	283	33.0	79,2	760	856	44.4
Total capitalization	100 %	100"/0	100 "/0	100%	100%	100 "/0
Long-term debt/equity	**1.33**	**0,88**	**016**	**030**	011	084
Total debt/equity	253	2,03	0,26	0.32	017	056

[a] Fujitsu Hitachi Matsushita Mitsubishi, NEC and Toshiba
[b] Advanced Micro Devices Motorola, National Semiconductor, Texas Instruments

SOURCES **Japanese companies**—"U S and Japanese Semiconductor Industries A Financial Comparison, Chase Financial Policy for the Semiconductor Industry Association, June 9 1980, p 62 **American** firms—Annual reports

amounts of short-term debt which is automatically turned over as it falls due—i.e., the loans are rewritten, normally at an interest rate consistent with prevailing market conditions. As pointed out earlier, these practices seem to place Japanese banks in positions of considerably greater risk than would be acceptable here.

Tables 60 and 61 emphasize the extent to which capital structures in Japan are weighted toward external financing. These practices must be taken into account when calculating costs of capital. The American financial system—and therefore the methods of establishing capital costs commonly used here—presumes a mix of alternative sources of financing. Not all of these are widely available in Japan; some do not even exist.

In the United States, for example, individual portfolio holders adjust their security positions in response to changing market conditions, trading off risk against potential returns. Americans—even those with modest assets—have become sophisticated investors, switching in and out of certificates of deposit, money market funds, corporate stocks, and other investments in response to small swings in relative rates of return. The escalation in real estate prices during the 1970's, reflecting high rates of return on investments in land and housing as well as tax advantages, is another example. In Japan, individuals do not have this range of investment opportunities; for example, markets for corporate bonds barely exist. The well-developed capital markets in the United States maintain a state of dynamic equilibrium with respect to one another which is not always attained in countries like Japan. Japanese capital markets—and those in many other countries—are narrower; nor are they as closely linked. Neither individual markets nor individual investment decisions respond as quickly or as concertedly to changing conditions, Borrowers have fewer potential sources of funds. Japanese corporations *must* use bank financing; savers *must* rely on bank deposits or government savings institutions, Under such circumstances, Japanese banks have little option but to accept risks that would be unacceptable in the United States—their other lending opportunities are too limited,

Ledgers of Japanese companies differ from those of American firms on the asset side as well as the liability side. Table 62 illustrates some of these asset side differences. Japanese electronics companies carry much more cash and other liquid assets, reflecting in part requirements for compensating balances imposed by banks; they have less tied up in accounts receivable and inventories. The fixed assets of Japanese firms—plant and equipment—are proportionately smaller, in part because of grossly understated land values; in some cases plant and equipment valuations may be reduced further by depreciation rates higher than in the United States.[41]

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[41] On the undervaluation of assets in Japan, see, 1. Kuroda and Y. Oritani, "A Reexamination of the Unique Features of Japan's Corporate Financial Structure, " *Japanese Economic Studies,*

Table 62.—Asset Categories as Listed on Balance Sheets of Electronics Firms in the United States and Japan (percentage of total assets)

U.S. companies (1979)	Advanced Micro Devices	Motorola	National Semiconductor	Texas Instruments
Cash and marketable securities	7%	5%	2%	60/0
Accounts receivable, net	28	26	32	29
Inventories, net	13	29	27	18
Other current assets	7	5	2	4
Total current assets ., ...	55	65	63	57
Net plant and equipment	45	34	35	42
Other noncurrent assets	—	1	2	1
Total noncurrent assets	45	35	37	43
Total assets	100 ”/0	100 ”/0	100%	100 ”/0
Japanese companies (1978.1979)	Hitachi	Matsushita	Mitsubishi	Toshiba
Cash and marketable securities	22 ”/0	180/0	15“/0	22 ”/0
Accounts and trade related notes received	21	15	31	22
Inventories, net	19	17	26	19
Other current assets	5	6	9	6
Total current assets	67	56	81	69
Net plant and equipment	16	12	13	15
Other noncurrent assets	17	32	6	16
Total noncurrent assets	33	44	19	31
Total assets	100%	100 ”/0	100 ”/0	100 ”/0

SOURCES U.S. firma-Derived from data in Moody'*Industrials*, 1980 Japanese firms—llerived from data in U.S. *and Japanese Semiconductor Industries: A Financial Comparison*, Chase Financial Policy for the Semiconductor Industry Association, June 9, 1980, appendixes

But the important point of table 62 is the large fraction of short-term, liquid assets held by Japanese electronics firms. These assets do not earn high returns. Thus, on the one hand, lower financing costs for Japanese firms are partially offset by lower returns on their large holdings of short-term assets. On the other hand, the greater risks that Japanese banks apparently accept are partially ameliorated by the high levels of these same current assets. The *result is to reduce the capital cost advantages of Japanese electronics firms while helping explain how they can carry such high levels of debt.*

What Role Does Japan's Government Play?

The relatively underdeveloped state of Japanese capital markets gives the government leverage over allocations of funds for investment. In the absence of a wide range of alternatives, both financial institutions and industrial corporations are more susceptible to government influence. Does, then, the Japanese Government indirectly subsidize target industries using the banking system as a conduit? A variety of mechanisms would be possible—for instance, government funds could flow to the banking community in the form of low-cost loans earmarked for certain uses. The funds might come from tax revenues or from private savings deposited in government-controlled institutions such as the postal savings system.

Unfortunately, just because the possible routes are indirect, evidence bearing on this question is scarce. The most useful comes from the collective financial statements of Japanese banks—table 63. The liability side of the ledger

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(footnote continued from p. 283)
summer 1980, p. 82. In general, depreciation rates in Japan are comparable to those in the United States except for selected investment categories that are favored by accelerated schedules. See, "Corporation Income Tax Treatment of Investment and Innovation Activities in Six Countries, " PRA research report 81-1, prepared for the National Science Foundation, Aug. 12, 1981, pp. 90-95; also J. A. Pechman and K. Kaizuka, "Taxation," *Asia New Giant,* op. cit., p. 317, and *Tax Rates In Major Industrial Countries: A Brief Comparison,* op. cit.

Table 63.—Assets and Liabilities of Japanese Commercial Banks[a]

	Value (billions of yen)	Percentage
Assets		
Cash	7,559	6.30/o
Securities	14,335	11.8
Short-term assets	86,634	71.9
Other	11,947	10.0
	120,475-	100%
Liabilities		
Deposits	86,302	71.6 0/0
Borrowings from the Bank of Japan	1,570	1.3
All other borrowings	315	0.3
Short-term liabilities	18,605	15.4
Reserves	2,210	1.9
Other	11,473	9.5
	120,475	100 %

[a] As of the end Of 1975

SOURCE *The Japanese Financial System* (Tokyo The Bank of Japan, 1978)

is of particular interest—specifically, borrowing from the central bank, the Bank of Japan. Although quasi-independent, the government holds majority ownership in the Bank, the operations of which are closely monitored by the Ministry of Finance.[42] As the table shows, lending by the Bank of Japan to commercial banks—the “overloan” phenomenon—amounted to only 1.3 percent of total liabilities in 1975 (the percentage is no doubt less today). As This is too little, by itself, to give the Bank or the government much influence over the rest of the banking system. Nor could funds from the Bank of Japan significantly reduce costs of money to commercial banks. Such weight as the government might exercise would, therefore, have to flow from other sources; some American observers hold that informal channels are quite sufficient.

The situation was different in earlier years, when overloans were much larger; their decrease as a proportion of the total liabilities of Japan's commercial banks is another indication of the changing character of the country's financial markets. Then does Japan's Government still influence lending decisions? In the past, target industries were certainly favored with low-cost capital, although the extent and force of this on industrial development is much less at present than 20 years ago. The government appears to act largely through informal and indirect mechanisms, rather than explicitly allocating low-cost funds. Economic development goals set by government after extensive consultation with financial institutions and industry have traditionally been supported by the banks. Because of the close working relationships among government, the banks, and private industry, suggestions made by government officials tend to be consistent with the predispositions of bank managers.

In practice, loans flow preferentially to larger companies, most of which are associated with one or more of the major banks through an industrial grouping. Interest rates on these loans are typically below those for small borrowers (such discrimination is common in all industrial countries), Still, despite the higher financing costs faced by new and small companies, firms such as Sony and Honda have become highly successful during the postwar period. Some have even managed to establish their own industrial groupings; Matsushita, which had fewer than 2,000 employees before the war, is the most prominent case in electronics.

Costs of capital in Japan depend far more on broad controls exercised over interest rates paid by the banking sector on deposits and charged on short-term loans than on government guidance of investment flows, High rates of capital formation have been rooted in savings—the mirror image of investment—as illustrated previously in table 54, The savings rate in Japan is especially surprising because for many years the government followed a deliberate policy of keeping interest on savings and other investments low. The effect was to prevent interest rates from becoming the primary mechanism for allocating capital, as would have occurred with market-determined rates. But if in earlier years capital rationing gave advantages to some sectors of the economy,

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[42] K. Haitani, *The Japanese Economic System: An Institutional Overview* (Lexington, Mass.: Lexington Books, 1976), pp. 164-165.

[43] An overloan simply means that commercial banks—individually or in the aggregate—are in debt to the Bank of Japan. See Suzuki, op. cit., pp. 1-13.

others paid the cost. In general, large corporations benefited at the expense of household savers.

Table 64 shows that personal savers in Japan have earned zero or negative real rates of return (after adjustments for inflation) for much of the past 20 years, depending to some extent on the repositories chosen. During the period 1961-69, interest on major categories of personal savings—as listed in the table—remained fixed at government-imposed ceiling levels. Longer term savings earned interest at about the rate of inflation; hence the real returns were essentially zero, Shorter term deposits earned negative returns. Much the same was true during the 1970's. With price inflation considerably more erratic—in large part because of sudden increases in energy prices, notably in 1974—interest ceilings were periodically adjusted, but negative returns remained the rule,

Have these savings been channeled through the banking system, appearing as loans to industry at artificially low rates? The question can be asked in another way: What trends would interest rates have shown had they been freer to adjust, and had savers enjoyed more alternatives in placing their funds? If, in fact, the Japanese Government has *rationed* capital, the answer must be as follows: left free to adjust, interest rates would have been higher. On the other hand, if the government's actions served primarily to allocate funds among sectors of the economy, then the answer is less obvious. To the extent that commercial banks borrowed from the Bank of Japan—and overloans were large during the 1960's—then interest rates were probably depressed relative to levels that better developed financial markets would have set, particularly if overloans had been prohibited. The current impacts are uncertain, if only because overloans have declined in recent years.

Table 64.—interest Rates and Price Inflation in Japan

	Annual change in Consumer Price Index	Annual average interest rates			
		Demand deposits	One-year time deposits	Postal savings	
				Ordinary	2-3 year
1961-69a	5.50/o	**2. 190/o**	**5.50/0**	3.60/0	5.5%
1970	7.7	2.25	**5.75**	3.6	5.75
1972	4.5	2.0	**5.25**	3.36	5.5
1974	24.5	3.0	**8.0**[b]	4,32	8.0
1976	9.3	2.5	**6.75**	3.84	6.75
1978	3.8	1.0	**4.5**	2.4	4.6

[a] Interest rates were held fixed *over* this period; the values given are the ceiling set by the government The change in Consumer Price Index is the average for the period

[b] Two-year or more

SOURCES. Price index—Kafsuyo Redo *Tokei* (Useful Labor Statistics) (Tokyo: Nihon Seisansei Honbu (Japan Productivity Canter, Labor Productivity Documents Center), 1981), p. 136, data based on ***Shohisha Bukka Shisu*** (Consumer Price Index) (Tokyo Soritu Tokei Kyoku (Prime Minister's Office, Statistical Bureau).
Interest Rates— 1%1-1974, H C Wallich and M. I Wallich, "Banking and Finance, " *Asia's New Giant,* H. Patrick and H. Rosovsky (eds.) (Washington, DC. Brookings Institution, 1976), p 261. *1976 and* 1978, Bank of Japan, Research Division, New York, N Y.

The Japanese Government has other means to help selected industries get investment capital. There is, for example, the Japan Development Bank—a public corporation through which moneys from postal savings and trust accounts can be funneled. In the early postwar years, the Bank was a major instrument of government policy, but its influence rapidly declined; the Development Bank provided 22 percent of all capital invested in industrial plant and equipment in 1953, but only 5 percent in 1961.[44] **Between** 1965 and 1974, loans from government financial institutions—of which the Development Bank is but one—averaged just 4.2 percent of new industrial funds.[45] Still, this small percentage came to about $3 billion annually, more than sufficient for major impacts on international competitiveness if concentrated on well-chosen targets.

Continuing Change in Japan's Financial System

In terms of competitiveness, and from the perspective of the American electronics industry, the critical questions deal with the future. Change in Japan has been rapid, and the pace may even accelerate. There are at least two reasons:

1. Shocks to the Japanese economy stemming from high energy prices beginning in 1973-74,

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'C. Johnson, *Japan Public Policy Companies* (Washington, D.C.: AEI-Hoover Policy Studies, 1978), p. 98.

[45] Haitani, op. cit., p. 169.

2. Changing aspirations and expectations among savers, consumers, and the general public, along with the increasing complexity of Japan's maturing economy,

The explosion of energy prices—with deep impacts on an economy that depends almost totally on imported fuels—has stimulated a reevaluation of economic goals. The government is paying more attention to efficiency in allocating resources, backing away from earlier commitments to high rates of economic growth regardless of costs elsewhere. As people's expectations rise, Japan is devoting more resources to the public sector, aiming to improve the quality of life, broadly conceived. Although public sector expenditures remain well below levels common in Western Europe or the United States, more money is going toward environmental protection and a variety of social welfare programs. Defense spending is slowly increasing, partly in response to U.S. pressures. Finally, the Japanese are discovering that the days are over when a few sectors—growing very rapidly—could lead the country's economic expansion. Future growth will be slower and more balanced.

These trends in the Japanese economy will be mirrored in the financial setting for industry, where change is already well underway. For example, the government has lost some of its influence over interest rates; as Japan takes a more active role in international financial markets, with funds flowing in and out in greater volumes, interest levels will more closely follow those in other industrial nations. The dynamics of the Japanese financial system are carrying it steadily toward the American model of open capital markets. This does not mean that the Japanese Government will abandon its past efforts to guide the economy. Japan will remain a nation where industrial policy is a powerful force. But, as large Japanese firms continue to expand internationally they will have more latitude for independent action, and the government will necessarily play a lesser role in the allocation of resources.

Four clear trends can be discerned in the evolution of the Japanese financial system:[46]

1. Interest rates are becoming more responsive to underlying conditions in capital markets, and as a result are less subject to the dictates of government.
2. Corporations, especially larger ones, are developing alternative sources of funding and relying less on banks.
3. Banks, partly as a consequence, are looking to individuals and small businesses as borrowers.
4. The Japanese Government, in response to trends-already visible, is moving toward closer links with the international financial community.

While pressure in Japan for market-determined interest rates is not new, only recently have events combined to make this outcome a virtual certainty .47 One precipitating factor has been the government's own need, following several years of deficit spending, to enter the capital market. The national debt rose from 11.7 trillion yen in 1972 to 62.3 trillion yen in 1978,[46] In earlier years, the banking system would have absorbed bond issues floated by Japan's Government to finance this debt, with interest rates set at low levels to minimize costs to the treasury. But as such bonds have become a larger portion of bank portfolios, and as an active secondary market for government bonds has developed, bank managers have become less willing to accept new issues at below-market rates. The government has had to raise yields to levels consistent with secondary markets. At least for government issues, a long-term bond market more typical of industrialized economies is developing.

Banks have also sought more freedom to set interest rates on certificates of deposit (CDs);

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[46] J. E. W. Kirby, "The Japanese and Their Changing Economic Environment, " *Business in Japan*, revised cd., P. Norburry and G. Bownas (eds.) [London: Macmillan, 1980], p. 85.

[47] M. Borsuk, "Japan/] Interest Rates: Consequences of Rates Sensitivity," *Far Eastern Economic Review*, Mar, 26, 1982, p. 59.

[48] Kirby, op. Cit., p. 88.

Japanese banks, after much negotiation and the acceptance of a variety of restrictions, were permitted to issue CDs beginning in mid-1979. By now, movement toward more flexible financial markets would be hard to stop, If interest rates are decontrolled in a portion of the economy, pressures elsewhere will lead to a parallel freeing of rates or else to severe distortions. Such forces are particularly potent given the widespread desire to see Japan become an international financial center,

In terms of the U.S. electronics industry, movement in Japan toward market-determined interest rates should help defuse concern over government-subsidized financing. Furthermore, as Japanese capital markets become better developed, new financial instruments will come into play. Firms will be able to secure capital from a wider variety of sources, at least some of which will be less susceptible to government pressure.[49] In short, investment decisionmaking will become more decentralized, as in other highly industrialized, capitalistic countries. Both business executives and government officials in Japan have been concerned over the high rates of bankruptcy of recent years. Many of these failures have been caused at least in part by the highly leveraged positions of Japanese corporations. As a consequence, companies have been attempting to broaden their sources of financing in both number and kind—one of the reasons some companies are marketing securities overseas, To attract foreign investment, Japanese companies will have to offer rates of return competitive with those in other countries and other currencies. This suggests that capital costs in Japan are unlikely to diverge very far from those in other parts of the world.

Finally, the orientations and strategies of the major commercial banks in Japan are shifting, As corporations seek more broadly based financing, and as the profit levels of banks decline, bank managers have been forced to reevaluate their own portfolios. Many are attempting to develop alternative markets for loans, including foreign lending and expanded consumer credit. The Ministry of Finance has recently given banks a good deal more latitude in making overseas loans, although informal quotas still exist.[50] Symptomatic of the change is the announcement of a loan at favorable rates to Fairchild for the construction of a semiconductor plant in Japan.[51]

Lending to households is also on the upswing. Mortgages, installment buying, and other forms of consumer credit have been more the exception than the rule, but bank loans for housing expanded fivefold during the decade of the 1970's, and now account for some 10 percent of total bank credit.[52] Today, as table 65 indicates, households still borrow much less in Japan than in the United States. Continuing movement toward greater consumer lending and more diversified bank portfolios again points toward capital markets in which the primary allocative mechanism will be the market-determined interest rate.

Internationally, Japan has made an explicit decision–involving both government and the financial community—to take a more prominent role in matters affecting the world's currencies.[53] This shift reflects a number of

Table 65.—Household Borrowing in Japan and the United States

	Mortgages and consumer installment loans outstanding as a percentage of GNP	
	Japan	United States
1965	2.30/o	60.8 "/0
1970	4.6	59.4
1975 . . . . #	12.1	63.7
1978, , ...	17.5	68.1

SOURCE: E Sakakibara, R. Feldman, and Y Harada, *The Financial System in Comparative Perspective*, Joint Economic Committee, Congress of the United States, Mar 12, 1982, p 21

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[49] Japanese industrial firms floated more than twice as many bond issues in foreign markets as domestically during **1980. See** M. Kanabayashi, "Japanese Business Borrowings Abroad Surged to Record in Year Ended March 31, " *Wall Street Journal*, May 12, 1981, p. 36.

[50] J. Marcom, Jr., "Borrowers Are Eager To Get Yen Loans But Must Grapple With Japan's Delay s," *Wall Street Journal*, July 7, 1982, p, 24,

[51] ,, Japan Offers Loan to Fairchild for IC Plant . . " *Electronics*, June 2, 1982, p. 73.

[52] Kirby, op. cit., p. 91.

[53] ,, Japanese Official Says Government Wants the Yen to Become Major *U.S. Import WeekI-y*, Feb. z, 1983, p. 572.

Photo credit Perk/n- Elmer

Electron-beam lithography system used for making integrated circuits and masks

converging events, the most important of which have been Japan's continuing trade surpluses. These surpluses have led to demands in other parts of the world that the yen be used as an official reserve and unit of account in private transactions, Foreign-held balances have been increasing rapidly as an active international market in yen develops.[54] Finally, foreign investment by Japanese corporations is expanding swiftly. Japanese foreign direct investment nearly doubled between 1979 and 1981, reaching a level of $8.9 billion in fiscal 1981.[55] The international position of the Japanese is beginning to look strikingly like that of the United States 20 years ago, with current account surpluses offset by outflows of direct investment funds.

The internationalization of the yen will have a major effect on Japan's financing practices. As long as the economy could be insulated from outside impacts, the government could successfully hold down interest rates. This insularity is breaking down as banks, private businesses, and individuals take advantage of the wider range of financial opportunities now open to them. To the extent that Japan becomes a center of international finance—a process already well underway—the domestic financial system will become irrevocably linked to larger world markets, And, as the United States and other Western nations have discovered, an integrated international market renders an independent monetary policy aimed at controlling interest rates virtually impossible.

France

In general, French electronics firms have not emerged as strong international competitors—nor have U.S. companies confronted insurmountable difficulties in competing within France, although the ingenuity of the French in creating nontariff barriers may match that of the Japanese. Therefore this section—and that following on West Germany—outlines financing methods much more briefly than for Japan,

In some ways the French financial *system* more closely resembles the Japanese case than the American.[56] Like Japan, France has a tradition of government intervention in what would be private investment decisions here, and the government exerts a good deal of control over allocations of capital.

France turned away from some of its earlier practices in the late **1970's**, and toward freer markets for capital as well as goods, Although the outlines of Mitterrand's industrial policy remain somewhat vague—more in terms of mechanisms than objectives—the Socialist Government has begun to alter a number of the specific practices inherited from earlier ad-

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[54] Foreign holdings of yen reached the equivalent of about $10 billion by mid-1980–still small in absolute terms but doubling over a period of 1½ years. See E. W. Hayden, "Tokyo as an International Financial Center, " *Atlantic Community Quarterly,* vol. 19, fall 1981, p. 351, which also outlines forces contributing to slackening government influence over Japan's financial markets, Hayden emphasizes that continuing distortions can be expected for some years to come.

[55] " Japan Capital Abroad Reaches Record in FY 81," *Japan Report,* Joint Publications Research %-vice JPRS 1,/10616, June 25, **1982, p. 10.** For **examples of Japanese** investments **in** Europe, see A. L. Otten, "Japanese Firms Press European Ventures To Help Profits and Deter Protectionism, " *Wall Street Journal,* Apr. 16, **1982,** p. 54.

[56] This section is largely based on J. Zysman, *Governments, Markets, and Growth: Financial Systems and the Politics of Industrial Change* (Ithaca, N.Y.: Cornell University Press, 1983), ch 3,

ministrations, But regardless of swings of the pendulum, government intervention in capital (and other) markets is a longstanding tradition in France, and the thrust of French policies as they relate to investment is not likely to change radically.

On the whole, the French financial system seems more tightly controlled by government than the Japanese system, and certainly far more so than in the United States—in part because so much of French industry is nationalized. One major difference between the French and Japanese cases is that France has been a great deal more tolerant of foreign-owned enterprises, One-fifth of the country's 200 largest firms fall in this category. When faced with weak domestic industries—including, at various times, semiconductors and computers—the French Government has sometimes chosen to allow, even encourage, foreign ownership.

Industry in France, as in Japan, gets most of its external financing from institutional lenders, generally banks. Relative to such countries as the United States or Great Britain, securities markets are small; within these markets, sales of bonds far outweigh equities, Even the comparatively small French bond market serves mostly as a source of funds for government and for nationalized companies, plus financial institutions of various types, Manufacturing firms look predominantly to banks for their credit needs, roughly paralleling the situation in Japan.

French industrial policy as it relates to investment is based on underpricing capital, then using a mixture of formal and informal mechanisms to ration funds to investors, Market-determined interest rates play a distinctly secondary role. To some extent, lending institutions—which must restrict total loans to a prescribed amount or be penalized—are free to choose recipients of funds. But the government also has a voice, primarily through the Ministry of Finance.

The Ministry can act in a number of ways, At one level, its influence is informally exercised through a network of contacts within the financial community. At another level, the government intervenes more directly. For example, a particular bank's loan limits might be relaxed to allow funds to flow to a favored firm or industry. Sometimes, companies receive grants or loans directly from the government.[57] Selected firms and industries may also benefit from low interest rates or loan guarantees.

The ability of the French Government to intervene in capital allocation decisions is facilitated because—much more than in the United States—the savings function is split from the investing function. That is, the financial institutions that take deposits differ from those that lend money. Typically, funds collected by deposit-takers are first lent to intermediaries specializing in longer term investments. These intermediaries, in turn, lend to private enterprises. Direct transactions between deposit-taking institutions and corporate borrowers are infrequent. Table 66 illustrates the contrast with the United States. On the average, the deposits and loans of American financial institutions are much more nearly balanced. Almost one-third of the total value of loans to nonfinancial concerns in France

Table 66.—Holders of Liabilities and Claims With the Nonfinancial Sector in the United States and France[a]

	United States	France
Deposit-taking institutions (banks, savings and loans):		
Proportion of total deposits	57.3%	71.7%
Proportion of total loans/claims ...	51.8	48,3
Long-term credit Institutions:		
Proportion of total deposits ...	5.5	8.2
Proportion of total loans/claims ., . . .	7.9	32.9
Investing institutions (insurance companies, pension funds):		
Proportion of total deposits ., ...	32.3	11.3
Proportion of total loans/claims .	31,2	9.3
Other financial institutions:		
Proportion of total deposits	4.9	8.8
Proportion of total loans/claims	9.1	95

[a] As of the end of 1975

SOURCE: J Zysman, *Governments, Markets, and Growth: Financial Systems and the Politics of Industrial Change* (Ithaca, N Y Cornell University Press, 1983)

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[57] For examples in electronics, see, E. DiMaria, "French Govt. to Bolster IC Industry With Grants and Loans," *Electronic News*, Apr. 27, 1981, p. J.

flow through specialized long-term lending institutions, an indication of their importance.

Many of the institutions that take deposits or lend funds in France are at least quasi-public; with the completion of the Mitterrand government's program—which includes the nationalization of an additional 18 commercial banks, plus the country's two largest investment banking houses—three-quarters of all deposits pass through publicly owned banks.[58] This gives the bureaucracy many tools for influencing investment decisions, Even where financial institutions are private, the government can mediate between savers and investors; its most powerful weapon—even if seldom called on—is simply the ability to undercut private lenders with public funds.

Despite the pervasiveness of its influence over investment decisions, the French Government faces severe constraints in employing this tool of industrial policy. French industry—particularly in high-technology sectors like electronics—has seldom been as competitive in international markets as West German or Japanese industry, much less American. While exceptions such as aerospace exist, the comparative weakness of French corporations limits their ability to operate autonomously in world markets. The French have lagged conspicuously in MOS ICs and minicomputers; low-cost capital has not proved much help in building a strong technological base for the country's electronics industry. Indeed, several of the larger French manufacturers are controlled by foreign multinationals. Many more are partly owned by foreign firms, often American. Examples have included CII-Honeywell Bull and Matra-Harris Semiconducteurs. Subsidiaries of foreign-owned enterprises need not depend on French financial institutions for capital; even minority ownership, which is often coupled with dependence on foreign technology, gives substantial leverage in dealing with the bureaucracy or with government-controlled financial institutions. Furthermore, French companies that prosper become less subject to the allocative dictates of the government, Not only do successful firms get less attention simply by virtue of their competitiveness, but such companies can more easily generate capital internally, or tap international sources.

Operating within these constraints, the French Government has used the financial system to affect the country's electronics industry in two basic ways. Not only has the government supported the industry with both direct and indirect financial assistance, but—often as a precondition for loans or grants—the government has sometimes insisted that the industry restructure. While restructuring has frequently been aimed at fostering competitiveness, maintaining employment has also been a motive.

In electronics, the best known examples of government-directed restructuring have been associated with the Plan Calcul, which effectively ended in 1976 with a merger of the computer firms Compagnie International pour L'Informatique (CII) and Honeywell Bull, the latter partially U, S.-owned. The French Government promised as much as $700 million over a 5-year period to the new concern, along with further assistance through purchases of both hardware and software (ch. 10). By such methods, private firms in France are encouraged to behave in ways consistent with the goals of the government; the carrots and sticks tend to be more visible than in Japan,

France is now pursuing a similar strategy in microelectronics, As discussed in detail in chapter 10, the aim is to develop an indigenous, internationally competitive industry—in part by encouraging joint ventures through which American firms transfer technology to a French partner. One carrot here is the promise of R&D funding reported to total more than $300 million over a 5 year period, The U.S. partners have tended to view this as perhaps their only route to sales within the large, lucrative, and closed French telecommunications market.

Quite apart from direct government aid, electronics firms find that their status as technological leaders compared to the rest of French

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[58] P. Lewis, "France Begins $8 Billion Takeover of Private Industry and Banking, " *New York Times,* Feb. 15, 1982, p 1.

industry makes it relatively easy to locate funds for R&D or expansion, Through its pervasive influence, France's bureaucracy can assure favored industries funding from either private or quasi-public sources.

But again as in Japan, the extent of government influence on corporate financing has diminished over the years. During the 1970's, companies meeting with success internationally could deal with French banks and capital markets largely free of government intervention. The government was more concerned with firms and industries no longer able to compete; to considerable extent, French industrial policy has been preoccupied with such sectors as textiles, steel, and shipbuilding. A good deal of assistance has gone to firms in these industries, which have been depressed in France as in much of the developed world, In this respect, the French Government has behaved like that in other industrialized nations, including the United States.[59]

The French are now aggressively promoting potential technological leaders like electronics, hoping to encourage firms that might prove able to compete internationally (ch. 10). The plans of the Mitterrand government are extraordinarily ambitious in the spending levels proposed for the support of new industrial technologies, with much of the effort in electronics focused on semiconductors, France's record in attempting to promote technologically advanced industries has thus far been mixed: disaster with the Concorde; success with the Airbus and helicopters, as well as nuclear power; notable progress in telecommunications; little relative movement as yet in microelectronics. Direct and indirect financial subsidies may contribute to technological success, but by the recent history in France are far from sufficient,

West Germany

Financial mediation in the Federal Republic again involves parties having much closer working relationships than typical in the United States. In particular, the stockholdings of banks are a major source of their very considerable leverage over German companies of the Aktiengesellschaft (AG) variety. The AG, or joint stock companies, were once far more numerous in West German industry, and most of the large concerns are still organized in this fashion, Over the postwar period, the number of Gesellschaften mit beschränkter Haftung (GmbH)-–privately held, limited liability organizations—grew rapidly; banks interact less closely with these.

One source of banking influence over the AG form of corporation stems from its two boards of directors: the shareholders elect a supervisory board, which in turn appoints an executive board, the latter responsible for operating management.[60] The supervisory board makes major decisions on matters such as new investments or product lines. While no individual can belong to both the boards of a single company, there are no bars to simultaneous service on the supervisory boards of several companies, even if they are competitors. Officers of banks holding equity in a West German firm often become directors, and a single bank may be represented on the supervisory boards of a number of competing enterprises. About 10 percent of the members of the supervisory boards of the 100 largest AG firms are bank officers—nor is this the only mechanism by which West German banks influence business activities.[61]

Indeed, the role of banks is even more central in West Germany than in Japan. There are three major reasons. The first is simply that German banks are allowed to hold common stock, as they can in Japan though not the

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[59] See V. C. Price, *Industrial Policies in the European Community* (London: St. Martin's Press, 1981), for an excellent discussion of how governments in Western Europe have attempted to deal with the problems of distressed industries,

[60] J. Kocka, "The Rise of the Modern Industrial Enterprise in Germany, " *Managerial Heirarchies: Comparative Perspectives on the Rise of the Modern Industrial Enterprise,* A. D. Chandler, Jr. and H. Daems (eds.) (Cambridge, Mass.: Harvard University Press, 1980), p. 77.

[61] See E. Hartrich, The *Fourth and Richest Reich* (New York: Macmillan, 1980), ch. 13; also R. Medley, "Monetary Stability and Industrial Adaptation in West Germany, " *Monetary policy, Selective Credit Policy, and Industrial Policy in France, Britain, West Germany, and Sweden,* staff study, Joint Economic Committee, Congress of the United States, June 26, 1981, p. 92.

United States. But, whereas Japanese banks are limited to a maximum of 5 percent ownership in a single company, the holdings of German banks have not thus far been restricted (although such legislation has been considered by the parliament in recent years). The second reason relates to financial structure. German industrial companies, again like their Japanese counterparts, are highly leveraged, tending to rely on bank loans rather than bonds. On the average, firms in the Federal Republic carry about four times as much debt as equity on their books.[62] The high proportion of debt is even more striking in light of the third characteristic of West German financial practice: this debt is heavily concentrated in the portfolios of only three banks—the Deutsche Bank, Dresdner Bank, and Commerzbank, all needless to say very large. These three banks hold seats on the boards of 70 of the 100 largest German corporations.[63]

Beyond the shares they own, banks in the Federal Republic frequently control proxy rights on privately owned shares carried in their vaults, These shares combine with direct equity ownership to create an impressive concentration of voting power. The banking community can vote more than 90 percent of the shares for many of the large publicly held corporations in West Germany.[64] Because major decisions must be approved by at least 75 percent of the shareholders, an effective veto is held by one or more banks if they control only a quarter of a company's common stock. Even more so than in Japan, banks in the Federal Republic absorb clear and explicit equity risks.

West Germany's competitors in Europe frequently complain over the relatively high leverage of German corporations, focusing on capital costs, together with the major holdings by banks of both equity and debt.[65] Their reasoning is virtually identical to that now heard in the United States concerning Japan: financing costs are lower because the major German firms make heavy use of low-cost bank loans.

As for highly leveraged Japanese firms, however, the magnitude of any advantage in cost of capital will depend largely on the tax benefits accompanying a high proportion of debt in a German company's financial structure. To the degree that inside knowledge and control provide better information, the involvement of banks in the management of German companies may also lower their perceived risks. If so, the banks might choose to lend on better terms. The same could be said about Japan, although the limits on direct ownership make it a less significant factor, In any case—West Germany or Japan—only small reductions in interest rates could plausibly flow from such sources.

The deep involvement of West German banks in corporate financing has its corollary in a relatively underdeveloped capital market. While stock exchanges exist, trading volumes are much lower than in the United States. Secondary markets for other types of financial instruments are rare. In fact, for most transactions in German financial markets, orders must be placed with the banking community. The usual modes of personal saving are bank accounts, insurance, and pension funds. Bonds, including those of financial institutions, account for less than 15 percent of savings, equity ownership less than 1 percent.

While banks carry great weight in the Federal Republic, government influence on the financing of private business is far less pervasive than in France or Japan. Although government ownership of business accounts for about one-fifth of all fixed capital investment—about the same as in the United Kingdom—public ownership in Germany is largely confined to the transportation, electric power generation, coal, chemicals, and shipbuilding sectors.[66] In recent

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[62] J. Ross-Skinner, "Germany's Powerful Banks," *Dun's Review*, January 1979, p. 68.

Medley, p. 115.

[64] M. Kreile, "West Germany: The Dynamics of Expansion," Between *Power and Plenty: Foreign Economic Policies of Advanced industrial States*, P. J. Katzenstein (ed.) (Madison, Wis.: University of Wisconsin Press, 1978), p. 191,

[65] E. V. Morgan and R, Harrington, *Capital Markets in the EEC: The Sources and Uses of Medium- and Long- Term Finance* (Boulder, Colo. Westview Press, 1977), p, 323.

[66] E. Owen-Smith, "Government Intervention in the Economy of the Federal Republic of Germany," *Governmental Intervention in the Developed Economy*, P. Maunder (ed.) [London: Croom Helm, 1979), p. 160. The investment figures were 21 percent in Germany for 1972 and 19 percent in the United Kingdom for

years, some of the government's holdings have been sold to private interests. Both Federal and Lander (state) Governments maintain ownership interests in banks, but their primary concern appears to be financing projects involving housing, agriculture, and small business. Government-owned banks do not compete for business with private banks. While direct government subsidies to industry are substantial, amounting to several billion deutsche marks annually (about half as much in dollars), most of the subsidies have been directed toward social welfare objectives or the support of industry in West Berlin and the border areas. Still, Federal funds have aided aircraft design and production, along with shipbuilding, coal mining, and housing construction.

The picture that emerges, therefore, is one of close working relationships between West German industry and the banking sector. Commercial banks provide the bulk of external financing for companies in industries like electronics, and take a correspondingly active role in management. In terms of control over the nation's economic activities, the banks occupy a central position and wield considerable power. While a variety of political interests have recently pressed for reductions in the presence of the banks, thus far change has been minimal. Government, in contrast, plays a less dominant role than in many other industrialized nations. Recently, the willingness of the West German Government to let market forces determine economic direction has come under strain. The eventual consequence may be a greater degree of intervention in macroeconomic matters (ch.10).

Summary and Conclusions

This chapter—as several others—concentrated on the U, S.-Japan comparison because Japanese companies are the most effective and aggressive competitors in the world electronics industry outside the United States.

From the narrow viewpoint of financing costs, it appears that government support for Japan's electronics firms–now manifesting itself particularly in semiconductors and computers—has resulted in somewhat lower costs of capital than would otherwise be the case. But in real, inflation-adjusted terms it is unlikely that this cost of capital advantage exceeds a few percentage points—almost certainly less than 5. By itself, the effect would be to make expansion somewhat less costly for Japanese firms, but the competitive advantage gained from this source alone would be small. Differences in costs of capital faced by firms within the industries of the United States or Japan are larger than the differences between average costs of capital in the two countries. Although Japanese electronics companies continue to utilize greater financial leverage than American firms, the advantages of this practice are marginal at best, Higher debt-equity ratios do *not* give Japanese electronics firms significant benefits in financing compared to American manufacturers.

Other analyses have resulted in estimates for the difference in cost of capital between the United States and Japan that are considerably larger. The explanation lies in expectations concerning future price inflation in the two countries, which other studies have not fully considered, To gain "real" returns, lenders must demand interest rates in excess of the inflation rate. Price inflation in the United States has exceeded that in Japan by considerable margins over the past few years, and the inflationary expectations of lenders have reflected this history. The direct consequences for costs of capital are perhaps less important than the effects on time horizons for corporate

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(footnote continued from p. 293)
1975. See *Public Enterprise in the EEC,* W. Keyser and R. Windle (eds.) (Alphen aan den Rijn, The Netherlands: Sijthoff and Noordhoff, **1978),** *Part 111–Federal Republic of Germany,* p. *3* and *Part VII— United Kingdom and Ireland,* p. 40,

investment decisions. High and uncertain future inflation rates lead managements to anticipate large swings in the cash flow returns from capital. The longer the time horizon, the greater the possibility that, at some future point, the returns will be insufficient to cover interest expenses, *Such uncertainties bias investment decisions in the United States toward the short term.*

Still, even if the real, inflation-adjusted costs of financing are not that much higher here than in other parts of the world, costs of capital are great enough to create serious dilemmas for the financial managers of American electronics firms. These dilemmas stem from the limits on debt broadly acceptable within U.S. financial markets, the need for rapid growth in capitalization to meet expanding market demand for electronics products, rising capital-intensity in some parts of the industry, and heightened foreign competition.

In addition to greater capital equipment costs, manufacturers of computers, semiconductor devices, and related products face mounting expenses for R&D and product development simply as a result of advances in technology and the increasing complexity of electronic systems, As in the past, competition will be strong even among domestic firms; added competitive pressures will come from the Japanese. When the industry was small, and new startups drove the technology, competition was a vital source of U.S. strength, Now that the industry is maturing, the ingredients of success are changing. Managers of American firms are reassessing their business strategies—particularly in terms of pricing—while finding themselves hard-pressed to finance R&D and new production facilities,

In recent years, American industry has not raised much capital from sales of stock. To increase equity without selling stock, electronics firms must generate substantial flows of retained earnings from profits and depreciation. To some extent, the depreciation schedules implemented by the Economic Recovery Tax Act of 1981 will increase cash flows available for reinvestment, as will other changes in the tax law. But competition is likely to hold down profitability, thus limiting the ability of American electronics manufacturers to finance rapid expansion through reinvested earnings.

Compounding the difficulty for firms in many portions of the industry is the rising level of capital intensity. More expensive production equipment is a fact of life for semiconductor firms. Equipment used for R&D as well as manufacturing rapidly becomes outdated. This is not necessarily a problem so long as writeoffs keep pace. But the changes in depreciation schedules adopted as part of the 1981 Tax Act—which fix depreciation on most equipment at 5 years for all industries—could disadvantage electronics firms, In the past, depreciation schedules were based, at least nominally, on the actual useful life of the investment. The new law shortens depreciation schedules for other industries, where plant and equipment often have much longer useful lifetimes, With all industries now depreciating on essentially equivalent schedules, firms in electronics and other technologically dynamic industries are likely to find themselves at a *relative* disadvantage. Their domestic rivals for investment funds benefit from greater increments in depreciation rates and hence in cash flows, augmenting their ability to attract capital for new investment.

U.S. electronics firms obtain financing from a variety of sources, depending largely on their size and stage of development. For many of the younger companies, the original source was the venture capital market—where investors provide money to infant businesses in the hope of greater returns than safer investments would yield. Venture organizations generally expect most of their return in the form of capital appreciation; as a consequence, their investment decisions are sensitive to taxation of capital gains. The 1978 reductions in capital gains taxes were an important force in enlarging the pool of funds available for new ventures in electronics.

As successful firms grow beyond the infant stage, they gain access to a greater variety of sources of capital—e.g., lines of credit with banks, bond markets. They may also be able to float public stock offerings. But managements of electronics companies, following the prevailing American pattern, have strongly preferred internal funding of growth. Some companies utilize considerable debt (table 53), but leverage in U.S. electronics firms for the most part remains low.

Such financial patterns—particularly those established by merchant semiconductor manufacturers during the 1960's and 1970's—will not be easy to maintain during the 1980's. Greater demands for capital equipment and for R&D are combining with intense foreign competition to make the financing of growth by small, independent companies more problematical. But despite the attention focused on international competition, the fundamental problem is growth—together with the upswing in capital intensity. Many once-independent firms have already been acquired by larger corporations, at least partially in consequence of their needs for capital.

As a result of these forces, the U.S. electronics industry will almost certainly be compelled to rely more heavily on external funds. This is one of the reasons for the concern over costs of capital. Many industry leaders have expressed doubts that supplies of capital will be adequate–or that, if capital is available at all, the costs will be too high, particularly compared with costs of capital in Japan. Of course, funds will always be available for investments that promise sufficiently high returns. Free capital markets will clear at some interest rate, and it is this interest rate—or price—that serves as the allocative mechanism in the U.S. financial system. *But it is quite possible that—from a broader perspective than simply returns to capital—projects that are otherwise desirable will not be funded. Examples include the long-term basic research that undergird a high-technology industry like electronics.*

As a result, the question of whether interest rates in the United States may be prohibitively high is a difficult one. The supply-side thrust of programs initiated by the Reagan administration was intended to produce significant growth in the pool of capital available for investment, If effective, such programs should result in lower market interest rates. But many of the steps taken will also stimulate *demand* for funds. It has not yet been possible to separate the effects on supply and demand flowing from these policies; the vital question of how future U.S. costs of capital will compare with costs in other countries, also uncertain, takes the whole matter a step further.

Turning to Japan, in years past capital costs for electronics firms there may have been significantly lower than in the United States. The reasons are several. Capital has, at various times, been channeled to favored industrial sectors, including electronics, By controlling interest rates, the Japanese Government effectively circumvented the market as a mechanism for allocating funds, But while remnants of this control remain, government influence over financing decisions by banks is now much weaker than 20 or even 10 years ago. Furthermore, as capital markets in Japan continue to evolve they will take forms more like those in other industrialized countries—i.e., market-determined interest rates will become the major mechanism for capital allocation, Stronger linkages with capital markets in other countries will mean that rates of return—and hence costs of capital—will not be much different in Japan than in the United States. Thus, even if Japanese electronics firms enjoyed lower costs of capital in years past, these advantages are likely to diminish in the future,

At the same time, the savings rate in Japan continues to be extraordinarily high, though declining somewhat at the end of the **1970's.** It may continue to gradually fall, but rates of capital formation remain much greater than in the United States even considering increasing public sector demands as a result of large budget deficits, Moreover, Japan's Government has a well-practiced capability for intervening in capital markets and steering investment toward favored sectors of the economy. What the Japanese have called "administrative guidance" will not simply disappear. Still, the changing character of the country's financial markets means that Japan's electronics firms will have less of an advantage in the future compared to their rivals in the United States and Europe—some of which may even find themselves tapping sources of capital in Japan to finance their own expansion.

As these trends proceed, major Japanese corporations will no doubt continue to diversify their capital structures, relying less heavily on commercial banks. Corporate borrowing in Japan as a percentage of gross national product is declining as firms diversify their sources of funds, The leverage of Japanese electronics companies gradually decreased over the 1970's, as figure 52 showed, while public sector borrowing has risen. Government bonds are becoming major long-term tradable securities. Securities of many types, both domestic and international, are becoming more widely available in Japan, and market forces are having their effects on interest rates. The government will have more difficulty in managing investment flows, and the capital structures of Japanese electronics firms will continue moving closer to those in the United States. Assuming these trends continue—and there is every reason to expect them to—at least some of the concerns of American industry with respect to Japanese financial practices should diminish.

CHAPTER 8

Human Resources: Education, Training, Management

Contents

List of Tables

List of Figures

CHAPTER 8

Human Resources: Education, Training, Management

Overview

Among the questions this chapter addresses are: How good are the people an industry depends on? Is the pool from which they are drawn big enough? How do they get their training? And, the mirror image of these: Does industry use their abilities wisely?

Countries without adequate human resources cannot hope to design and manufacture products like computers; even televisions are beyond the capabilities of many developing economies. In the United States, people—unskilled or skilled workers, engineers and technicians, managers—are a vital resource for electronics firms; thriving semiconductor companies have been built around the talents of three or four engineers.

But people are only the starting point. How talents are developed, skills utilized, depends largely on management: managers shape the organization, decide on policies, set the style and tone. The sections that follow examine human resources as a factor in competitiveness, primarily from the standpoint of electronics in the United States. Matters of education and training are followed by an examination of management practices. One of the questions addressed is: To what extent does the vogue for Japanese management represent anything new and different in the American context, as opposed to a reemphasis of themes that have always been present? The comparisons on education also focus on Japan, in part because of the recent publicity given to that country's lead over the United States in numbers of engineers graduated.

Such topics are particularly appropriate at a time when rates of productivity growth have slowed in the United States. Is the education and training of American workers appropriate for technology-intensive industries like electronics? Do managements make the best use of the talents and abilities of the labor force? Are countries like Japan doing anything that is really different—or better? In the early part of the century, these questions were already being asked, as part of the "scientific" study of management. It is no coincidence that American management experts schooled Japanese executives now known for their dedication to quality (ch. **6).**

The popular press tends to oversimplify the set of issues covered by "human resources, " Some commentators define human resources narrowly, as encompassing the skills and attitudes of the work force; this approach often leads to stereotyping of employees in countries like Japan or West Germany. Seeing the Japanese worker as the product of a culture that rewards hard work and diligence captures part of the truth but obscures the larger institutional and economic context. Others stress management techniques, often narrowly defined, as a key to labor productivity, Quality control circles are the best-publicized current example. While certainly critical in the utilization of a firm's human resources, management should also be viewed as part of a broader picture. Management practices themselves reflect a mix of schooling and experience shaped by the structure of work and organization within a society.

This chapter views the American labor force —and the electronics industry—from two fundamental perspectives. First, workers bring with them a set of skills largely acquired prior to joining a company. The question then is to compare education and training in the United States—particularly of white-collar personnel, but also blue-collar employees–with that of the men and women who staff foreign electronics firms, Second: Will there be enough appropriately trained people to meet the needs of a rapidly expanding U.S. electronics industry?

Labor mobility is a separate but related issue. A growing industry, such as semiconductor manufacturing, may be able to meet its manpower needs by attracting workers from other parts of the economy, Within the industry, one semiconductor firm may be able to lure employees from its competitors, Mobility has traditionally been high in the United States for those with knowledge and experience.

But what of those left behind by technological change? To a considerable extent, other nations have used retraining programs as instruments of public policy for enhancing employee mobility and aiding those whose skills are out-of-date. This has been less common in the United States, where mobility and continuing education depend on individual initiative. Leaving aside questions of remedial education and the training necessary for entry level jobs, with which the United States has experimented largely for reasons of social welfare, a *strong case can be made for an enhanced Federal role in training and retraining programs to support the competitiveness of growing high-technology industries like electronics.*

The other perspective on human resources in this chapter relates to corporate management. Contrasting the practices of Japanese and American managers shows many of the lessons of effective management to be universal, the unique character of Japanese management something of a myth. Nonetheless, there are lessons to be learned from firms in Japan, as well as from successful organizations in the United States. Competitive firms here and abroad tend to share a common trait: management practices that give employees a say in decisions affecting their work, along with support for skill development. Emphasis on employee participation and human relations can contribute to productivity and worker satisfaction, but conclusive evidence linking particular management techniques (such as quality control circles)—here or in any country—to competitive success is conspicuously lacking.

Education and Training

The U.S. electronics industry is built on the capabilities of production workers, skilled technicians, and white-collar managers and professionals. On the shop floor, blue-collar employees operate semiconductor fabrication equipment, assemble computers or TV sets. Much of this work is essentially unskilled, meaning that a typical job can be learned in a few hours. Technicians—grey-collar employees—often with vocational school training, play an important role both on the factory floor and in research and development (R&D) laboratories. They maintain, troubleshoot, and repair sophisticated equipment—and sometimes fabricate it—as well as testing and inspecting components and systems. Technicians also build and help develop prototypes of new products. Other employees with specialized skills include draftsmen and nondegree designers, production foremen, field service installers and repairmen, computer system operators, and technical writers. White-collar workers—many with college degrees—perform functions ranging from plant management to accounting and financial control, business planning, and legal advising. Engineers and scientists—some with advanced degrees—design and develop products, plan manufacturing processes, specify production equipment, and carry out R&D projects in fields ranging from solid-state physics to computer architectures, All of these skills are essential to a competitive industry, not just those of the well-educated and well-paid professionals; grey-collar technical workers, in particular, have a critical place in technology-based organizations. Some jobs depend much more heavily on formal education and training than others, but it is fair to say that better skills and abilities at all levels will add to the competitive ability of an enterprise, as well as adding to peoples’ upward mobility.

The United States has maintained a lead in many fields of technology and science since World War II, in large part because of the excellence of the educational system here. Nonetheless, other advanced industrial nations provide their work forces with training in technology, mathematics, and science that *on the average* is probably more intensive. It is easy to forget, in the publicity that surrounds Nobel Prizes, the Apollo program, or the nascent biotechnology industry, that competitiveness rests on the skills and abilities of great numbers of people whose contributions will never be publicized or even acknowledged. At a time when literacy levels in the United States decline as those elsewhere rise, and the Soviet Union graduates five times as many engineers, it makes sense to look at the foundations for the Nation’s human resources as well as the pinnacles of its achievements.

In fact, the evidence of U.S. weakness in technical education and training is strong and continuing to mount.[1] The best people and best educational institutions in the United States are probably as good as ever, maybe better. But the *breadth of capability* that once distinguished the U.S. labor force may be diminishing, The National Science Foundation/Department of Education (NSF/DOE) report cited above concludes that American achievements in basic research remain unchallenged, but that the *average* high school or college graduate in this country has only the most rudimentary knowledge of mathematics or science. The trends are clear, beginning at secondary levels where students avoid courses in these subjects. Only one-sixth of U.S. secondary school students, for example, take courses in science or mathematics past the 10th grade. Technology, as opposed to science, is totally lacking in secondary schools, despite the abundant evidence of public fascination with technological achievements. Indeed, few people seem to distinguish technology from science, hence misnomers such as science fiction.

The NSF/DOE report, along with many others, also points to apparent shortages of entry-level computer professionals and several types of engineers, and the difficulties of secondary schools, vocational institutes, community colleges, and universities in finding and retaining qualified teachers in the physical sciences, mathematics, engineering and computer science, and in vocational programs, Moreover, equipment used for teaching laboratory courses in engineering and the sciences is years out of date and in short supply. In the future, American industry, particularly high-technology sectors like electronics, may simply not have an adequate supply of employees with the kinds of skills needed to maintain U.S. competitiveness.

U.S. Secondary School Education in Science and Mathematics

Falling mathematics and science enrollments in American high schools indicate that, while there is a small group of students who want and get advanced courses, the great majority avoid these subjects when they can. Average scores on national tests of achievement in mathematics and the sciences are lower than a decade ago. Students who elect to take Advanced Placement Tests in science or mathematics make about the same scores as in the past, indicating that the core of serious students gets good preparation; but overall, Scholastic Aptitude Test (SAT) scores fell for **18 con**secutive years until holding steady in 1981. *

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[1] “Science and Engineering Education for the **1980’s and Beyond, ” National** Science Foundation and Department of Education, October 1980. See also *Today’s Problems, Tomorrow L’rises: A Report of the National Science Board Commission on Precollege Education in Mathematics, Science and Technology* (Washington, I) C,: National Science Foundation, Oct. 18, 1982): *.’+. ience and Engineering Education: Data and information,* NSF *82-30* (Washington, D.C.: National Science Foundation, **1982), and** *Science Indicators- 1980* (Wash ington, DC.: National Science Board, National Science Foundation, **1981),** chs. 1 and 5. The L’, S.-[“.S. S R. comparison in engineering graduates comes from p. 209 of the last-mentioned report.

*According to the Educational Testing Service, Princeton, N.J., mean scores in 1981 for college-bound high school seniors were *424* for the verbal portion of the SAT and 466 for the mathematics

Some of the decline can be attributed to the greater percentage of students who now attend college and thus take the tests, but an advisory panel convened to examine the SAT concluded that, since 1970, other factors—including lower educational standards and diminishing motivation on the part of students—have been much more important.[2]

Fewer American high school students are electing mathematics and science courses, particularly the two fundamental physical sciences, chemistry and physics; of those who do elect science, more chose the life sciences. While the majority of U.S. high school graduates have taken biology, only about a third have had chemistry; the fraction drops to about one-tenth for physics.[3] The situation is replicated in high school mathematics, where only one-third of U.S. graduates take 3 years of coursework. Regardless of how good their grades may be, three-quarters of American high school graduates do not have the prerequisite courses to enter a college engineering program.[4] What this means for industries like electronics is not only that the average high school graduate is unprepared to study engineering or one of the physical sciences in college, but may be unable to enter a career calling for middle-level technical skills without a good deal of additional training.

Secondary Schooling Abroad, Especially in Japan

U.S. enrollments in science and mathematics contrast starkly with the picture in Japan. Not only do about 90 percent of Japanese high school students graduate—compared with 75 to 80 percent in this country—but all are required to complete 2 years of mathematics plus 2 years of science. Competition for entry into the best colleges is intense; Japanese students choose rigorous electives and spend much more time on homework than their American counterparts. Those who wish to attend college study mathematics each year, moving beyond trigonometry—the point where many U.S. high school curricula still stop.[5] The stress in Japanese secondary schools on science and mathematics for all students is far from unique. The Soviet equivalent of the American high school curriculum includes a heavy dose of coursework in these areas—for instance, 2 years of calculus. West German secondary school students, even those who wish to specialize in fields such as the classics or modern languages, get extensive training in mathematics and science; by the same token, those planning technical careers receive their liberal arts education in high school. Neither curricula nor academic standards vary as widely among West German schools as in the United States.[6]

In Japan, large numbers of students who do not go to college get technical, vocational, or semiprofessional schooling as preparation for jobs in industry where they will work with and provide support for engineers and scientists. The result is a large pool of well-prepared candidates for entry-level grey-collar jobs.[7]

The investments that students in Japan make in science and mathematics yield measurable benefits. On a number of international achievement tests, Japanese students score consistently above their counterparts in other industrial nations.[8] Nonetheless, secondary education in

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(footnote continued from p. 303)

portion, identical to 1980 scores, In 1966, the means were 466 for verbal and 492 for mathematics. While testing criteria may not have remained precisely the same over this period, the downward trend is unambiguous.

[2] “Science and Engineering Education for the *1980's* and Beyond,” op. cit., pp. 107-108.

[3] P. D. Hurd, ‘‘Falling Behind in Math and Science, *Washington Post,* May *16, 1982,* p. C7. See also Science *and Engineering Education: Data and Information,* op. cit., pp. *57, 59.*

[4] “Engineering: Education, Supply/Demand and Job Opportunities,” Electronic Industries Association, Washington, D. C., October *1982.*

[5] M. W. Kirst, “Japanese Education: Its Implications for Economic Competition in the 1980's,” *Phi Delta Kappan,* June 1981, p. *707.* Only about *30* percent of U.S. high schools offer calculus, and fewer than 10 percent of American high school students take the subject; see Hurd, op. cit., and *Science and Engineering Education: Data and Information,* op. cit., p. *59.*

[6] *Engineering Our Future: Report of the Committee of Inquiry into the Engineering Profession* [London: Her Majesty's Stationery Office, January 1980), p. 219. Also, D. W. Sallet, “Education of the Diplom Ingenieur,” *Journal of Engineering Education,* vol. *59,* June 1969, p. 1105.

[7] S. B, Levine and H. Kawada, *Human Resources in Japanese Industrial Development* (Princeton, N. J.: Princeton University Press, 1980), pp. *74, 80.* Engineers in Japan are evidently supported by many more technicians than in the United States.

[8] R. S. Anderson, *Education in Japan* (Washington, D. C.: U.S. Government Printing Office, 1975), p. 130.

Japan has major weaknesses. The most obvious is the strong traditional emphasis on rote learning and imitation, coupled with a dependence on textbooks and lectures rather than demonstration and learning-by-doing (in reality, U.S. education is probably no better in this regard). Critics of the system argue that this stunts the development of creative abilities.[9] Academic competition in Japan is, furthermore, so intense that the Japanese Ministry of Education has expressed concern that other aspects of child development are being neglected. Despite the undoubted validity of some of these criticisms, the fact remains that high school students in Japan receive training in science and mathematics that is, on average, more extensive than in the United States. Even for students who do not go on to technical or professional jobs, such training contributes to quantitative skills, precision in thinking, and to an understanding of the physical world. Such a background helps people to comprehend the technologies that their daily lives depend on. In the future, their employment opportunities may depend on this as well.

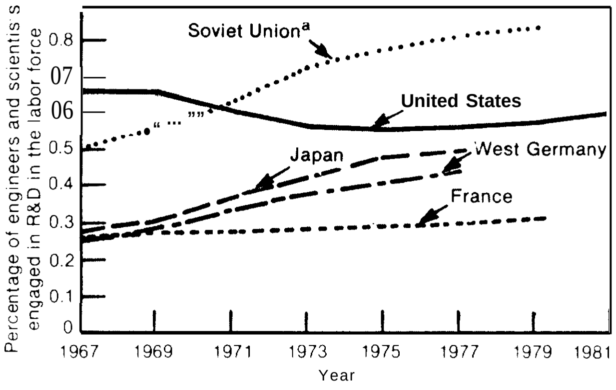
University and Continuing Education in the United States

In some respects, the Japanese and American educational systems are opposites. The Japanese concentrate their efforts on precollege training where the United States is weak. On the other hand, the quality of university education in Japan is much inferior. In a very real sense, the American system of higher education must compensate for secondary schooling that is generally poor.

Although this comparison may be qualitatively valid, it begins to break down in terms of numbers. While the United States continues to produce more Ph.D.s in science and mathematics than Japan, Japanese undergraduate programs have been turning out greater numbers of engineers since 1967. In 1981, Japan graduated 75,000 engineers compared to 63,000 here, despite a population half that of the United States. The margin is a little greater for electrical engineering graduates—25 percent.[10]

As figure 53 shows, the United States once held a commanding lead in the proportion of engineers and scientists in the work force, While the advantage over other Western nations probably still exists (various countries categorize scientists, engineers, and technicians differently, making comparisons ambiguous), it has narrowed greatly, And, as table 67 demonstrates, engineering graduates are now a smaller proportion of their age group in the United States than in Japan or West Germany—countries where a far greater fraction of engineers in any case devote their efforts to commercial rather than defense industries.

Figure 53.— R&D Engineers and Scientists in the Labor Force



[a]Lower bound estimate

SOURCE *National Patterns of Science and Technology Resources 1982* (Washington DC National Science Foundation 19821 p 33

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[9] See, for example, the assessment of M. Nagai, former Japanese Minister for Education: "Higher Education in Japan, " *Japan Quarterly*, vol. 24, 1977, p 308. While many Japanese are quite self-conscious about their country's supposed lack of innovation and originality in engineering and the sciences, the product developments flowing in recent years from Japan's industries show great creativity in the *application* of technology.

[10] The 1981 breakdown by disciplines is not available for Japan, but in 1980, 19,355 13, S.-level degrees were awarded in electrical and computer engineering, compared to 15,410 in the United States. Figures for Japan are from the Ministry of Education, those for the United States from P. Doigan, "Engineering and Technology Degrees, **1981** ," *Engineering Education*, April 1982, p. 704, and P. Sheridan, "Engineering and Technology Degrees, 1980, " *Engineering Education*, April 1981, p. 713

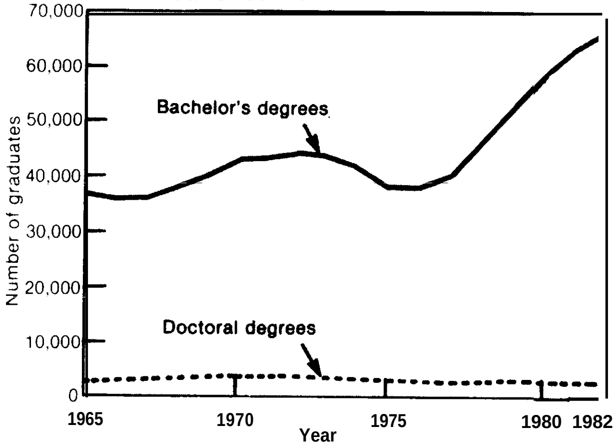
Table 67.—Engineering Graduates as a Percentage of Their Age Group[a]

United States	1.6°/0
Japan	4.2
West Germany	2.3
France	1.3
United Kingdom	1.7

[a] First degree graduates, including foreign nationals, ın 1978, except for West Germany and France, where the percentages refer to 1977 Inthe Unifed States a significant fraction of engineering graduates are from overseas" in 1982, 8 percent of B.S degrees in engineering went to foreign students,29 percent of M.S degrees, and 40 percent of Ph D degrees See P. J Sheridan, "Engineering and Technology Degrees, 1982," *Engineering Education*, April 1983, p 715

SOURCE *Engineering Our Future Report of the Committee of Inquiry into the Engineering* Professlon (London Her Majesty's Stationery Office, January 1980), p 83

Figure 54.—Engineering Graduates of American Universities



SOURCES *1965-79*—"Data Related to the Crisis ın Engineering Education, " American Association of Engineering Societies, March 1981, p 17

1980—P J. Sheridan, "Engineering and Technology Degrees, 1980, " *Engineering* Education, April 1981, p. 713

1981—P Doigan, "Engineering and Technology Degrees, 1981 ." *Engineering Education*, April 1982, p 704

1982—P J Sheridan, "Engineering and Technology Degrees, 1982, " *Engineering Education*, April 1983, p 715.

Engineering Education

As table 68 indicates, graduates in engineering, the physical sciences, and mathematics in the United States accounted for steadily falling proportions of new degrees at both undergraduate and graduate levels during the 1970's. The number of degrees in the mathematical sciences, including statistics and computer science, actually fell between 1970 and 1980.

In engineering, undergraduate enrollments have jumped since the mid-1970's–and the number of graduates has followed, as shown in figure 54—leading to overcrowded classes, overloaded faculty, and severe pressures on the quality of education. The number of full-time undergraduates enrolled in U.S. engineering schools went from about 20,000 in the early 1970's to an all-time high of more than 400,000 in 1982.[11] At the graduate level, the trends are quite different—but not encouraging. The number of master's degrees in engineering has increased slightly over the past decade, but the number of Ph.D.s has declined—one reason for faculty shortages in engineering schools. Figure 54 illustrates the trends at both B.S. and

Table 68.—U.S. Degrees Awarded by Field

	Engineering	Physical sciences	Mathematics[a]	Total as percentage of degrees awarded in all fields
1980: B.S.	*37,808*	*16,057*	11,437	17%
M.S.	6,989	3,387	1,765	17
Ph. D.	786	NA	NA	NA
1970: B.S.	42,966	21,551	29,109	12%
M.S.	15,548	5,948	7,107	13
Ph. D.	3,620	4,400	1,222	31
1980: B.S.	58.742	23,661	22,686	10%
M.S.	17,243	5,233	6,515	10
Ph. D.	2,751	3,151	963	21

NA = Not Available

[a] Including statistics and computer science.

SOURCE" Engineering—"Data Related to the Crisis in Engineering Education, " American Association of Engineering Societies, March 1981, p 17, Physical Sciences and Mathematics—National *Patterns of Science and Technology Resources 1981,* NSF 81-311 (Washington, D. C.. National Science Foundation, 1981), pp. 78-80

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[11] P. Doigan, "Engineering Enrollments, Fall 1982, " *Engineering Education,* October 1983, p. 18. At the bottom of the most recent trough, in 1973, 187,000 students were enrolled in engineering; by 1982, the total was 403,000.

Ph. D. levels. Not only have doctoral enrollments failed to keep up, but about half of all Ph.D. engineering candidates are now foreign nationals; many of them leave the United States after graduation. *

An important cause of declining enrollments of Ph. D. candidates in engineering has been the high starting salaries that holders of new bachelor's degrees command–in 1982, about $26,000. Swelling demand by industry for engineers has attracted undergraduates to the field, at the same time siphoning many off from the pool of prospective graduate students. To someone who might otherwise consider a Ph. D. followed by a teaching career, the rewards of immediate employment can seem much more attractive than several years of low-paying stipends or graduate assistantships, then the salary of a junior faculty member. While pay for college teachers has always been well below that in industry, the other attractions of an academic career have diminished in these days of overcrowded classrooms, outdated equipment, and limited research funding.

Poor facilities and an escalating student-to-faculty ratio are leading to declines in the quality of education provided in American engineering schools. For many years, the proportion of programs in engineering and computer science that were unconditionally reaccredited during periodic reviews held steady at about 70 percent, but in 1981 only 50 percent of the programs examined received full accreditation.[12] *This sudden change indicates the gravity of the problems facing engineering education in the United States.*

The most common and most serious causes of declining educational quality are faculty shortages and obsolete laboratory equipment.

Photo credit General Motors

Engineer holding bracket designed with computer assistance

Even when funds have been available to hire new faculty, good candidates are rare because of the low numbers of new Ph.D.s and the uncompetitive salaries offered by universities. Estimates of the number of unfilled faculty positions in U.S. engineering schools have been in the range of 1,400 to 2,000--about 10 percent of the total number of faculty positions in engineering.[13] Furthermore, universities can no longer depend on graduate students to relieve some of the load on regular faculty by assisting in classroom teaching and laboratory instruction.

The equipment problem is equally serious. While faculties do their best with the resources available, it is difficult to teach a digital design laboratory with equipment from the analog era. And laboratories, as well as classrooms, have become overcrowded as undergraduate enrollments have climbed. Quality suffers when students have less contact with faculty, as well as less exposure to up-to-date laboratory equipment and computing facilities. Many univer-

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*See note to table 67. In 1982, 1,167 of 2,887 engineering Ph. D.s went to foreign nationals; both industry and universities have become heavily dependent on foreign-born engineers, especially at the doctoral level. Figures on graduates reflect earlier enrollments; currently, nearly 50 percent of Ph. D. candidates in U.S. engineering schools are foreign nationals.

[12] "Adequacy of U.S. Engineering Education, " *Emerging Issues in Science and Technology, 1981* (Washington, D.C.: National Science Foundation, June 1982], p. 60. Programs with deficiencies may be reexamined after a shorter than normal interval or placed on probation

[13] As of the fall of 1982, a survey of U. S engineering school reported 1,400 authorized and budgeted faculty positions vacant, of a total of about 18,000. The number should be *regarded as* a lower bound because few universities have increased the number of authorized faculty positions at rates commensurate with growth in undergraduate enrollments. The most severe problems are in computer specialties. See J. W. Geils, "The Faculty Shortage: The 1982 Survey" *Engineering Education*, October 1983, p. 47.

sities, hurt by past slumps in engineering enrollments, are reluctant to put scarce funds into expansion to meet what may be a transient demand, More fundamentally, universities have had great difficulty in adjusting to shifting student choices at a time when total enrollments have stopped rising. Tight budgets have caused programs in the sciences as well as engineering to fall behind the times.[14]

The well-publicized situations at large, State-supported schools such as Iowa State University and the University of Illinois, typical of the institutions that form the core of the U.S. system of engineering education, are representative.[15] Iowa State simply ran out of facilities to handle enrollment increases in computer engineering, despite operating on a 6-day schedule. Because of overcrowding, students were warned that they might not be able to complete their programs in 4 years. Transfer students at Illinois must have a grade-point average of 4.2 on a scale of 5 to enter engineering, while the universitywide requirement is only 3.25. Shortages of facilities and teaching faculty forced 16 of 30 large American engineering schools to adopt some form of restriction on the number of students they admit.[16]

Only the elite universities have been largely spared such problems, and even these have had trouble attracting enough good graduate students. But because the best schools have always limited their enrollments, they have been able to raise the average quality of incoming students while keeping expansion to manageable rates, Engineering departments at schools like Stanford or MIT have also been able to retain their faculties. One of the dangers implicit in responses by industry or the Federal Government to the problems afflicting engineering education is that resources may flow disproportionately to the top-ranked, research-oriented universities. Of the nearly 300 colleges and universities that offer engineering in the United States, it is the middle tier—both public and private—that turns out the vast majority of graduates and faces the most serious problems,

Supply and Demand

Even though enrollments are still climbing, and the number of B.S. graduates in engineering has been going up at about 10 percent per year (fig. 54), it is not at all certain that the number of engineering graduates in the United States will meet future needs. As discussed in more detail later in the chapter, there will almost certainly be entry-level shortages at some times in some specialties—e.g., computer engineering—and the shortfall in Ph.D.s for teaching is bound to continue; according to one estimate, there is a current shortage of 3,500 doctoral-level engineers in industry beyond that of Ph.D.s for university faculties.[17]

While the rapid rise in engineering enrollments has led to fears by some that the United States might be headed for an oversupply by the 1990's, such concerns seem overstated if only because many graduates of engineering programs move on to other fields. Competent engineers have virtually always been employable in the United States, regardless of economic conditions. Nevertheless, the American labor force contains nearly 1½ million engineers, and some portions of the engineering community deny the reality of the current "shortage," claiming that what industry really wants is a large pool of entry-level people to help keep

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[14] "Science and Engineering Education for the **1980's and Beyond**, " op. cit., pp. 68-69. Courses in physics and chemistry also depend on laboratory and computer facilities. For a discussion of laboratory equipment shortages with the emphasis on research needs, see "Obsolescence of Scientific Instrumentation in Research Universities," *Emerging Issues in Science and Technology, 1981,* op. cit., p. 49.

The nine State-supported engineering schools in Texas have reported equipment needs totaling $88 million, about 70 percent of this for undergraduate teaching laboratories, The situation in Texas is probably fairly typical; an extrapolation to the United States as a whole results in an estimate of about $1 billion for new laboratory equipment in engineering alone. See "$1 Billion for Instructional Equipment, " *Engineering Education News,* June *1982,* p. 1.

[15] "Engineering Education Under Stress, " *Science,* Sept. 25, 1981, p. 1479; C. Phillips, "Universities in U.S. Are Losing Ground in Computer Education, " *Wall Street journal,* Jan. 14, 1983, p. 1.

[16] "Universities Limiting Engineering Enrollments, " *Engineering Education News,* March 1981. The limitations are based simply on numbers; as at Illinois, qualified students are being turned away.

[17] "National Engineering Action Conference, " *Engineering Education News,* April **1982, p. 1.**

salaries of midcareer engineers low. There is a good deal of truth to this. Entry-level shortages arise in part because employers prefer to hire new engineers with fresh skills at lower pay. This is an easier and perhaps cheaper way of meeting their needs than coupling the experience of midcareer engineers-many of whom find themselves with increasingly obsolescent skills—with well-designed continuing education programs.

Regardless, at least some specialties seem bound to face continuing shortages by almost any criterion. These specialties include a number that are particularly relevant for the future competitiveness of the U.S. electronics industry; most notably, entry-level computer professionals are expected to be in high demand well into the 1990's, Programs of instruction in computer science and engineering still tend to be small and underdeveloped. Some are in engineering schools—often within electrical engineering departments—others in schools of arts and sciences, where computer science may be associated with mathematics departments. Many teaching departments lack the critical mass that would help them thrive, not surprising in a field which did not exist 25 years ago. In computer science, the United States graduates only 250 Ph.D.s each year, a number which has been declining—one reason computer science and engineering faculties are suffering greater proportional shortages of faculty than (other) engineering departments.[18] At present, qualified software engineers are in short supply; although people with many types of training can fill jobs as applications programers, there are far fewer candidates for jobs in the design and development of computer-based systems themselves.

Other new and/or specialized fields suffer similar problems. Perhaps half-a-dozen American universities have the facilities needed to design and fabricate large-scale integrated circuits. Microprocessor applications courses may require equipment that schools cannot afford, Few universities have adequate resources for computer-aided design in any of the fields of engineering. At the same time, such difficulties can be viewed as similar to those that have always existed. It has never been easy to give students a sense of the development effort that goes into an airplane or a nuclear powerplant. In this sense, the adaptations required by the emergence of large-scale integrated circuits or cheap computing power are nothing new.

Industry Initiatives

To help meet the needs of their members, two of the trade associations in electronics have established programs to support engineering education. The American Electronics Association has asked for money to augment faculty salaries and establish chairs in electrical engineering, as well as to expand fellowship programs for students; the Semiconductor Industry Association is funding research, thus providing indirect support to both students and faculty members through stipends and salaries, as well as money for equipment.[19]

A different approach has been taken by Wang Laboratories, which manufactures minicomputers and office automation equipment. The Wang Institute, located near Boston, offers a master's degree in software engineering through its School of Information Technology. Initially endowed by An Wang, the company's founder, the Institute is now an independent, nonprofit organization. With a curriculum designed to give training both in the technical aspects of computer software and in planning, management, and human relations, the school —which graduated its first students in 1982—grew directly out of the inability of companies like Wang to meet their personnel needs. Tuition is about $8,000 per year, less than half the actual cost of the program; the difference is

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[18] Seventeen percent of faculty positions in computer science and engineering were vacant at the beginning of 1982, versus about 9 percent for engineering as a whole. See "Universities in U.S. Are Losing Ground in Computer Education," op. cit.: "The Faculty Shortage: The 1982 Survey," op. cit.

[19] "AEA, SIA to Vie in Fund-Raising Efforts," *Electronic News*, Nov. 16, 1981, p. 36. Companies in other industries have begun parallel efforts.

covered by endowments and contributions.[20] Because of the emphasis on job-related skills, candidates for admission must have at least 2 years of professional experience, in addition to a B.S. degree in an appropriate field. The Wang Institute is one of a number of experiments presently underway in nontraditional training in specialized technical fields.

University-Industry Relations

Despite these and other examples of new and close relationships between business and educational institutions—for instance, the industry-supported Center for Integrated Systems at Stanford—university-industry relations, in the United States as in most countries, tend to be uneasy. Tensions between the theoretical learnings of faculty members and the more practical concerns of private firms, particularly smaller companies that do not engage in much research, are common. This also holds for professions such as business administration; to some extent it applies to the sciences as well.

In engineering, these tensions have deep historical roots; by the first decade of the 20th century, the academic perspective had largely won out over the shopfloor orientation that many in industry had advocated.[21] Later, between the wars, U.S. engineering education began to stagnate, During World War II, numerous R&D efforts—including many in electronics—were spearheaded by scientists (particularly physicists) with engineers filling subordinate roles. This lesson was one of several pointing to the need for reevaluations of engineering education.

The resulting turn toward theory led to “engineering science” as the core of undergraduate curricula. In the post-Sputnik period beginning in the late 1950’s, engineering schools emphasized quantitative, analytical skills even more. Accompanied by a strengthening of mathematics requirements, the focus on engineering science came at the expense of engineering design, as well as manufacturing and production processes. This was also a time when the spread of digital computers made numerical solutions to many previously intractable problems a reality, further strengthening the movement toward analysis at the expense of synthesis. In recent years, there has been something of a swing back.

Industry has always wanted graduates who can go to work immediately, while acknowledging the virtues of theoretical preparation in the engineering sciences as preparation for advancement and for continuing education. Demand for the “old-f ashioned,” practically oriented engineer has led to a proliferation of curricula in what is usually called engineering technology.

Engineering Technology

Technology programs—some 2 years in length and leading to an associate degree, others full 4-year B.S. courses of study—represent an attempt by American colleges and universities to equip entry-level employees with immediately applicable job skills. Graduates of these programs—more than 26,000 at the associate and bachelor’s levels in 1981 (40 percent of the total in engineering)—can be thought of as paraengineers; they get less extensive and less rigorous training in mathematics, the sciences, and in engineering science, but considerable exposure to routine technical problems.[22] While B.S. technology graduates are bet-

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[20] Information supplied by Wang Institute. See also M. A. Bengs, “A Unique Institution for High-Tech Training, ” *Boston Globe*, Mar, 2, 1980, and “Institutionalizing the Students of Software,” *Computer Design*, December 1982, p. 189.

[21] M. Calvert, The *Mechanical Engineer in America, 183G191O: Professional Cultures in Conflict* (Baltimore, Md.: Johns Hopkins University Press, 1967).

[22] In 1976, 16,685 associate degrees and 5,721 B.S. degrees in engineering technology were granted in the United States; in 1982, the figures were 17,198 for associate degrees, and 8,325 at the bachelor’s level. The 1976 data are from “Engineering and Technology Degrees, 1976, ” the 1982 from “Engineering and Technology Degrees, 1982, ” op. cit.

Well over 200 schools have technology programs, about the same number as for engineering. Most of the associate degrees are awarded by community college and vocational-technical schools. In a university, B.S. programs in technology and engineering may be offered by different colleges, particularly where the technology curriculum has grown out of an industrial arts setting; alternatively, both programs may be found in a “College of Engineering and Technology, ” Many faculty members in engineering have resisted the movement toward technology education, feeling that it detracts from the profession and threatens their own image. Outside the community of educators, a good ter prepared for advancement and for creative work than technicians, their upward mobility is considerably less than for engineers. In at least one sense, the problems that have hit engineering education are more serious still for technology: the practical, hands-on experience that these programs seek to provide depends heavily on equipment similar to that actually used in industry.

Community Colleges and Local Initiatives

In recent years, community colleges have expanded more rapidly than any other segment of higher education. Many offer engineering technology, as well as preengineering programs that send students on to universities. Moreover, community or junior colleges and vocational-technical schools train many of the technicians who take jobs in U.S. industries like electronics. While the number of students earning associate degrees in technical fields has grown in the last decade, there is little information on the quality of these programs. Some offer up-to-date training in needed specialties, while others are accused of turning out people for jobs that have already disappeared.

Public 2-year and community colleges face chronic problems in funding their programs and retaining faculty.[23] Even in Silicon Valley (the area near San Francisco where so many electronics firms have located)—which is now getting a great deal of attention as a model for industrial development—these institutions have never been well-integrated into the local environment, and seem isolated from industry as well as from the mainstream of university-oriented education.[24] Despite the concentration of electronics companies, the six community colleges in the area have faced severe shortages of equipment for student laboratories, and a relationship with industry in which each group seems generally supportive of the other but in which the various parties do not always manage to communicate or cooperate effectively.

Only a few States or localities have thus far attempted to meet needs for technology-based

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deal of confusion persists concerning the role and function of technology education—not surprising when associate programs graduate men and women trained essentially as technicians, while a B.S.-level technologist is much closer to an engineer.

Differences in academic standards among technology programs may be even greater than in engineering. In contrast to countries like West Germany, where all technical universities are held to similar standards, quality in American engineering and technology programs varies widely, even among those that are fully accredited.

[23] "Science and Engineering Education for the 1980's and Beyond,'" op. cit,, p. 93.

[24] E. L, Useem, "Education and High Technology Industry: The Case of Silicon Valley," Institute for the Interdisciplinary Study of Education, Northeastern University, Boston, Mass., September 1981, pp. 12-18. Useem's study, based on more than 100 interviews, finds that neither educators nor companies are responding very well to the regions educational needs—particularly at the secondary level.

Photo credit Ted Spiegel 1983

Computer-assisted test to determine design data on metal fatigue

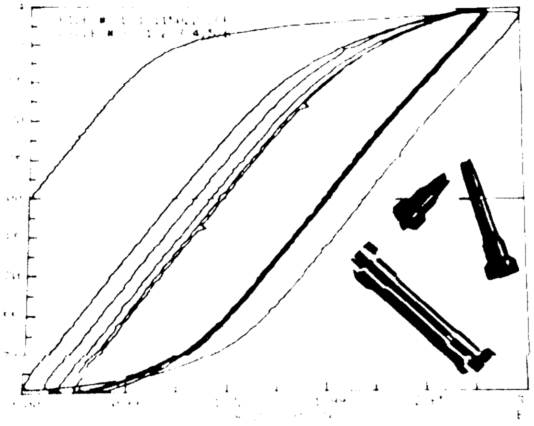

Photo credit: Ted Spiegel. 1983

Results of test shown in adjacent photograph. Many engineering schools have had difficulty in acquiring modern equipment of this type education and training outside their college or university systems. North Carolina has established a Microelectronics Center linking several universities and industry at Research Triangle Park near Raleigh; the State has also set up the North Carolina School of Science and Mathematics for high school students with unusual ability. But this is more the exception than the rule, and budgetary constraints in many localities may limit further development of nontraditional alternatives.

Continuing Education

Ongoing education and training for engineers and other technical workers—including those without degrees—is a vast and amorphous activity, Colleges and universities enroll large numbers of students in graduate or continuing education programs, some of whom take only a few courses while others actively pursue degrees. Such programs, many of which cater to part-time and evening students, face problems paralleling those of undergraduate engineering and science curricula. The low visibility and lack of prestige of continuing education aggravates the difficulties; faculty turnover is high, quality uncertain. For example, enrollments in New York University's adult education courses in computer programing have been increasing by 20 to 25 percent per year, but budget limitations have made it difficult to purchase needed equipment, as well as to find and keep competent faculty.[25] This situation is replicated in private and public colleges and universities throughout the country.

Many professional societies are active in continuing education, principally through short courses—sometimes offered in conjunction with universities—on topics of interest to their members, Current favorites in electronics include microprocessor-based systems, and programing in newer computer languages like Pascal. Colleges and universities offer their own short courses, as do private, profit-seeking enterprises. Some companies have operated educational arms—e.g., RCA Institute. Short courses and related noncredit programs vary widely in quality and rigor. Some hold to high standards, others offer little more than can be gleaned from trade magazines.

Although many firms offer on-the-job training and continuing education for their engineers, scientists, and technicians, it is impossible to generalize concerning the extent and effectiveness of such efforts. Some companies allow employees to spend several hours per week taking college courses on company time; others will pay tuition provided the student gets a good grade. Some develop in-house programs. Others refuse any assistance, relying entirely on individual initiative. Some organizations have a companywide policy covering continuing education; in other cases, decisions are left with lower level supervisors. In many companies, internal training programs are intended primarily for new employees; in other instances, firms organize or support programs aimed at a broader slice of their work force. While extensive in-house training is most common in large corporations, smaller electronics firms have also been turning to such efforts to help meet their manpower needs,

Beyond case-by-case insights, the overall dimensions of company-run training programs in the United States are largely unexplored; the American Society for Training and Development estimates that business and industry allocate some $30 billion to $40 billion a year to education and training, but little information is available on how such moneys are spent, and by whom, or just what is counted in arriving at the total.[26]

Looking more narrowly at engineers and scientists, perhaps 10 to 15 percent of those with at least a bachelor's degree are taking further

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[25] G. Anders, "Colleges Faltering in Effort to Ease Critical Shortage of Programmers, " *Wall Street Journal,* Aug. 24, 1981, p. 15.

[26] Information from the American Society for Training and Development. Also "Addition to the Record: Statement of Anthony P. Carnevale, for the American Society for Training and Development, " *Projected Changes in the Economy, Population, Labor Market, and Work Force, and Their Implications for Economic Development Policy,* hearings, Subcommittee on Economic Development, Committee on Public Works and Transportation, House of Representatives, Nov. 18-19, 1981, p. 233. Carnevale notes that 35 percent of firms surveyed by the Conference Board offer remedial programs in reading, writing, and arithmetic for their employees.

academic coursework at any given time.[27] The great majority are probably recent graduates, with many of these pursuing advanced degrees on a part-time basis.

In electronics, a number of larger U. S. semiconductor firms—for example, Intel, which has also been a leader in the Semiconductor Industry Association's research cooperative—have instituted programs of on-the-job training for personnel at a variety of levels. Almost all semiconductor manufacturers evidently provide some training, but the intensity and length of the programs vary from company to company. Continuing education for electronics and computer engineers in Silicon Valley is readily available for students who can meet the entrance requirements of schools like Stanford or the University of California at Berkeley; Stanford has also pioneered interactive television links enabling it to offer in-plant courses throughout the area. However, local electronics companies—with a few notable exceptions like Hewlett-Packard—have had little involvement with secondary-level public education in Silicon Valley, and most of the interactions with universities seem to center on the elite institutions where faculty consulting strengthens ties with industry. [28]

Semiconductor firms are not alone in offering in-house training to their employees. Some electronics manufacturers report that, during their initial year on the job, new employees spend up to 7 hours per week in formal coursework.[29] Hughes Aircraft's training program for new graduates in electrical engineering is especially comprehensive. so Bell Laboratories and IBM are also well-known for continuing education and training; low employee turnover at large companies like Hughes or IBM favors investment in human resources just as it does in Japanese electronics firms. In contrast, smaller U.S. semiconductor manufacturers may have annual personnel turnovers of 35 percent or more; such companies are understandably reluctant to devote resources to training men and women who may then jump to competing firms. High turnover rates in electronics hold for grey-collar technicians as well as engineers.[31]

In contrast, organizations like Bell Laboratories can finance continuing education for employees—even send them back to school full time—with less fear that people will quit once they have a new M.S. or Ph.D. in hand. In part, this is simply because many engineers and scientists view Bell Labs as an exciting and prestigious place to work; for some, it is more a goal than a stepping stone, Bell supports part-time graduate study at local universities, as well as full-time, on-campus programs at a number of leading engineering schools; the company also offers a variety of in-house training activities, plus a tuition reimbursement plan for employees pursuing undergraduate or vocational training. [32]

While it is thus true that a considerable number of American engineers and scientists elect to take additional academic coursework, many individuals make such commitments independently, often with little or no encouragement from their employers. Smaller companies, and some large ones, often feel that they cannot afford to support such efforts–i.e., that the payback would be insufficient. As the NSF/DOE study notes:[33]

> At present, continuing education is a fractionated, uncoordinated set of operations in which academia, industry, professional societies, and individual entrepreneurs pursue their own individual paths in response to what they perceive as their individual needs. There has been virtually no Federal support for con-

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[27] The figure was 13 percent for 1978. A somewhat larger nun]-ber took non-credit courses of various kinds, See "13a attelle Study Shows 80 Percent of Organizations Support Continuing Education for Scientists, Engineers, " *Information From Battelle*, Mar, 5, 1980.

[28] Useem, op. c it., pp. 9-12

‘Q’’ Employment in the [J, S Electronics Industry, Volume I," prepared for OTA by Sterling Hobe Corp. under contract No. 033-1210, p. 234.

[30] See R. Connolly, "(companies Still Short of EEs," *Electronics*, May 19, 1982, p. 105.

[31] See R. W. Comerford, "Automation Promises To tighten the Field-Service Load," *Electronics*, Apr. 7, 1982, p. 110. These turnover rates are good evidence that personnel shortages have been real and acute.

[32] " Educational opportunities at Bell Labs, " Education Center, Bell Laboratories, Holmdel, N.J., 1981.

[33] " Science and Engineering Education for the 1980's and Beyond," op. cit., p. 96.

tinuing education, in part because the costs of industrial programs have been regarded as business expenses.

Because retraining for midcareer engineers and skilled workers will be increasingly important in the years ahead, particularly in view of the aging of the American labor force, the Federal Government may need to reconsider its involvement.

The Government already plays an important role as direct employer. In 1978, nearly 90,000 engineers worked for the Federal Government, about 6 percent of the country's total engineering labor force. Many are employed by the Departments of Defense and Energy, and the National Aeronautics and Space Administration. The Air Force alone faces a shortage of over 1,000 engineers; if the Nation's defense budget is to increase during the 1980's **as** planned, demand for engineers—both within the Government and among defense contractors—will swell even further. Some have argued that engineering manpower shortages could jeopardize the country's security.[34] As one response, the Defense Communications Agency is planning **a** National Science Center for Communications and Electronics, intended **to** help cope with the shortfall in the defense community. Funded with the aid of corporate contributions, the Center, to open in 1983, will develop education and training courses for participating secondary schools and universities. as

Over the past several decades, nearly half of all U.S. engineering students have received financial assistance of one sort or another from the Federal Government. Funds for laboratory equipment intended for teaching and research, as well as for curriculum development, have come from Washington—for science and engineering, principally through the National Science Foundation. Tight *Federal budgets for education may have the unfortunate consequence of shrinking the pool of graduates in engineering and science, and their quality, at a time when the United States already finds that it does not have enough skilled professionals to staff its commercial industries or meet its military needs,*

University and Continuing Education In Japan

If Japanese secondary school students study mathematics and the sciences more extensively than their counterparts in the United States, at the university level Japan's educational system is inferior. Postsecondary education expanded rapidly over the postwar period; many private colleges were founded, some with low standards. While the small group of elite universities provides more rigorous training, they have faced the same criticisms as Japanese secondary schools—excessive reliance on rote learning and the acquisition of facts, rather than more general skills in analysis and synthesis. In neither science and mathematics, nor in engineering, does the quality of university-level education in Japan match that in the United States.

Engineering

Electrical engineering students in Japan spend many hours in the classroom and laboratory, and take a series of courses rather like that of Americans, but Japanese companies continue to find graduates unprepared to go to work, while faculty members point to major weaknesses in curricula.[36] Programs in engineering and computer science leave little room for unstructured or independent learning. Electives are limited. Students tend to work in groups; according to critics, this fosters conformity at the expense of creativity and individual initiative. The education that Japanese college students receive outside their technical fields, moreover, is less demanding than here. Deficiencies in higher education are among the reasons that Japanese companies place great stress

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[34] "Testimony of Gen. R. T. Marsh, Commander of Air Force Systems Command," *Engineering Manpower Concerns,* hearing, Committee on Science and Technology, House of Representatives, Oct. 6, 1981, p. 11. Perhaps one-quarter of the country's engineers work in defense-related fields.

's'' The NSCCE: A New National Program, " *Electronics,* Dec. 29, 1981.

[36] S. Tubbs, "Electrical Engineering at Kyoto University, " *Engineering Education,* May 1982, p. 812; T. Sugano, ''Preparation of New Electronics Professionals in Japan: Note for Presentations Given at the Japan Society Meetings of May 1, 1981, in Palo Alto, Calif., and of May 4, 1981, in New York. "

on internal training—they must, simply to bring new employees up to a satisfactory level of competence.

Far fewer engineering students in Japan go on to the graduate level—either M.S. or Ph.D. —than in the United States. Table 69 illustrates the stress on undergraduate training and the comparatively small numbers in graduate school. In 1980, undergraduate enrollments in Japanese engineering programs were almost the same as those in the United States, but the number of graduate students was about four times less.[37] Those students who do choose to attend graduate school find that—as in undergraduate programs-course work and research are less rigorous than in American universities.

As the figures in table 69 suggest, while academic competition is keen at secondary levels, with Japanese students vying for places in the most prestigious universities, postgraduate training brings few rewards. Because corporations in Japan rely heavily on in-house training to impart job-related skills, and because research does not have the prestige that it carries in the United States or Europe, Japanese engineers have little incentive to go on to graduate school. Patterns are similar in other professions. Graduate work in business or law is a popular road to career advancement in the United States, but not in Japan, where business schools are virtually nonexistent and lawyers form a miniscule part of the labor force.

Table 69. —Enrollments in Japanese Colleges and Universities

	Number of students, 1980				
	Junior college	Technical college	University	M.A./M.S	Ph.D
Engineering	20,100	46,300	337,800	14,900	2,400
Physical science			54,600	3,740	2,590
All other programs	346,100	—	1,349,100	17,160	13,210
Total	366,200	46,300	1,747,500	35,800	18,200

SOURCE Kagaku Gijutsu Benran (Indicators of Science and Technology Kagaku Gijutsucho Keikakukyoku (Science and Technology Agency, Planning Bureau) 1981 pp 100103

Continuing Education and Training

Despite the self-criticism that Japanese level at their institutions of higher education, the performance of the country's engineers and scientists across many fields, along with the demonstrated competitiveness of Japanese corporations in high-technology industries like electronics, demonstrates that the system, taken as a whole, functions well. Indeed, some of the self-criticism appears to be no more than a mechanism for urging people and organizations to greater efforts.

Deficiencies in universities are at least partially offset by informal mechanisms for self-education, as well as company-run training programs. western observers repeatedly note that men and women in Japan are voracious readers with a strong penchant for self-study, The average Japanese not only spends more time reading than the average American, but more of what he reads is job-related. The spread of quality control methodologies through Japanese industry, outlined in chapter 6, depended heavily on self-study through books, magazines, and radio and TV broadcasting. The national broadcasting company, NHK, transmits nearly a hundred educational programs to attentive audiences each week, including the popular "science classroom" series.

Japan's Government also provides free training for recent high school graduates, as well as for workers who need improved skills before they can join or rejoin the labor force, Over the years, courses taken by those in the second category—adults already in the job market—have expanded greatly. They fill many of the same functions for smaller companies as the in-house training programs conducted by large corporations. Data collected by the Ministry of Labor indicate that more than 200,000 trainees were enrolled in publicly supported vocational programs in 1977, although the content of these

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[37] American engineering schools enrolled 72,600 M.S. and Ph.D. students in 1980, about 40 percent on a part-time basis—"Engineering Enrollments, Fall 1982, " op. cit. Although only 337,800 undergraduates were enrolled in Japanese engineering schools compared to nearly 400,000 in the United States, the retention rate is much higher in Japan. Once admitted, Japanese students face far fewer hurdles than Americans, and a higher percentage graduate.

programs has been criticized for not keeping up with the needs of industry.[38]

Company-Run Training Programs

Internal training and continuing education comprise an integral part of organization and management in larger Japanese companies. This is perhaps the most fundamental difference between the Japanese and American approaches to technical education. While many American corporations engage in such activities, Japanese programs are much more comprehensive, Developed in part to compensate for deficiencies in formal education, training has evolved to complement employment patterns in which many employees spend their entire careers within a single organization.

Of course, not all Japanese firms or workers fit this pattern. Table 70 shows that big companies provide much more training than small. One reason is that managers are generally rotated within large organizations, a practice often accompanied by study programs. More important, long-term employment within a single firm—sometimes called "lifetime" employment—is the rule only in the major corporations (and then only among male employees).

While training programs within Japanese companies generally impart specialized skills—e.g., computer programing—they serve other purposes as well, purposes that may seem paternalistic or coercive to Western observers. For example, corporations rely on in-house training to help build a sense of loyalty to the group and to the organization.[39] The widely remarked cooperative spirit of Japanese employees is no accident.

well-known features of Japanese organizational structures such as quality control circles also serve a training function, one in which the informal elements—and the stress on intergroup cooperation—are at least as important as any knowledge imparted. In an unusually comprehensive program in a Japanese automobile plant, engineers teach other employees in a "workshop university."[40] After completing an extensive program of after-hours study—2 years or more, with no special remuneration—the workshop university graduate is rewarded with a certificate from his section chief. The aim is not only to improve individual skills, but to keep employees intimately involved in day-to-day matters that affect productivity and manufacturing efficiency—ranging from workplace organization, job flows, and task descriptions to interpersonal relations.

Among the most systematic of the industrial training programs in Japan have been those developed by leading manufacturers of electronics and electrical equipment, Since the 1920's, firms such as Mitsubishi Electric and Matsushita have been known for recruiting promising young employees directly from high school, and giving them extensive and formalized in-house training." Such programs emerged in response to shortages of qualified workers in the aftermath of World War I. Japan's Government fostered universal primary education, but

Table 70.—Distribution by Size of Japanese Firms Providing In-House Training

Size of company by number of employees	Proportion of companies with training programs (as of 1974)
1,000 or more employees . .	95.1 0/0
500-999	85.3
300-499	75,9
100-299	58.8
30-99	26.3
5-29	10.1
All firms	41 .3 "/0

SOURCE' H. Shimada, *The Japanese Employment* System, Japan Institute of Labor, Industrial Relations Series, Tokyo, 1980. Based on data from Ministry of Labor, *Jigyonai Kyoikukunren Jisshi Jokyo Chosa* (Survey of Intra-Firm Vocational Training and Education), 1974

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[38] H. Shimada, "The Japanese Employment System, " Japan Institute of Labor, Industrial Relations Series, Tokyo, 1980, p. 21.

[39] For a detailed analysis of training within a Japanese bank, see T. P. Rohlen, *For Harmony and Strength: Japanese White-Collar Organization in Anthropological Perspective* (Berkeley, Calif.: University of California Press, 1974). In the bank studied by Rohlen, some of the training programs emphasized technical skills while others were directed at "character building. " Both varieties were designed to help integrate workers into the corporate community. Over the course of a year, about one-third of the staff went through one or more programs at the bank's own training institute,

For a comprehensive treatment of training practices at Toyota, see R. E. Cole, *Work, Mobility, and Participation* (Berkeley, Calif.: University of California Press, 1979).

[40] *Work, Mobility, and Participation*, op. cit., pp. 183-184.

A: Levine and Kawada, op. cit., p. 267.

during that period gave little attention to secondary schooling. Vocational training was left to the private sector, where companies designed their own programs to train the workers needed for expansion and industrialization. If the government had pursued a more comprehensive manpower policy, including the support of secondary and vocational education, Japanese firms probably would not have moved so far in this direction.

Initially, then, internal training was a direct response to shortages of skilled labor, and effort was directed at blue- and grey-collar workers rather than managers or engineers. Despite vast improvements in Japanese secondary education since the 1920's, most large companies retain—indeed have continued to develop—these programs. Many operate their own educational institutes; Hitachi, for instance, maintains two, sending graduates of technical high schools for year-long courses of study.[42] The company, which is not untypical, also offers a large number of specialized training courses on an ad hoc basis. Hitachi has given more than 1,000 over the past two decades (some many times); they include foreign languages and topics in management, with specialized subjects such as international business available for executives. As Students in a typical course spend 30 hours in the classroom and twice that on outside assignments; the average skilled worker or technical professional at Hitachi takes two such courses a year,

It is difficult to compare the direct costs of such activities with the corresponding benefits to the firm. But even in large organizations with extensive training programs, such as Toyota, expenditures reportedly total less than 1 percent of salaries and wages.[44] The returns—tangible and intangible—appear substantial.

International Differences in Education and Training

A principal conclusion from the preceding sections is that, while American universities continue to provide an excellent education for this country's engineers and scientists—as witnessed by the large numbers of foreign graduate students who come here to study—the *average* American high school or college graduate is poorly prepared to function in a technologically based society. Compared to their counterparts in a number of other advanced industrial nations, American students get less training in mathematics and science, and even if they study these subjects, learn virtually nothing about technology.

Deficiencies in mathematics are particularly serious. Mathematics acts as a filter at the entrance to many careers, Although the importance of mathematics to the practice of engineering is sometimes exaggerated, a high level of competence relative to the average is needed to complete a degree program. A student who does not master algebra and trigonometry in high school drops immediately into the class of those needing remedial work; he or she will not be admitted directly into a university program in engineering or science, Those with deficiencies who try to catch up often fail. Part of the problem is simply that as many as one-fourth of high school teaching posts in mathematics are currently vacant, and a comparable fraction are filled by individuals only temporarily certified to teach, many of them marginally qualified at best.[45] Industry has hired away many high school mathematics teachers at attractive salaries, in part to fill vacancies for computer programmers and systems analysts.

The American educational system also does a poor job of preparing those who do not go to college. Even among high school graduates, functional illiteracy is common (estimates for the population as a whole range around 20 percent). Vocational education and training vary

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[42] R. Dore, *British Factory—Japanese Factory* (Berkeley, Calif.: University of California Press, 1973), p. 65.

[43] M. A. Maguire, "Personnel in the Electronics Industry: United States and Japan," prepared for OTA under contract No. 033-1360, pp. 54-56. (In training for managers in Japan, see T. Amaya, "Human Resource Development in Industry,)' Japan Institute of Labor, Industrialized Relations Series, Tokyo, 1983, pp. 21-24.

[44] *Work, Mobility, and Participation*, op. cit., p. 185.

[45] ' A Science Dean Describes Teaching as in Sorry State," *New York Times*, Mar. 6, 1982, p. Cl, Shortages of teachers in science as well as mathematics appear to be worsening; see Science *and Engineering Education: Data and Information*, op. cit., p. 7.

widely in quality; excellent programs and inadequate ones can be found virtually side-by-side.[46] Other countries have developed more coordinated and comprehensive approaches to vocational training, with benefits both to individual workers and to industry. [47]

Skilled technical workers are a vital resource for the U.S. electronics industry, and deficiencies throughout the middle levels of the American labor force could constrain the future growth and development of semiconductor and computer firms, as well as companies in other high-technology fields. Technicians, designers and draftsmen, and field service personnel must be literate, have basic quantitative and technical skills, and, ideally, understand something of the logic of the systems they work with. Without such abilities, they cannot use advanced production and R&D equipment to greatest effect, nor exercise sound judgment in the technical problems they face on a day-to-day basis. Individuals without these skills have little upward mobility; an assembly line worker needs at least some quantitative facility to be able to move into jobs such as machine repair, quality control and inspection, or shop-floor supervision.

The demand for grey-collar technical employees in industries like electronics is high; one study has estimated a growth rate in the United States of nearly 18 percent per year, faster than the projected growth in demand for engineers.[48] But in pointed contrast to countries like Japan or West Germany, the American educational system has not responded in any large-scale fashion to these needs, In Germany, fully 60 percent of the labor force has specialized training in grey-collar technical skills, while in the United States the figure may be as low as 10 percent.[49]

A scarcity of adequately trained technical workers could be just as serious a problem for American industries like electronics as constraints on capital investment or a stagnating overall economy. Labor mobility has traditionally been a mechanism for opening manpower bottlenecks; indeed, the U.S. electronics industry already depends heavily on foreign-born—though U.S.-educated—engineers. The next section looks more closely at the structure of the U.S. labor market, particularly mobility,

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[46] See, for example, G. W. Wilbur, ‘‘Va. Vocational Education Seen As Hindrance to Development,” *Washington Post, Nov. 29, 1982.*

[47] The extensive system in West Germany is described in *Vocational* ‘f’raining in *the* Federal Republic of Germany (Brussels: Commission of the European Communities, 1978). See also S. Hutton and P. Lawrence, *German Engineers: The Anatomy of a Profession* (Oxford: Clarendon Press, 1981), pp. 94-95; and J. M. Geddes, “Germany Profits by Apprentice System, ” *Wall Street Journal,* Sept. 15, 1981, p. 33.

[46]’’ Technical Employment Projections of Professionals and Paraprofessiona]s, 1981 -1983-1985,” American Electronics Association, May 1981; see also “Testimony of Robert P. Henderson, Chairman and C. E. O., Itek Corp., Lexington, Mass.,” *Forecasting Needs for the High Technology Industry,* hearing, Subcommittee on Science, Research, and Technology, Committee on Science and Technology, House of Representatives, Nov. 24, 1981, pp. 61-97.

4%. J. Prais, “Vocational Qualifications of the Labour Force in Britain and Germany, ” *National Institute Economic Review,* November 1981, p. 47; response of R. H. Hayes, *Business Management Practices and the Productivity of the American Economy,* hearings, Joint Economic Committee, May 1 and 11, and June 1 and 5, 1981, p. 46.

Supply and Mobility of Labor

Shortages of men and women with knowledge and skills at a time of high overall unemployment point to weaknesses in U.S. labor market policies, including manpower training and adjustment assistance. so While “full employment” has been a policy goal for many years, the upward trend of the unemployment rate over the past decade has combined with

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‘For a relatively comprehensive, and critical, analysis of labor market policies in the United States, see R. J. Vaughn, “The Job Development Administration: A National Employment, Education and Training Policy, ” *Projected Changes in the Economy, Population, Labor Market, and Work Force, and Their Implications for Economic Development* Policy, op. cit., p. 33. During 1981, perhaps 1 million U.S. jobs went unfilled, while 10 million people were without work, See K, Sawyer, ‘‘Learning Jobs in School, ” *Washington Post,* July 28, 1982, p. 1.

sporadic shortages of workers having specific skills to create a new circumstance, one to which the Federal Government has failed to respond.

Over its history, the United States has seen periodic labor shortages, for both skilled and unskilled workers. More recently, it has begun to seem that—even if the general quality of American education were to remain high–the labor market might simply not be able to supply the right numbers of people, in the right places, at the right time, There are a host of reasons for such concerns, ranging from changing attitudes toward work, to the aging of the U.S. population, to local constraints such as high housing costs, * As the work force ages, and the needs of the U.S. economy shift, retraining will be the only way to utilize people's talents fully.

This section asks whether the development of the U.S. electronics industry will be constrained by limited supplies of engineers and computer scientists (overall employment trends are examined in the next chapter), together with a related question: Are the high levels of labor mobility that have characterized some parts of the U.S. electronics industry essential for continued growth and competitiveness? The comparative neglect of training and retraining in the United States stems in part from the ease with which companies have been able to hire new employees with needed skills; this in turn has reinforced tendencies for workers to move from job to job in search of fresh opportunities or higher pay. The labor market in Japan functions much differently, There, the system emphasizes long-term employment (for some) and loyalty to the firm; mobility is low. Management practices in Japan have sought to compensate for the weaknesses of such a system, while taking advantage of the stability it brings; rather than looking for new people to revitalize faltering efforts, Japanese firms redeploy those they have.

Overall Labor Market Trends

The labor forces of Japan and the United States expanded swiftly during the 1960's, largely as a result of postwar baby booms. Table 71 shows the rates of increase in both countries to have been considerably greater than in Western Europe. Japan's labor force grew from 49 million in 1966 to 56 million in 1979, while that in the United States went from 79 million to 105 million over the same period.[51] Although Japan has experienced some labor shortages, the relative abundance of working-age men and women in both Japan and the United States contributed to economic expansion during the postwar period. Younger workers made up an especially large proportion of Japan's labor force during the 1950's. During the 1970-80 period, both countries continued to experience rapid increases in their working-age populations (table 71); growth in their labor forces will slow during the 1980's.

Rising employment levels in industrialized economies over the past two decades have been accompanied by shifts toward the service sector; agricultural employment has declined, with manufacturing roughly stable or declining slowly (see ch. 5, fig. 32). Japan has been something of an exception, with a rise in industrial employment coupled with a sharp drop in agriculture; both the industrial and the service sector grew as a result of migrations from the farm. Such trends will continue as in-

Table 71 .—Labor Force Growth in Several Countries

	Average annual increase in labor force	
	1960-70	1970-80
United States	1,80/0	1.5 %
Japan	1.3	1,3
West Germany	0,3	0.7
France	0.8	1.1
United Kingdom.	0.2	0.3

SOURCE 196070—W Galenson and K Odaka, "The Japanese Labor Market ," *Asia's New Giant*, H Patrick and H Rosovsky (eds) (Washington, D C Brookings Institution, 1976) p 590
1970-80—*World Development Report* 1980 (Washington, D C The World Bank, August 1980), p 147

"In Silicon Valley, a housing shortage has driven prices so high that semiconductor firms have found it difficult to hire from outside the area: few candidates can afford to move.

[51] *Labour Force Statistics* 1968-1979 (Paris: Organization for Economic Cooperation and Development, 1981), pp. 18-19.

dustrial employment in the advanced countries slowly shrinks relative to services.

It is perhaps understandable that, during a period of rapid overall labor force expansion and continuing movement into services, the U.S. Government paid little attention to manpower policies: the economy was growing rapidly; periods of high unemployment were viewed as transient; people could take advantage of a relatively broad range of opportunities. The situation today is much different: aggregate expansion has slowed; the skills needed by industry are more specialized; unemployment has become persistent. Current unemployment is especially troubling because it is caused in part by mismatches between the capabilities of people looking for work and the jobs available; in such circumstances, more rapid aggregate expansion may do little good, and may even be impossible if growth industries cannot hire the people they need.

Personnel Supplies for the U.S. Electronics Industry

In the United States, shortages of software engineers and semiconductor designers have been heavily publicized over the past few years. Not only has demand been high—even through the deep recession of 1982—but warnings of longer term shortfalls have been common. One educator predicted that American schools will graduate a cumulative total of 70,000 new B.S. degree-holders in electrical engineering and computer science over the period 1982-85, while nearly 200,000 will be needed.[52] As discussed in the next chapter, demand for computer service technicians is expected to double during the current decade, with job openings for programmers and systems analysts going up almost as fast.

A number of job-market surveys and estimates of aggregate demand for engineers have been conducted in the recent past. The Labor Department estimated that in 1980 there were 17,000 unfilled entry-level engineering positions throughout the Nation. Other estimates have ranged up to 25,000.[53] NSF's projections for engineers together with scientists indicate that the total supply of new graduates should meet the demand by the end of the decade. However, NSF may be overestimating the extent to which scientists can function in engineering jobs; in any case, shortages are anticipated even by NSF in the computer field, for statisticians, and in several engineering specialties. About one-third of the 1.4 million job openings in science and engineering over the 1978-90 period are expected to be computer related (including programmers). Despite NSF's relative optimism, other forecasts—admittedly often conducted by or for industry, and thus perhaps skewed by the preference of companies to be able to pick and choose when hiring new employees—have projected massive shortages of engineers, perhaps as many as 300,000 by 1990.[54] All such forecasts should be approached with considerable skepticism. None of the methodologies—whether based on simple trend analysis, on survey techniques (as for many of the engineering manpower studies), or on econometric models (as used by the Bureau of Labor Statistics)—has a good record for projecting employment; there are too many imponderable.

While forecasts and projections can warn of possible future shortages, insight also comes from current levels of unemployment in some occupations. Unemployment rates have been remarkably low in technical fields. During 1980, when overall U.S. unemployment averaged about 7 percent, only 0.6 percent of computer specialists found themselves out of work.[55] The unemployment rate for engineers

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[52] "Congress Warned of Shortages in Electric], Computer Engineers, " *Electronic News, Nov.* 23, 1981, p. N. The rather alarmist estimates were those of K. Willenbrock, Southern Methodist University.

[53] Henderson, op. cit., p. 63.

[54] Henderson, op. cit., p. 66; "Science and Engineering Education for the 1980's and Beyond, " op. cit., pp. 48-50, 60; M. A. Harris, "Manpower Surveys Continue to Disagree," Electronics, July 28, 1983, p. 108. NSF concludes that interfield mobility–particularly influxes of those trained in mathematics—will mitigate but not eliminate the shortage of computer specialists. One potential problem is that, even if the total supply of engineers roughly meets the demand, small firms with limited resources may still be unable to hire new people.

[55] *National Patterns of Science and Technology Resources 1982,* NSF 82-319 [Washington, D. C.: National Science Foundation, March 1982), p. 68. This amounts to only 2,000 people. While unemployment rates for professionals of all types are normally well below the overall unemployment rate, the 0.6 percent figure for computer specialists is unusually low.

(as a group) in 1980 was less than 1 percent; engineering unemployment averaged 1.8 percent over the decade of the 1970's, a period that included the aerospace "collapse, " when the unemployment rate for engineers reached 2.9 percent.[56] Aggregate unemployment levels during the decade averaged 6.2 percent, more than three times as high.

The persistence of unemployment rates far below the national average indicates that an "oversupply" of new graduates in engineering is unlikely. And, while mathematicians and physical scientists, as well as engineers, may sometimes have trouble finding the jobs they consider most desirable, men and women with training in such fields can move into a wide variety of occupations; many scientists eventually find themselves practicing engineering. It is hard to argue that the United States could have too many graduates of science, mathematics, or engineering curricula.

Data on salaries and job offers for new engineering graduates provide additional evidence of high demand. In 1981, engineers made up only 8 percent of new college graduates, but received more than 65 percent of all job offers—and at starting salaries twice as high as for those in the humanities.[57] Salary offers to engineers and scientists rose at higher rates than for other categories of graduates throughout the 1970's, Demand remained high even during the recession of 1981-82.[58]

Another indicator of personnel shortages is mobility across disciplines—the number of people who switch to fields other than those in which they got their formal education. Much of the demand for computer specialists has been filled by men and women with training in mathematics, engineering, and the physical sciences; fewer than one-third of those working as computer professionals have degrees in computer fields.[59] High turnover rates are part of the same picture; as noted earlier, turnover has been rapid among both engineers and technicians in the U.S. electronics industry.

Regardless of uncertainties in the projections, then, few people are worrying that the United States will have too many engineers in the years ahead; capable individuals with training in engineering comprise one of the most employable parts of the labor force. *The prospects of shortage are real in the sense that various projections differ mostly in the magnitudes of the shortfalls predicted.*

In contrast to the wide public awareness of potential shortages of engineers and computer scientists, supplies of grey-collar manpower have received remarkably little attention. Thus, it is impossible to discuss needs for technicians, service personnel, and other skilled workers in quantitative detail. But the situation for machinists illustrates the kinds of problems to be expected. The Bureau of Labor Statistics estimates that annual job openings will average 22,000 over the near future; meanwhile, in 1978 only **2,300** machinists completed registered programs of apprentice training.[60]

The Question of Mobility

Lateral mobility helps moderate sporadic shortages of workers with particular sets of skills. Just as clearly, individuals can only move within a limited realm; a surplus of physicists might help compensate for a scarcity of computer engineers, but few biologists would be able to function in such jobs.

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[56] Science *Indicators— 1980,* op. cit., p. 320. The peak year for unemployment among engineers was 1971.

[57] P. Abelson, "Industrial Recruiting on Campus, " *Science,* Sept. 25, 1981, p. 1445. The data comes from a survey by the College Placement Council covering more than 60,000 offers to new recipients of bachelor's degrees. The salary data also points out the big differences between industrial and academic starting salaries,

[58] In 1982, two-thirds of computer and office equipment firms surveyed by NSF reported difficulty in hiring electrical and computer engineering graduates, as opposed to 95 percent in 1981, See "EEs Still Needed, Though Shortage Has Eased, Says NSF," *Electronics,* Jan, 13, 1983, p. 69.

[59] " Science and Engineering Education for the 1980's and Beyond, " op. cit., p. 39. This reflects in part the slow development of academic programs in computer science and engineering.

[60] S. Qualtrough and J. Jablonowski, "Filling the Need for Skilled Workers, " *American Machinist,* June 1979, p. 131. But see also N.H. Rosenthal, "Shortages of Machinists: An Evaluation of the Information, " *Monthly Labor Review,* July 1982, p. 31. Although the electronics industry employs machinists, far greater numbers work in heavier manufacturing industries, Regardless of the statistics, a good deal of anecdotal evidence bears out the difficulty that manufacturing firms of all types have had in finding journeyman machinists, tool and die makers, and other skilled craftsmen.

American workers move within and across technical fields further and more frequently than their counterparts in other industrial nations. Managers and technical professionals change jobs much more often in the United States than in Japan; mobility is greater in Europe than in Japan, but still considerably less than here.[61] In the U.S. electronics industry, turnover has been high among unskilled workers, where unions have been weak, as well as among those whose abilities have been in high demand.

The effects of labor mobility cut several ways. It is little solace to a firm losing key people if they start a new enterprise that contributes to U.S. competitiveness. At the same time, organizations with low rates of personnel turnover—in any country—must guard against stagnation, find ways to generate new ideas; this is one of the reasons for internal training and job rotation programs in Japan, The pluses and minuses of high or low rates of labor mobility depend on factors such as rates of technological change, current economic conditions, and corporate strategies.

Patterns of mobility across industries and countries depend, among other things, on incentives such as promotion policies and wage/benefit packages; managements have considerable latitude in tailoring these to enhance or discourage turnover. Government programs dealing with adjustment—e.g., training and retraining, unemployment assistance—also act as incentives or disincentives. While generalizations emphasizing cultural differences are sometimes advanced to explain mobility patterns in the United States as compared to Japan, examining incentives—and the ways in which public policies affect them—provides a sounder basis for understanding. Although Japan's labor force tends to be less mobile than that of the United States, a good deal of variation exists across industries and firms in *both* countries.

Labor Force Mobility in the United States

The United States draws strength from the mobility of its labor force, not only in moderating skill shortages, but as a stimulus to innovation, technology diffusion, and entrepreneurship. New firms in rapidly growing segments of electronics—semiconductors, computer software and peripherals—are often built around engineers and managers who leave one company to start another. On the other hand, rapid staff turnover, as pointed out above, works against company-run programs of education and training. In part to counteract the attractions of entrepreneurial ventures, a number of large and successful American electronics firms—including Hewlett-Packard, Texas Instruments, and IBM—have adopted personnel policies aimed at retaining their employees. Likewise, merchant manufacturers such as National Semiconductor and Intel attempted to maintain staffs and avoid layoffs during the semiconductor sales slump of 1981-82. In this regard, American electronics manufacturers are quite consciously emulating their Japanese competitors.

Still, white-collar mobility has been a sine qua non of the more dynamic merchant semiconductor firms, which have competed aggressively for both technical and managerial talent, Silicon Valley manufacturers have offered a wide range of benefits, including extensive recreational facilities, to recruit white-collar professionals. Some have even paid bounties to employees who bring in new people, prospects for rapid advancement—and the lure of someday getting in on the ground floor of a new organization—have helped attract managers and engineers, as has the California setting, The mobility of talented people has helped diffuse electronics technology, contributing to rapid commercialization of new developments —which in turn has helped build an internationally competitive industry.

The lawsuits occasionally filed against ex-employees by firms seeking to prevent leakage of their technology are among the more strik-

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[61] On West Germany, see *German Engineers: The Anatomy of a Profession,* op. cit., p. 48ff.

Photo *credit* *Ted Spiegel, 1983*

Many electronics technicians get their original training in the military

ing illustrations of the relation between personnel mobility and technology diffusion, Motorola's unsuccessful 1968 case against executives who went over to Fairchild was an early example. In 1980, Intel sued a group of former employees who left to start a company named Seeq; the basis of Intel's suit, which ended in a negotiated settlement, was that the ex-employees intended to base part of their business on trade secrets dealing with the design and manufacture of large-scale programmable ROMs (read only memories).[62] Legal action to prevent technology outflows is an extreme case; more commonly, firms adopt positive programs of rewards and incentives to keep valuable employees, Again, the semiconductor industry has been a leader—helped by a working environment that many employees find stimulating. Of course, features that help retain people also serve a company well in attracting new employees,

Turnover has also been high among unskilled blue-collar workers in many parts of the U.S. electronics industry. In domestic semiconductor plants, production employees tend to be female and ethnic. According to one estimate, women make up 40 percent of the Silicon Valley work force, and are heavily concentrated in lower paying jobs; three-quarters of assemblers are women .[63] In contrast to the mobility of top-echelon managers and technical professionals, turnover among unskilled production workers is associated with a lack of skills; they can be laid off during business slumps and replaced later.

Mobility in Japan

The stereotype of Japan's "lifetime" employment system contrasts sharply with patterns in the U.S. electronics industry. According to the popular view, the Japanese system ensures job security until retirement. Also part of the stereotype is a sequence of promotions based largely on seniority rather than merit, with employees waiting patiently to move up the pay scale, assured of their ultimate reward. These aspects of the Japanese system have been viewed as integral parts of a company-as-family model, making unions in the American or European style superfluous. "Enterprise unions, organized on a company basis rather than by trade or occupation, have been seen as part-and-parcel of a socioeconomic milieu characterized by harmony among workers and managers—this in turn leading to low interfirm mobility coupled with high employee motivation and productivity. While pieces of this model are visible within Japan's economy, it

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[62] S. Russell, ''s~(;q Loses B id for Rehearing,'' *Electronic News*, Jan. '25, 1982, sec 1, p. 50

[63] R. Howard, "Second Class in Silicon Vane\," *Working Papers*, September-October 1981, p. 25, See also M. Chase, "Semiconductor Firms Get Mixed Review on Safety in Study by (California Agency" *Wall Street Journal*, Jan. 1, 1982, p. 6.

applies to only **a** minority of the labor force; moreover, the stereotype obscures crucial details that affect the working lives of all Japanese.

To begin with, labor relations were far from smooth in Japan as recently as the 1950's. Furthermore, lifetime employment is typical only of large Japanese companies, and many of these encourage their employees to retire at a relatively early age—commonly around 55 or 60. Afterward, many "retirees" must find new work—which may turn out to be a part-time or lower paying job with a subsidiary of their former employer—because retirement benefits are low.[64] Moreover, in small firms especially, but also in large enterprises, Japanese workers *do* leave their jobs, Horizontal mobility—i.e., movement from one firm to another without advancement—is fairly common among younger Japanese workers, particularly those with low skills, Women seldom have much job security or upward mobility, much less the many temporary employees that are another feature of Japan's labor market.[65] Women are generally encouraged to resign upon marriage—certainly at childbirth—and if they return have no seniority. The 3.4 million temporary and day workers, men and women—accounting for about 6 percent of the work force–are the first to be let go in the event of recession. Temporary employees provide flexibility to cope with economic slumps without laying off regular workers, The proportion of temporary employees in Japanese manufacturing firms has increased markedly since the recession of the mid-1970's.[66] Furthermore, although corporations in Japan attempt to adjust to business downturns by reducing working hours before laying off regular employees, when recessions deepen—as in 1974-75—they reduce employment levels at rates quite comparable to those in Europe, if not the United States. Smaller Japanese companies have seldom been reluctant to cut back their labor forces.

Nor does the stereotyped picture of seniority-based wages in Japanese corporations (the *nenko* system) hold up under scrutiny. One study finds that promotion is based on a "compromise" between seniority and ability, the particulars varying considerably across firms.[67] Smaller, more rapidly growing organizations tend to emphasize meritocratic promotion, while older, established firms remain less willing to single out talented individuals from others of their age group. Age and ability are, furthermore, weighted differently depending on level, with progress in the upper ranks a stronger function of ability. Clark concludes that the ambiguity built into Japanese promotion practices encourages people to do their best: while promotion has generally been automatic after a certain period of service, there is also the possibility that outstanding performance will be rewarded with rapid advance. And, although the *nenko* system may appear to underpay well-trained and able young workers, over the longer term they can expect to attain salary levels well above those in their age bracket who have lower skills or less education; salary profiles for older male workers in Japan show considerable spread.

Finally, **as** the Japanese labor force has aged, employment practices have begun to change. With the fraction of older workers increasing, salary competition for the best qualified recent graduates will intensify; recent surveys of hiring suggest that, in certain fields, including electronics, shortages of younger employees are likely. Data compiled by the Ministry of

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[64] Japanese electronics firms, along with the rest of Japanese industry, have been under some pressure to extend retirement ages. In the mid-1960's, retirement in the major electronics firms was generally compulsory at 55 to 57 for men, perhaps *50* for women. By the mid-1970's, many companies had extended these ages by about 5 years. See S. Takezawa, et al., *Improvements in the Quality of Working Life in Three Japanese Industries* (Geneva: International Labour Office, 1982), pp. 66-67, 95.

[65] A. H, Cook and H, Hayashi, *Working Women in Japan* (Ithaca, N.Y.: Cornell University Press, 1980). See also F. Ginsbourger, "Japan's Dark Side," *World Press Review*, July 1981, p. 32.

%.-y. Lin, "Wage-Price Behavior Under External Price Shocks and Productivity Slowdown: A U.S.-Japan Comparison, " Discussion Paper No. 402, Economic Growth Center, Yale University, April 1982, p. 22a.

[67] R. Clark, *The Japanese Company* (*New* Haven: Yale University Press, 1979), pp. 115-116. On the development of the *nenko* system, see T. Inagami, "Labor-Management Communication at the Workshop Level, " Japan Institute of Labor, Industrial Relations Series, Tokyo, 1983. Inagami also includes data on promotion patterns (pp. 10-14).

Labor indicate that younger Japanese workers can choose between two or three entry-level jobs, but those aged 55 and over must win out over 5 to 10 other jobseekers to find a position.[68] As a result of such trends, wage compression for older employees seems likely to intensify, retirement ages may be extended further, and the role of seniority in promotion decisions will diminish. Generational conflict between younger employees, for whom high demand will push up salaries, and older workers who stand to lose by comparison, may follow.[69] If and when such events come to pass, the features that now make the Japanese employment system seem unique will stand out less.

The United States and Japan Compared

While the contrasts are often exaggerated, Japanese and American employment practices do lead to quite different patterns of mobility. HOW do these interact with the structures of the electronics industries in the two countries to affect international competitiveness? Firms in each nation have alternatives in seeking the people they need. One option is to hire employees away from other companies, an approach more likely to be successful in the United States. An alternative is *internal* recruitment—intrafirm mobility—in conjunction with retraining, an avenue particularly appropriate in a system such as Japan's, where people tend to identify more strongly with the corporation than with a vocation or profession. Still another method of coping with shifting occupational needs is to alter or expand the potential pool of new entrants. Despite the vitality that the U.S. electronics industry has drawn from employee mobility, there is no need to associate either high mobility or a lack of mobility—in and of themselves—with enhanced competitiveness; nor should high mobility be considered more "modern" than low (or vice versa). High mobility in the United States goes with other aspects of the U.S. economy, just as low mobility is consistent with Japan's socioeconomic environment.

Public policies influence the choices made by corporations among the options outlined above. Government support for training technicians can enlarge the talent pool. Vigorous manpower policies, designed to support expanding sectors of an economy, will stimulate interfirm and interindustry mobility, Tax writeoffs for company-run programs of education and training would encourage intrafirm mobility, High turnover rates have made American corporations wary of investments in training or retraining that may pay off to their competitors. "Talent raiding''—so characteristic of American semiconductor firms—often becomes the alternative.

Employment practices in the United States may change as a result of the demographics of aging, just as the aging of the Japanese labor force is altering patterns in that country. As the U.S. population grows older, continuing education for those in midcareer—blue- and grey-collar workers, as well as white-collar professionals—will become a necessity, When the labor force was expanding rapidly, employers could count on new graduates to fill many of their needs; this is less true today, particularly in light of current inadequacies in technical education, American firms may find themselves emulating the internal training efforts of their Japanese competitors, with management practices designed to enhance a company's human resources becoming critical elements of corporate strategy. The remainder of this chapter turns to questions of management and the organization of the workplace, asking—among other things—whether there really is a uniquely Japanese approach to management.

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[68] Clark, op. p. 32.

[69] R.E. Cole, "Changing Labor Force Characteristics and Their Impact on Japanese Industrial Relations, " *The Paradox of Progress*, L.E. Austin (ed.) (New Haven, Corm,: Yale University Press, 1976), p. 194.

Organization and Management

As the end of the 19th century brought rapid economic growth and technological change to American industry, new management techniques arose to deal with shopfloor organization. The old ways, developed during the days of hand work, proved a poor guide to factory production using mechanized equipment, particularly in the emerging mass production industries

Frederick W. Taylor, founder of the scientific management school, is the best remembered of those who pioneered new methods.[70] Taylor began as an engineer at an ironworks, and his approach to management—including plant layout and job flows, and the man/machine interface—reflects the bent for rationalization associated with his profession. While Taylor himself, and the techniques he developed and advocated around the turn of the century, showed considerable appreciation for the human element in factory work, many of his followers carried scientific management to the extreme of treating people as another variety of machine, Scientific management still bears this stigma—and "Taylorism" is a dirty word for many who associate it with the Chaplin of *Modern Times*.

Taylor believed that, for every task in manufacturing, there was an optimum method that could be "scientifically" discovered. By reducing each job to its essential elements—employing, for instance, the techniques of what has come to be known as time-and-motion study—the workplace was to be rationalized and productivity maximized. Although Taylor thought that this approach should also increase cooperation among workers, one of the chief criticisms of scientific management has always been its rather mechanistic conception of the individual, leading to an emphasis on simple, repetitive tasks,


Photo *credit: Westinghouse*

Integration of programmable robots into the factory environment poses a new set of problems for manufacturing industries

The idea of a scientific means for organizing factory work attracted American businessmen. New machine tools, the assembly line, mass production of durable goods like bicycles, home appliances, and automobiles, presented a rapid succession of new problems; industrialists eagerly embraced Taylorism as a means of dealing with them. The management science movement springing from Taylor's early work has continued to thrive and to spread internationally; it still shapes curricula and textbooks in American business schools and industrial engineering programs.

The human relations approach to management was developed primarily by industrial psychologists, beginning a decade or two later,

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[70] F. W. Taylor, *The Principles of Scientific Management* (New York: Norton & Co., 191 1). N. P. Mouzelis, *organization and Bureaucracy: An Analysis of Modern Theories* (Chicago: Aldine Publishing Co., 1967), gives a useful historical overview of various approaches to organizational management.

In contrast to the engineers who espoused Taylorism, the human relations school stressed peoples' attitudes and motivation as keys to productivity and manufacturing efficiency. Studies in the human relations vein explored the workplace as a social organization and the individual employee as a member of the group; practitioners saw their goal as fostering an amicable working environment, one built around the existing shopfloor culture. While advocates of scientific management tended to be antiunion, the human relations school accepted unions as an integral part of the social system of the factory,

Just as the reductionist tendencies of scientific management have been criticized, so the human relations approach has been faulted for its stress on harmony to the neglect of the real conflicts of interest characteristic of work life, and for overemphasizing small group behavior while failing to deal with the organization as a whole.

Variants of these two attitudes toward management—which reflect contrasting theories of organization—continue to proliferate. The two are based on fundamentally different notions of what makes organizations—whether factory, store, or office—function, and hence on methods for improving their operation. At present, the human relations approach has become identified with the popular view of Japanese management, but both schools have American origins. This is not, of course, to say that Americans cannot learn from foreign experience. Organizations in other countries have adapted management practices originating in the United States to their own needs, and it may be time for a reverse flow into American corporations.

Organizational Types and Management Styles

The Manager as Professional

In the United States, management is a discipline with its own graduate schools and advanced degrees; M.B.A. programs increased by an order of magnitude over the past two decades, and now graduate more than 50,000 men and women each year. In contrast to Japan and Western Europe, where top managers tend to move up from the ranks—and a few individuals still reach high levels having started on the shop floor-American firms, especially the larger, publicly held corporations, have tended to bring new employees directly into management-track jobs. Typically graduates of academic programs in business administration, some of them fill staff positions, others move quickly into middle management, Thus the management profession—with its extensive network of specialized academic programs—has become a principal vehicle for transmitting and validating the techniques used in American business.

Management training in this country prepares people for work in hierarchical organizations. Distinctions between those who plan and those who do the work are more sharply drawn in American corporations than elsewhere; this division—and the equally sharp distinctions between those responsible for production, or "operations, " and the rest of management—has increasingly come under scrutiny and criticism.[71] In contrast, Japanese and European business practices are rooted in on-the-job experience and company-run training programs. Management institutes exist, but are typically oriented toward the needs of midcareer executives seeking fresh perspectives.

While the ideal types of "American" and "Japanese" management are exaggerations that fail to capture the variety existing within the two countries, they nonetheless point to differing conceptions of the nature of modern organizations. The Japanese model is based on authority stemming from tradition and socialization; the American approach is less personal and more legalistic. Central to the Japanese model are group decisionmaking, cooperation between labor and management, and long-term tenure in an organization viewed as analogous

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[71] See ch. 6. The following pair of articles in the July-August 1981 issue of the *Harvard Business Review* are typical examples of this criticism: R. H. Hayes, "Why Japanese Factories Work, " p. 56, and S. C. Wheelwright, "Japan-Where Operations Really Are Strategic, " p. 67.

to a family. Ideally, these result in a well-integrated system, with human resources as the firm's most important long-term asset.[72]

Decisionmaking in Japan

Symbolic of the Japanese approach is the *ringi seido* (approval system), through which middle-level personnel obtain sanction and approval from the top echelons by circulating a document to which each person affixes his seal or signature.[73] The process yields systematic but slow "bottom-up" decisionmaking. A decision is final once the company president adds his seal; since many individuals participate, there is considerable communication—if not always true consensus—and, once the outcome has become apparent, little uncertainty. Contrasts are frequently drawn between the tendency of "individualistic" Americans to continue pushing their own views, even after contrary decisions by upper management, and the Japanese case—where, as the saying goes, "when the train leaves the station, everyone is on board. " The point is that whatever disagreements precede the *ringi* decision, they are supposedly buried afterwards, the policy fully supported by all.

While authority in a Japanese company is vested in the president, employees at many levels participate in the consensus-building process. Not all of them have the precise and well-defined responsibilities that characterize job descriptions in an American corporation. Ambiguity attaches to organizational structure in Japan, rather than to people as in the United States. The Japanese system does not involve much bargaining among managers and subordinates, nor is it participative in the sense often used in the West. In contrast to U.S. practice, where management decisions and business planning get detailed attention, the *ringi* system allows people throughout the firm to agree on generalities, with the specifics to be worked out later.

Group decisionmaking as embodied in the traditional Japanese approach is a good fit with corporate organizations that offer individual employees considerable security and involve them with the company outside their immediate duties and working hours, Company housing and recreational facilities, group outings and even vacations, along with internal training programs, can all be viewed as incentives for building loyalty among a fairly immobile labor force. In best light, the system is "wholistic" in orientation; in worst light, it is a sophisticated brand of industrial paternalism.[74] The widespread acceptance of company rather than craft or trade unions and the comparatively few days lost to strikes in Japan (table 72) indicate that this labor-management system—oriented toward consultation and conformity—has worked to the benefit of the corporations that have designed and implemented it. As table 72 illustrates, large numbers of workers participate in strikes even in Japan, but little time is lost because work stoppages are short, often serving functions that are at least partially symbolic.

Contrasts With the United States

Extensive involvement with the company outside normal working hours and group decisionmaking diverge markedly from patterns in the United States, where—rather than spreading responsibility for decisions through the organization—top management is expected to

Table 72.—Work Stoppages Due to Labor Disputes in Several Countries (1978)

	Total number of participants in work stoppages	Total number of employee work-days lost
United States . . .	1,600,000	39,000,000
Japan	660,000	1,360,000
West Germany . .	490,000	4,280,000
France	1,920,000	2,200,000
United Kingdom .	1,040,000	9,400,000

SOURCE: "Japan, An International Comparison —1980," Keizai Koho Center, p. 49.

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[72] N. Hatvany and V. Pucik, "Japanese Management and productility," *Organizational Dynamics*, spring 1981, p. 8.

[73] For a detailed description of the *ringi seido, see* M. y. Yoshino, *Japan Managerial System: Tradition and Innovation* [Cambridge, Mass.: MIT Press, 1968), pp. 254ff.

[74] As late as 1976, more than one-quarter of Hitachi's male employees still lived in company housing; the figure had been nearly 40 percent in 1967, See *Improvements in the Quality of Working Life in Three Japanese Industries,* op. cit., p. 69.

provide leadership. Corporate cultures in the United States give pride of place to strong-willed executives who leave their mark on an organization. Power, status, and privilege also attach to Japanese executives, but with real differences. The ability of managers to show immediate results—profitability over the next quarter being the current target of critics—is central to the American model, group effort to the Japanese. Well-defined and often narrow responsibilities, centralized authority, rigidly hierarchical organization charts—plus the possibility of swift promotion and high rewards—characterize the "results-oriented" management styles of American firms. Ambiguity is viewed as undesirable, expertise cultivated; men and women enter the firm as specialists in accounting or finance, marketing or strategic planning. Individualism is tolerated, but within well-defined bounds–witness the "white-shirt syndrome" still hanging over companies like IBM.[75] The comparatively high levels of personnel mobility in the United States, and the tradition of adversarial relations between unions and management, are part of this picture.

A further difference between Japanese and American management practices—discussed in more detail in chapter 6—is the emphasis companies in Japan place on manufacturing and its integration with the rest of the firm. Toyota's much-noted system of just-in-time (kanban) production and inventory control is only one example. Since Japanese managers tend to rise relatively slowly through the ranks, with periodic lateral moves, stress on manufacturing is perhaps natural. In contrast to the situation in the United States, where production—more especially quality control—has little prestige, is even viewed as a dead-end job, a number of Japan's top corporate executives began their careers as quality control or manufacturing engineers.

Both Japanese and American approaches to management have their strengths and weaknesses. Few corporations exhibit management styles as clear-cut as the stereotypes suggest; in both countries, firms have identities that may vary from division to division as well as changing over time. The wholistic orientation of the Japanese style carries strong paternalistic overtones, with discrimination against women and minority groups a fundamental part of the system.[76] And, although Japanese management is sometimes viewed as people-oriented, personal interactions are marked by pervasive if subtle status distinctions. Paternalism does lead to job security for some fraction of the labor force in Japan, security which is less common in the United States, The American approach, while often assumed to maximize opportunity, does so in part by encouraging competition—some would say to excess—among individuals seeking advancement and personal gain.

Comparisons of American and Japanese management often focus on particular techniques—e.g., quality control circles in Japan, management by objectives in the United States—rather than the schools of thought, such as scientific management or human relations, from which these techniques derive. But improvements in management seldom result from the isolated adoption of some technique. This quotation from a Japanese engineer points out the difference between technique and underlying attitude:[77]

> One difference I find hard to explain to my Western colleagues is that we do exactly the same things that the industrial engineer does in Detroit or Pittsburgh; but it means something different. The American industrial engineer lays out the work for the worker. Our industrial engineers are teachers rather than masters. We try to teach how one improves one's own productivity and the process. What we set up is the foundation; the edifice the worker builds. Scientific management, time and motion studies, materials flow-we do all

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[75] "Life at III M-Rules and Discipline, Goals and Praise Shape IBMers' Taut World, " *Wall Street Journal,* Apr. 8, 1982, p. 1.

[76] Even the more bemused commentators on the Japanese model, such as Ouchi, note its racism and sexism, See W. G. Ouchi, *Theory Z: How American Business Can Meet the Japanese Challenge* (Reading, Mass,: Addison-Wesley, 1981), p. 91.

[77] Quoted in P. F. Drucker, "What We Can Learn From Japanese Management, " *Harvard Business Review,* March-April 197], p. 117.

> that, and no differently from the way you do it in the States. But you in the States think that this is the end of the job; we here in Japan believe it is the beginning. The worker's job begins when we have finished engineering the job itself.

It is too easy to write off such statements as empty philosophizing.

Worker Participation

The past decade has seen continuing interest in industrial democracy, more so in Western Europe than in the United States.[78] Stemming at least in part from persistent economic problems, some companies and some governments have experimented with methods for increasing the involvement of the labor force—particularly blue-collar employees—in decisionmaking and work design. One aim has been to moderate wage demands. This section outlines several of the modes of employee participation that have evolved in Europe, as well as the quality control circles originating in Japan. The purpose is to capture some of the variety of foreign approaches, and ask how such mechanisms might help the productivity and competitiveness of American industry. A large number of specialized techniques for redesign of the working environment and employee involvement have been developed, both here and overseas; no attempt has been made to describe any except quality circles, which are covered because they have attracted so much attention.[79]

Participative Mechanisms

In the United States, industrial democracy has been associated with collective bargaining by labor unions—an interpretation of worker participation neither so encompassing as in Western Europe nor quite so narrow as in Japan. While American unions have continued to bargain over wage-benefit packages, European workers have succeeded in extending their influence over workplace and organizational decisions. In some contrast, quality control (QC) circles were developed by managers in Japan as tools for improving labor productivity and product quality. Most of the interest in QC circles among Americans has also originated with management. If American workers, particularly in companies with strong unions, have sometimes been reluctant to embrace QC circles, quality-of-work-life programs have found a better reception with labor.

The worker participation movement in Western Europe is based on two presumptions: first, that labor is just as important to production as capital; second, that blue-collar employees have the right to be represented in corporate decisionmaking. Participatory mechanisms include work groups at the shopfloor level, work councils at the plant or enterprise level, collective bargaining, labor representation on boards of directors, employee-owned enterprises, and worker representation on socioeconomic advisory bodies to governments, Beyond these direct involvements, publicly owned companies are a longstanding fixture on the European scene, with governments paying more or less attention to their management depending on political pressures and economic conditions.

At the shopfloor level, work-life programs give employees a voice in determining how individual tasks should be performed, with the aim of increasing job satisfaction as well as improving productivity. Employee involvement in work methods can be viewed as a reaction against the scientific management tradition, in which an expert—typically an industrial engineer—has full responsibility for task design. Sometimes, work-life programs reduce produc-

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[78] Much of the material on European countries in this section is based on A. L. Ahmuty, "Worker Participation in Management Decision-Making in Western Europe: Implications for the United States," Congressional Research Service Report No. 79-136E, Apr. 23, 1979. See also B. C. Roberts, H. Okamoto, and G. C. Lodge, "Collective Bargaining and Employee Participation in Western Europe, North America and Japan, " The Trilateral Commission, 1979.

[79] For an overview of a number of these, see R. M. Kanter, "Dilemmas of Participation: Issues in Implementing Participatory Quality-of-Work-Life Programs, " *National Forum*, spring 1982, p. 16. Several case studies can be found in J. A. Fadem, "Automation and Work Design in the United States, " Working Paper Series No. 43, Center for Quality of Working Life, Institute of Industrial Relations, University of California, Los Angeles, 1982.

tivity (as traditionally measured), a sacrifice that firms like the automobile manufacturer Volvo appear to have accepted in the interests of employee satisfaction, (Volvo replaced a number of assembly lines with batch assembly operations, giving workers more variety.)

At the enterprise or plant level in Europe, work councils—independent of unions—give employees a voice in codetermining a firm's future, Labor representatives on these councils participate in financial and other business decisions, although at the head of the agenda tend to be matters like personnel policy, health and safety, and shopfloor organizational practices. American-owned companies in West Germany have seldom been comfortable with codetermination; in the United States, the few labor-management committees that have been established tend to have a much narrower focus, and to be viewed primarily as vehicles for enhanced communication. One of the best known is the National Committee to Improve the Quality of Work Life, established by the United Auto Workers and General Motors in 1973. Current economic conditions may motivate more such experiments.

One of the most far-reaching experiments in employee participation has been instituted in West Germany. In the early 1970's, the Ministry of Research and Technology, in cooperation with the Ministry of Labour and Social Affairs, began a program aimed at the "humanization of work, " Based on the Work Councils Act passed by the German parliament in 1972, the premise is that government should not only safeguard employee health and safety, but undertake to improve opportunities for individual development and participation in decisionmaking.[80] In general, the response of workers to these initiatives seems to have been less positive than for earlier programs of codetermination, particularly in industries like electronics where the workplace is already relatively benign. West German workers have remained more interested in power over matters such as hiring and firing practices,

Blue-collar employees in the United States have restricted their attempts to influence company policies and decisions to the traditional concerns of labor-management relations. Union officials have been ambivalent about moving beyond questions of wages, benefits, and working conditions—probably for fear of losing some of the bargaining power that comes with an adversarial stance, al In contrast to Western Europe, participation by American workers on boards of directors has been rare—mostly brought on by circumstances such as Chrysler's recent financial plight. Although the many plant closings in industries like steel have led to proposals that employees purchase facilities scheduled to be shut down, few such plans have gone forward,

While collective bargaining is virtually universal in advanced market economies, there are man y differences of form and substance, In Japan, about 95 percent of all unions are organized on an enterprise basis.[82] In addition to collective bargaining between unions and management, negotiations take place each spring between groups of firms and unions, The "spring offensive" is most visible in the steel, electrical machinery, shipbuilding, heavy machinery, and automobile industries, as well as public corporations (where a special mediation committee decides on the settlement). Wage decisions during the spring offensive help set patterns for smaller firms. Still, compared with the United States or many European nations, labor in Japan has little real power.

Quality Control Circles

QC circles have been heavily publicized as mechanisms for worker participation. Quality circles are relatively autonomous, composed

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[80] "Research on the Humanization of Work, " Action Programme of the Federal Minister for Labour and Social Affairs and the Federal Minister for Research and Tech nology," Dec. No. 2181/74e. See also *Programm Forschung zur Humanisierung des Arbeitslebens*, Der Bundesminister fur Forschung und Technologies, 1979.

[81] For an evaluation of labor-management com m it tees in the United States, see K. Frieden, "Workplace Democracy and Productility, " National Center for Economic Alternatives, Washington, D.C., 1980, p. 31.

[82] "Labor Unions and Labor-Management Relations, " Japan Institute of Labour, Japanese Industrial Relations Series, Tokyo, 1979.

of a small group of workers—perhaps a dozen—typically led by a foreman or senior employee.[83] In Japan, financial incentives play a relatively minor role, without the emphasis on prizes for suggestions or improved performance that some American firms have adopted. QC meetings in Japanese companies are often held outside normal working hours, and workers may not be paid for their time. Although the circles now work on job-related problems beyond quality control per se—e,g., production methods, worker training—they grew out of the postwar stress on quality inspired by Americans such as Deming (ch. 6). The contribution made by Japan's business leaders was the expansion of quality control to involve participation by virtually everyone in the firm. Employee training via circles, for example, is intended to reduce the need for specialists in quality assurance and production engineering. As discussed in chapter 6, the quality and reliability of electronic products depends on factors ranging from engineering design to relationships with suppliers; while the quality of many Japanese goods is now excellent, it would be a mistake to attribute this to any one technique such as the QC circle.

Cole notes that even in Japan enthusiasm within a QC group tends to wane, and circles need to be periodically revitalized. It would be no surprise to find a Hawthorne effect at work in many of the success stories involving QC circles (i. e., a situation in which any of a wide variety of changes in the workplace environment would improve employee motivation and productivity, at least temporarily). The effectiveness of QC circles also depends on the extent of employee identification with the company; members participate more fully if they feel that their work is recognized and appreciated within the organization. A group-oriented Japanese corporation is more likely to foster such attitudes than many of the American firms now experimenting with QC circles. But even in Japan, QC circles are sometimes perceived as a coercive management tool. Overenthusiastic accounts of quality control circles in Japan sometimes give the impression of a panacea; in reality, Japanese firms vary widely in the extent to which they utilize QC circles—regardless of commitment to circle activities, they are only one management technique among many.

Over a hundred American firms—including General Motors, Ford, and General Electric—have experimented with QC circles, but the question of whether or not they will work as well in the United States as in Japan has not been answered. Certainly there are obstacles here that do not exist in the typical Japanese organization. In the U.S. context, for example, monetary incentives may be essential; the Lockheed program is typical in that employees are not expected to meet after hours, or without extra pay.[84] Experience also shows that American middle managers must be persuaded to accept and support the QC approach, else they may perceive the circles as challenges or as implicit criticisms of past performance.

Unionized firms add another dimension. Where QC circles have been introduced into American companies without the consultation and support of union leaders, they have not been successful. Organized labor remains ambivalent; AFL-CIO spokesmen have felt that QC circles could be a tool for breaking up unions, and the evolving attitude appears negative, as

Japanese firms with plants in the United States have generally introduced circles gradually and with considerable care, if at all. Quasar, owned by Matsushita since 1974, did not install its first circles until 1982; the company plans to have 25 in operation by the end of 1983.[86] QC circles in Japan function in a con-

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[83] Cole has carried out the most systematic studies on quality circles. The discussion below is based largely on *Work, Mobility, and Participation,* op. cit., pp. 135ff. Also see R. E. Cole, "Will QC Circles Work in the U.S.?" *Quality Progress,* July 1980, p. 30; *Improvements in the Quality of Working Life in Three Japanese Industries,* op. cit., pp. 76ff; and Inagami, op. cit., pp. 31-34.

[84] "Quality Control Circles Save Lockheed Nearly $3 Million in Two Years," *Quality,* May 1977, p. 14.

[85] R. S. Greenberger, "Quality Circles Grow, Stirring Union Worries, " *Wall Street Journal,* Sept. 22, 1981, p. 29.

[86] Information from Quasar. Thus far, the company views its experience in the United States with QC circles as successful, but perhaps not so successful as in Japan. For examples of other experiences in electronics, see J. D.Couger, "Circular Solutions, " *Datamation,* January 1983, p. 135.

text that includes enterprise unions, a relatively immobile work force, and seniority-based wage increases, Not all the elements in the Japanese approach or in QC circles themselves are likely to prove attractive to workers and managers in the United States.

Japanese and American Management Styles: How Much Difference?

Do Japanese firms operating in the United States exhibit a distinctive management style? Or in adapting to the new setting do they act more like American firms? Keeping in mind the structural differences that have been outlined, how different are management styles even within Japan from those in the United States? By comparing a foreign subsidiary both to its parent and to local competitors, variables of ownership and geography can be separated. This section presents the conclusions of a study of managerial differences among U.S. and Japanese firms, The survey sample included upper and middle managers from: 1) Japanese subsidiaries of American companies, 2) Japanese-owned subsidiaries in the United States, and 3) both American and Japanese firms in their home country. Appendix 8A, at the end of this chapter, explores the data on national differences in management style more systematically.[87]

The survey results show that *American- and Japanese-owned electronics firms do not diverge greatly in management style.* In many respects, managerial practices were more closely associated with geographical location than with ownership; i.e., Japanese-owned firms in the United States acted more like American firms, U.S. subsidiaries in Japan more like Japanese companies. In itself, this should be no surprise, given that foreign subsidiaries everywhere are mostly staffed by local people. Even if upper managers come from the parent, there is only so much they can import and implement.

The one respect in which Japanese-owned firms in *both* the United States and Japan stand out is their emphasis on employee motivation and participation, and on diffusion of responsibility through the ranks. The survey results indicate that the anecdotal evidence on Japanese concern for employee motivation reflects a genuine distinction: in terms of the models of management style outlined earlier, the Japanese approach is closer to the human relations pole. At the same time, the range in behavior across both Japanese and American firms is wide.

Japanese-owned firms stress communication and personal interaction both horizontally and vertically, At least some aspects of consensual decisionmaking have been transported to the United States, One can question the extent to which Japanese managers accept and act on the information received through these communication channels, as opposed to using them to manipulate opinion and impose top management decisions. Nonetheless, in employee surveys, managers in Japanese-owned firms both here and in Japan were more often described as sensitive to others and accessible to subordinates than managers of American-owned companies. This in itself contributes to employee motivation and satisfaction.

Such behavior patterns can be associated with the human relations school of management. The principal contrast with American-owned firms is along the *informal* dimensions of organizational behavior; there was little difference between the U.S. and Japanese firms surveyed in terms of organizational hierarchy or formal lines of communication. The distinguishing features of Japanese management appear to be rather intangible, matters of attitude more than method.

U.S. subsidiaries of Japanese companies have generally found this emphasis on human relations and employee participation to work well. Typically, the firms surveyed have modified management techniques imported from Japan to fit the American context without abandon-

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[87] App. 8A, together with the summary here, is based on a report prepared for OTA by M. A. Maguire. It includes an independent analysis of data from a project directed by R, T. Pascale, The subset dealing with electronics has been of primary interest to OTA, For a discussion based on all the data, including other Industries, see R. T. Pascale and A. G. Athos, *The Art of Japanese Management* (New York: Simon & Shuster, 1981).

ing the human relations thrust. Furthermore, some of the best performing American firms display a similar concern for employee participation, with the implicit goal of giving individual workers a stake in the success of the enterprise. While it is impossible to determine the precise degree to which human relations-oriented management contributes to the performance of particular companies, it does appear to be a common trait in well-managed and competitive organizations in both countries.

Summary and Conclusions

Commitment to the development and utilization of human resources is closely associated with corporate success, and, through this, with industrial competitiveness. In electronics, U.S. manufacturers have had difficulty filling critical positions in engineering; a concurrent shortage of skilled technicians, while not so well publicized, could prove as serious a bottleneck. At present, the United States seems *in danger of falling behind other countries at training people in the skills needed for high-technology industries like electronics;* deficiencies exist in both public and private sectors. Education, provided first and foremost by the public schools, determines the skills and capabilities that people bring with them to the work force. The ability to continue learning—on the job as well as off—also depends on the quality of that formal education. While some American firms provide or encourage continuing education and training for their employees, others do little or nothing.

Inadequacies in the education and training of the American labor force are growing more serious, Beginning at secondary levels, the preparation of Americans in science and mathematics is simply not on a par with other industrialized nations—e.g., Japan. A smaller fraction of U.S. college students major in technical fields. While many American universities are, at the moment, limited in their ability to handle greater numbers of engineering students, a more fundamental problem is the relatively small fraction of the college-age population qualified to enter such programs. The typical U.S. high school graduate is not only poorly prepared in mathematics and science, but uninformed concerning technology. *Deficiencies in mathematics are most serious; these disqualify people at an early age from a broad range of career opportunities, depriving the Nation of a vast potential resource.*

For those qualified for admittance, programs in engineering, mathematics, and the sciences offered by American colleges and universities—both undergraduate and graduate—remain unsurpassed. Nonetheless, they have slipped relatively; engineering schools, in particular, are suffering from a lack of qualified faculty and from inadequate and obsolete equipment. The pressures of expanding undergraduate enrollments have led to a deterioration in the quality of education. Continued low enrollments of ph. D. students mean that the shortage of engineering teachers will continue; *what might have been a transient problem is rapidly turning into a serious long-term concern.*

Moreover, the *average* American worker is less prepared than his or her counterpart in a number of other countries for productive employment in industries like electronics. As a result, the United States is heading toward more shortages of skilled blue- and grey-collar workers—technicians, designers and draftsmen, engineering aides, field service personnel. Likewise, many white-collar jobs are filled by people with little understanding of mathematics, science, or technology—and with little preparation for comprehending technical subjects even on a lay basis. Meanwhile, *unemployment in the United States has been rising—in part the result of a mismatch between what people are able to do and what needs to be done.*

One way private firms can compensate for deficiencies in formal education is to establish in-house training and retraining programs; in addition to such efforts, many American firms support continuing education outside the company. The incentives for such efforts, however, are lower here than in Western Europe or Japan because of the mobility of the U.S. labor force, The frequency with which Americans take new jobs heightens the risk that the company will lose its investment. Nonetheless, a number of U.S. electronics companies have developed ambitious employee training efforts, and the semiconductor industry is developing programs in conjunction with universities that will help to educate new people, as well as supporting the R&D base. Despite their promise, such initiatives will not by themselves be sufficient to meet the skill requirements of the electronics industry in the years ahead, much less the broader needs of the U.S. economy.

Government in the United States–Federal, State, and local–has traditionally carried the major responsibility for education and training; expanded public sector programs for training and retraining appear necessary for building the competitiveness of American industry, As demographic forces tilt the labor force toward greater proportions of older workers, retraining will be essential if the talents of mid-career employees are to be effectively utilized. As U.S. industry continues to advance technologically, workers who find themselves displaced by structural change will be dependent on retraining to find productive employment elsewhere. As job opportunities shrink for those with limited skills, men and women with poorer educations, and without the developed ability to learn on the job, will more and more find themselves unemployable. Given the competition and mobility characteristic of the American economy, the *private sector cannot reasonably be expected to provide the needed training and retraining; only government bodies—at all levels—can take on this responsibility*.

The efforts of private industry begin with the people available in the labor pool. In large measure, the art of management lies in maximizing the contributions of existing and prospective employees—to which end a number of the more successful electronics companies, in the United States as well as Japan, have developed management systems that emphasize employee participation. Giving individuals a voice in decisions that affect them increases motivation and commitment to the organization.

Despite the vogue for Japanese management techniques, the human relations approach is in no way unique to Japan or to Japanese corporations; the similarities among competitive firms in Japan and the United States are more striking than the differences. Specific mechanisms, such as quality control circles or labor-management committees, appear of secondary importance compared to less tangible signs of attentiveness by management to the attitudes and talents of employees.

While many U.S. corporations have developed their own brands of human resources-oriented management, others could profit by more attention to worker participation; American managers seem to be gradually realizing that they may be underutilizing their employees. Table 73 shows that executives of U.S. firms rank employee participation as the most important single influence on productivity. Whether they *act* on such beliefs is another matter; but, of the forces that affect competitiveness, management is the most immediately amenable to change by individual companies. A renewed commitment by American companies to the development and utilization of human resources could pay large dividends in international competition.

Table 73.—Rankings by American Managers of Factors Contributing to Productivity

Factor	‘Average rank[a]
Employee participation programs	3.61
Better communications	4.11
Better labor-management relations	4,45
Increased training	4.46
Quality improvement	4.81
Increased automation	5.02
Productivity incentive programs	5.13
Cost reduction programs	6.01
Increased R&D	6.28

[a] Based on a scale of 1 to 10, with I being the most effective and 10 being the least

SOURCE *Mechanical Engineering*, September 1981

Appendix 8A.—Japanese and American Management Styles: A Comparison

Survey Results

A survey covering managers and other employees in four electronics companies provides the basis for this comparison:

- *company A* 1, an American consumer electronics firm operating only in the United States;
- *company J,* a Japanese consumer electronics firm with operations both in the United States (J-A) and in Japan (J-J); and
- *companies* A2-) *and A3-J,* the Japanese subsidiaries of two American firms, one a manufacturer of computers, the other of semiconductors (not necessarily in that order),

All the firms were high performers in their respective portions of the electronics industry,

The data can be grouped in several ways. For instance, a geographic grouping gives: first, the two organizations in the United States—one American-owned (Al), and one Japanese-owned (J-A]; and, second, the three operations in Japan—one Japanese-owned (J-J] and two American-owned (Az-J, A3-J). Alternatively, grouping the sample by ownership yields a set of three American-owned firms (Al, A2-J, A3-J) which can be compared with the Japanese-owned organizations [J-A and J-J). For most purposes, the ownership distinction is more illuminating, probably because top managers who set the tone of an organization generally came from the parent firm. In contrast, most of the middle-level managers had been recruited locally; thus in organization J-A they were largely Americans.

The survey covered both middle and upper managers, utilizing interviews as well as written responses. Nonmanagerial employees were also sampled via questionnaires to gather data on job satisfaction. The data must be interpreted with caution because of the small number of organizations. At the same time, the survey results for electronics come from a much larger body of data covering 10 industries; differences across industries were few,

A primary objective was to gather information on communications and decisionmaking styles. Survey questions were designed to indicate whether American firms differed from Japanese in the extent to which decisionmaking and communications could be described as hierarchical and formal (the hypothetical U.S. model) rather than informal and cooperative (the hypothesis for Japan).

The results show that all the American-owned firms—Al, A2-J, and A3-J—relied more heavily on written communications, both here and abroad. More surprisingly, firm J-A—the U.S. subsidiary of a Japanese company—was in many respects more "Japanese" in decisionmaking and communications than the parent organization (J-J); the data show a greater proportion of upward communication and a lower proportion downward in the United States than in the same firm's home offices. Overall, however, the survey results–table 8A-1–showed much less variation in patterns of communication among these firms than the pure Japanese and American models would predict. Additional survey questions indicated that the subsidiary A2-J is more "dependent" on its American parent, as measured by written communications with headquarters, than the subsidiary J-A was on its Japanese parent.

The survey results also shed light on hierarchy and formalization in the organizational structure of each company in terms of the *size/level ratio:* the total number of employees in the organization divided by the number of hierarchical levels. The *lower* the size/level ratio, the *more* formal and hierarchical is the firm's structure, Again, the results may seem somewhat surprising: the Japanese company was the most hierarchical, with its domestic and U.S. operations scoring the same—133 (J-J) and 134 (J-A). One of the American electronics firms measured 150 in its Japanese organization (A3-J), little different from the Japanese-owned company, The other two American-owned organizations had ratios of 284 (A2-J) and 533 (Al). In other words, none of the American firms are particularly formalistic or hierarchical on this measure (which can be rather sensitive to differences in the overall size of the companies compared). Another indicator, the extent to which they make use of written job descriptions, found the American-owned companies ranked higher in formalization.

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[1] This appendix is based on "Personnel in the Electronics Industry: United States and Japan, " prepared for OTA by M. A. Maguire under contract No. 033-1360. The report includes an independent analysis of data collected for a project directed by R. T. Pascale. Pascale's own treatment, including discussion of companies in other industries, can be found in R. T. Pascale and A. G. Athos, *The Art of Japanese Management [New* York: Simon & Shuster, 1981),

Table 8A-1 .—Responses of Middle and Upper Managers to Questions Dealing With Communications and Decisionmaking Styles

	Companywide averages				
	Al	J-A	J-J	A2-J	A3-J
Questions dealing with manager's own behavior:					
Number of telephone calls and face-to-face contacts per day	81	69	72	24	55
Number of written communications per day	10	4	3	8	7
Hours in meetings per day	2	2.5	3	2.3	3
Percentage of calls to those higher in the organization	21 °/o	25°/0	23°/0	14°/0	36°/0
Percentage of calls to those lower in the organization	40%	31%	31 °/o	56%	37°/0
Percentage of meetings with those higher in the organization	13%	16°/0	4 %	80/0	10O/o
Percentage of meetings with those lower in the organization	640/o	56°/0	84°/0	88°/0	80°/0
Questions *dealing with manager's evaluations of their supervisors' decisionmaking styles:*					
Percentage of decisions supervisor makes alone	**36°/0**	**21 °/o**	**29°/0**	**23°/0**	**25°/0**
Percentage of decisions supervisor makes after factual input from subordinates	**20°/0**	**30%**	**20°0**	**40°/0**	**25°/0**
Percentage of decisions supervisor makes with participation by subordinates	43°/0	49°/0	51 °/o	37%	50°/0

SOURCE M A Maguire Personnel in the–Electronics Industry United States and Japan, " prepared for OTA under contract No 0331360 p 8

Responses to questions about characteristics essential to managerial success revealed a greater emphasis in the Japanese-owned firms on communication within the organization both vertically and horizontally; this was true both in domestic (J-J) and American (J-A) operations. Managers in the American company A1 would tend to "make as many decisions as possible at his/her level without bothering senior management, " and "respect the chain of command, discuss ideas with immediate superior before discussing them with members of other departments. " In contrast, managers in the American subsidiary of the Japanese company J-A thought it important to "communicate extensively with managers in other departments;" managers in the parent firm (J-J) also stressed communication. Within one of the American-owned subsidiaries in Japan, A2-J, the responses indicated a feeling that each manager should make as many decisions as possible at his/her own level. Here the survey results do confirm a difference in management attitudes between Japanese- and American-owned companies, with the American-owned electronics firms exhibiting a greater degree of independent decisionmaking even within their overseas subsidiaries.

Questions calling for a composite picture of the manager immediately above the respondent elicited several distinctions among the five organizations. On eight dimensions, those questioned were asked to describe the actual characteristics of their superiors (not the attributes they would like to see). The managers in the U.S. subsidiary J-A were described as: "readily accessible to subordinates several echelons below," "permits broad latitude for subordinates to work out solutions to problems in their own way, " and "sensitive to others who work for him, " In the parent firm in Japan (J-J), the typical manager "tries to achieve consensus" and "permits broad latitude for subordinates, " but is also described as aggressive.

While a reasonably uniform picture emerges for the subsidiary J-A and its parent J-J, there was much greater diversity among the characteristics of managers within the American-owned firms. This was especially notable in company Al. Likewise in company A2-J, respondents agreed on only one thing: that their superiors were aggressive. Coupled with the similar characterization in the Japanese organization J-J, this suggests that, while aggressiveness has not always been viewed as central to Japanese management, it may in fact be common in high-performing firms in both countries. The survey results do paint a more heterogeneous picture of the managers in American-owned organizations. American companies operating in Japan exhibit some of the traits associated with Japanese management, but it is the Japanese company which, as expected, has managers who most strongly emphasize consensual decisionmaking and human relations. On this dimension, the composite managerial portraits indicate a clear difference in American and Japanese styles.

The human relations school stresses sensitivity to subordinates. Table 8A-2 compares responses of *nonmanagerial* employees to questions related to job satisfaction, together with data on rates of absenteeism and expenditures on employee programs. The Japanese-owned firms might be expected to exhibit a greater degree of manager-employee interaction—presumably leading to greater satisfaction among the labor force. The results in table *8A-2* show that very few workers

Table 8A-2.—Data Related to Employee Satisfaction

	Location of organization				
	United States			Japan	
	Al	J-A	J-J	A2-J	A3-J
Percentage of workers rating themselves “very satisfied” with their jobs	**20°/0**	**28°/0**	**2°/0**	**O**	**0**
Percentage of workers rating themselves “satisfied” or “very satisfied” with their jobs	**74°/0**	**88°/0**	**58°/0**	**63°/0**	**95°/0**
Daily absenteeism	**3°/0**	1%	<10/0	<1 ”/0	1%
Social/recreational expenditures per worker	$1.40	$15	$33	$50	$38

SOURCE M A Maguire, “Personnel in the Electronics Industry United States and Japan, ” prepared for OTA under contract No 033.1360, pp. 19, 20

in Japan are willing to describe themselves as highly satisfied with their jobs, but the picture changes considerably—with firms in Japan comparing more favorably—if “satisfied” responses are included.[2] Japanese firms, known for their company-as-family approach, might also be expected to spend more on social and recreational opportunities for employees, As table 8A-2 indicates, this is indeed true for organizations within Japan, regardless of ownership. In any case, the results in table 8A-2 on job satisfaction should be interpreted with caution, as such questions typically yield high proportions of positive responses. Moreover, clear-cut relationships between expressions of job satisfaction and measured productivity levels are rarely found,[3]

The differences observed between subsidiaries here and parent firms in Japan may result from conscious decisions to downplay Japanese management practices. The style that emerges is likely to be a hybrid of American and Japanese practices, In any event, this conclusion follows from the survey data as a whole: there *is no sharp contrast between the management approaches of American- and Japanese-owned companies.* Many of the patterns observed are more closely associated with the geographical location of the organization than with ownership. Upper managers from the parent firm tend to adopt many practices of the host country. On some dimensions—e.g., accessibility of managers to lower level employees—the Japanese-owned firms do stand out. But in other cases, there are no clear distinctions; only on measures of sensitivity to employee attitudes and participation are these consistent.

Matsushita’s Purchase of Quasar

What happens when a Japanese corporation takes over an American firm? Changes in management practices might offer insight into the Japanese approach. The purchase in 1974 by Matsushita Electric of Motorola’s Quasar division—which produced televisions–provides a case in point. (Unfortunately, conspicuous examples of a U.S. firm taking over a Japanese enterprise are lacking.)

After Matsushita took control of Quasar, the new owners reorganized the factory operations, located near Chicago, invested in new equipment, and began redesigning the product line. At the center of these efforts was the goal of improved product quality. In contrast to the old production system, which relied on as many as seven quality control inspectors per assembly line, Matsushita adopted a more integrated approach with responsibility for quality spread broadly. By 1980, the defect rate on Quasar’s assembly lines was about 2 defects per 100 sets, compared to 1/2 defect per 100 sets for Matsushita’s factories in Japan.[4] These quality improvements were the result of *system wide* changes. While resulting from a series of decisions made by Matsushita’s management, they comprised far more than just matters of style or technique. For example, the company’s extensive modernization of the capital plant entailed expenditures of about $50 million for automated equipment, as well as an entirely new chassis factory in Mexico.[5] Motorola officials stress that they knew just as well what had to be done to make the Quasar facility more efficient, but had decided to allocate available resources to other parts of the company’s business,

If Quasar’s gains in product quality and plant efficiency came at considerable cost in new equip-

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[2] Japanese workers also express relatively low rates of satisfaction with activities such as quality circles. See S. Takezawa, et al., *Improvements in the Quality of Working Life in Three Japanese Industries,* (Geneva: International Labour Office, 1982], pp. 77, 98.

[3] S. E. Weed, T. R. Mitchell, and W. Moffitt, “Leadership Style, Subordinates’ Personality and Task Type as Predictors of Performance and Satisfaction in Supervision, ” *Journal of Applied Psychology, vol. 61, 1976.*

[4] J. Mihalasky and A. B. Mundel, “Quality and Reliability of Semiconductors and CTVs: United States v. Japan, ” Report No. *C972* prepared for OTA by Consultant Services Institute, Inc., under contract No. *033-1170.0,* p. 77.

[5] T. C. Hayes, “The Japanese Way at Quasar,” New *York Times,* Oct. 16, 1981, p. D1.

ment investments, the emphasis on worker participation and responsibility for quality is also significant. Quality control circles were not introduced until recently, but Quasar employees have been encouraged to set their own production targets and to meet in informal weekly discussions about plant operations with foremen. Such practices are hardly unique or exotic, but the attentiveness to all aspects of the manufacturing process stands out. Still, none of this has helped Quasar expand its market share substantially.

Quasar, like other Japanese subsidiaries in the United States, shows a flexible and adaptive management style, with manufacturing operations and quality control having a central place. Nonetheless, if and when Japanese companies hire still larger proportions of American managers, and adapt further to the U.S. environment, they may become more like wholly American organizations.[6]

Conclusion

Both the survey results and the Matsushita example indicate that well-run organizations tend to be open to new ideas and methods, including those coming from the lower levels of the organization. Distinctions between Japanese- and American-owned firms are fewer and less clear-cut than sometimes claimed. While American employees might resist some of the techniques associated with Japanese management, worker participation-even loyalty to the firm—can be fostered in a variety of ways, Some of these methods smack of paternalism, but not all. As a number of American firms have amply demonstrated, worker participation and attention to human relations can be a big help in building competitive organizations.

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[6] A recent study by the Japan External Trade Organization (JETRO) on Japanese-owned manufacturing operations in the United States indicates that the number of Japanese nationals transferred to subsidiaries tends to decrease over time. See "Japanese Manufacturing Operations in the U.S.," Japan External Trade Organization, September 1981. Data on managerial styles collected for the JETRO study confirm the trends described here: Japanese subsidiaries evolve styles that mix features common to the Japanese model with other practices more characteristically American.

CHAPTER 9

Employment Effects

Contents

List of Tables

List of Figures

CHAPTER 9

Employment Effects

Overview

Shifts in the competitiveness of an industry like electronics—or for that matter technical change alone—have both direct and indirect consequences for employment. In addition to changes in the labor force requirements both of firms within the industry and firms that supply it, the effects can spread broadly across the economy. Job opportunities within the United States appear or disappear with changes in demand for electronics products, with shifts in international competitive position, and with increases in productivity. These forces interact in complex fashion.

Will continuing developments in electronics —computers, office and factory automation, information services—cause employment to increase or decrease? Such questions have been debated for years, in the context of this and other industries, The conventional response is that technical change creates, in the aggregate, more jobs than it destroys. While the kinds of jobs available will change—as terminals appear on more desks, opportunities for systems analysts (who plan and help operate data processing installations) replace those for keypunch operators, for one instance—new technology creates new demand fast enough that total employment goes up. The conventional response assumes that such patterns will continue, But, just because in the past technical change created more jobs than it destroyed does not mean that this will be true in the future. Such questions are broader than can be addressed here, Too many forces affect levels of employment, not to mention skill requirements. Analysis on a detailed, disaggregated basis sufficient to isolate the influences of electronics (and upon it) would be extraordinarily difficult. This chapter has more limited aims: to summarize what is presently known about employment in electronics, both past trends and future prospects. within the industry, changes in competitiveness have immediate consequences for employment, If the U.S. electronics industry declines in competitiveness, and sales fall in domestic and/or foreign markets, employment will follow, If rates of increase of sales drop, employment may also decline—depending on increases in labor productivity. Similarly, if U.S. electronics firms expand their overseas production activities—for re-import or for sales in foreign markets—changes in domestic employment normally follow, As competitive advantages shift internationally, labor market dislocations can occur even if the total number of jobs remains the same. Such dislocations can include geographical shifts in demand for workers, along with changes in educational and skill requirements; as computers and other electronic systems have become more sophisticated, white- and grey-collar jobs have expanded much more rapidly than openings for unskilled or semiskilled workers.

Shifts in the international competitiveness of American electronics firms also affect other parts of the economy. Moreover, structural unemployment can be created by changes in electronics technology that alter the ways goods are designed and manufactured. Electronic typesetting has reduced the need for skilled workers in newspaper publishing. Technological change may create new jobs for supervisory and maintenance workers, but it is hard to imagine that as many people will be employed in designing, manufacturing, and maintaining industrial robots as are displaced by them. Still, net effects—particularly over extended periods of time—can seldom be disentangled from the other factors on which employment depends. If aggregate economic growth is slow, and productivity rises—e.g., because of investments in labor-saving equipment like robots, or computer-integrated manufacturing more generally —jobs will be lost unless other sectors of the economy, such as services, compensate.

The preceding chapter explored the education and training of American workers, as well as management practices which determine how effectively the talents of the labor force are utilized and the possibility of shortages of those with specialized skills. Chapter 8 included extensive comparisons between the United States and Japan. Here, the focus is primarily on the United States, beginning with a review of the automation debates of earlier years. Next, data on employment trends in electronics are examined in the context of import penetration, as well as offshore manufacturing by American firms. The chapter surveys employment forecasts for electronics, along with case studies of impacts on other manufacturing and service industries, While there is no way of knowing how aggregate employment will fare, technological change—together with shifts in the competitive positions of American electronics firms—will clearly have major impacts on *some* industries and *some* job categories.

Impacts of Technical Change in Electronics on Employment

The Automation Debate of the 1950's and Since

People have worried over technological change because of its impacts on employment —and sometimes actively resisted new technologies—at least since the beginnings of the industrial revolution. The automation scare of the 1950's focused on computers taking over the workplace—a fear that has resurfaced, more so in Europe than the United States. Twenty-five years ago, some commentators predicted steadily rising unemployment due to automation; others were skeptical that computers alone would have such grave consequences. Throughout the 1960's, a number of international groups, including the Organization for Economic Cooperation and Development (OECD) and the International Labour Office, continued to study the effects of computers and automation on employment. As it happened, the industrial nations experienced an upswing in economic growth during the 1960's that put the automation debate temporarily to rest. Falling levels of unemployment were sufficient indication to many that overall demand was the key to jobs, with structural aspects decidedly secondary; so long as aggregate demand grew, new jobs would be created to offset the losses resulting from labor-saving technologies,

The 1970's brought renewed concern; economic growth slowed and unemployment rose, The trend was sometimes masked by the ups and downs of the business cycle, but by the end of the decade, as figure 55 shows, it was clear that unemployment had been steadily rising in most of the industrialized West. Now the question has become: Will this trend persist?

Rather than mainframe computers as in the 1950's, people now point to microprocessors and microcomputers as the new technologies with the greatest potential job-displacing effects.[1] As was the case 25 years ago, optimists and pessimists view the consequences of such developments quite differently. To the optimists, labor-saving technology is nothing new. Many more jobs will be created than lost, they say. Moreover, in the short term the impacts of microelectronics will not be that dramatic because most investments in automated equipment come during periods of economic growth, when capital is available. As a result, workers may be redeployed but only rarely will lose their jobs. The optimists view structural

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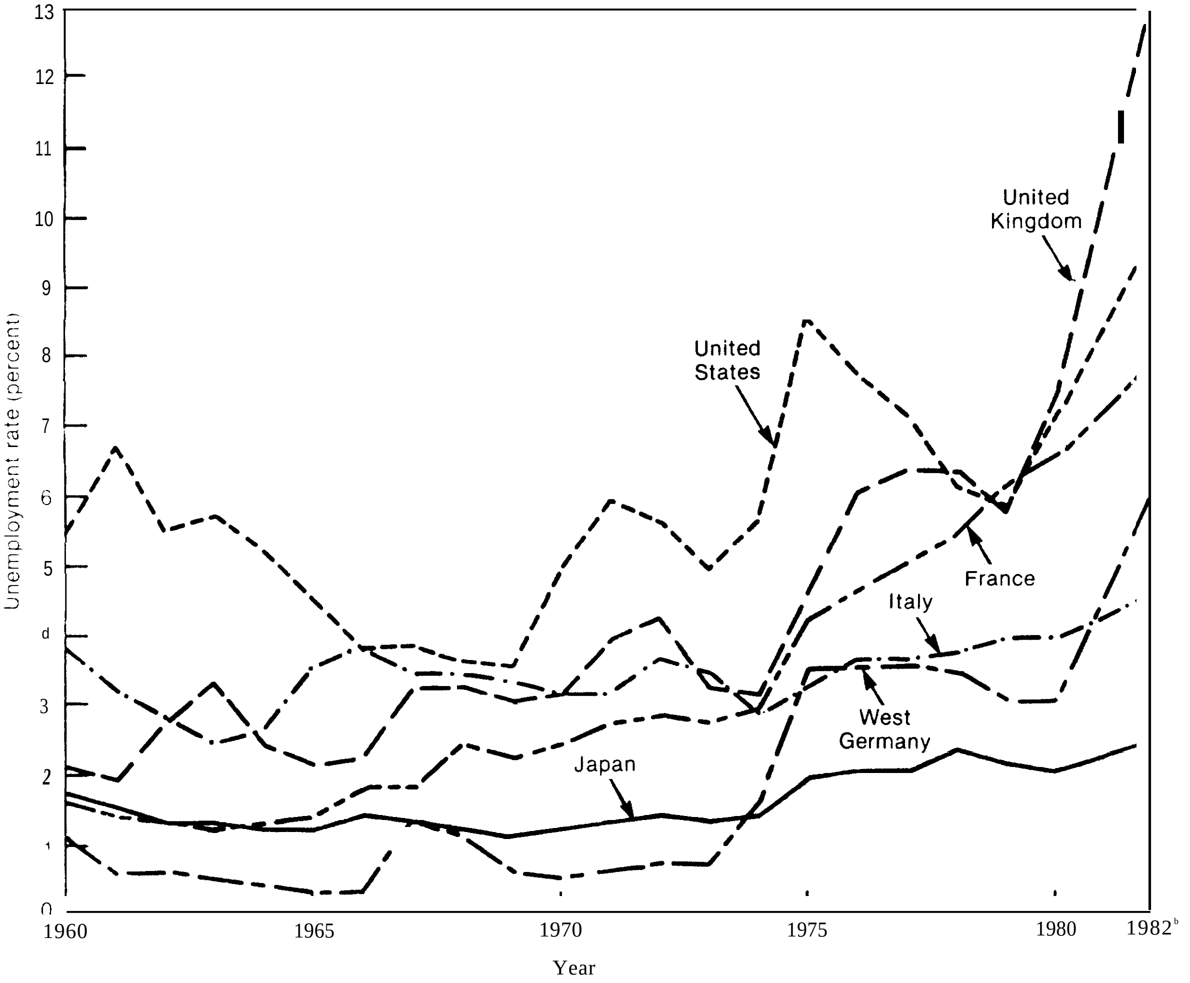
[1] See, for example, C. Norman, *Microelectronics at Work: Productivity and Jobs in the World Economy,* Worldwatch Paper 39 (Washington, D. C.: Worldwatch Institute, October 1980); *Advances in Automation Prompt Concern Over Increased L? S. Unemployment,* GAO/AFMD-82-44 [Washington, D. C.: General Accounting office, May 25, 1982).

Figure 55.— Unemployment in Industrial Nations[a]



[a] Unemployment rates approximating U.S. concept. Data for the United Kingdom exclude Northern Ireland

[b] 1982 [illegible] for the United States and Italy based on first 9 months

SOURCE *Economic Report of the President* (Washington D C U S Government Printing Office, February 1983), p 287

transformation as a process that creates jobs in newer sectors of the economy: employment in manufacturing may shrink but opportunities will increase in services; as the proportion of manual workers declines, the number of white-collar employees grows. Automation, furthermore, will free people from some of the worst jobs: dirty, boring, dangerous factory work; sorting and filing; processing checks; perhaps even delivering the mail. To the pessimists, of course, some of these jobs are not so bad – and many of the least attractive will remain (custodial work, fast foods, selling insurance). Still, from the optimist's viewpoint, the expansion of high-technology industries means more opportunities for an educated labor force. Competition from low-wage, newly industrializing countries (NICs) need not cause great concern; so long as the world economy continues to grow, industrialized nations can concentrate on advanced products made by better paid and better training workers, leaving the lower technology sectors to the NICs. Everybody should benefit.

Others are less sanguine, their skepticism rooted in the belief that the world economy is now fundamentally different than in the 1950's and 1960's. "Structuralists" argue that permanent shifts spelling chronic unemployment and underemployment have taken place, Fundamental to this view is the slow economic growth of the 1970's; to the pessimists, sudden rises in energy prices and other shocks to the international economy are not enough to explain the slowing pace of growth, They argue that, at least in manufacturing, the expansion in output needed to maintain current employment levels has been increasing—i.e., that output must grow more rapidly than in the past in order to maintain a constant number of jobs. If true, and if this trend persists, it will become more and more difficult to *expand* employment by stimulating demand.[1] Since labor productivity in the manufacturing sectors of industrial nations has risen consistently faster than gross national product (GNP), the pessimists emphasize that compensating expansion in employment must come from sectors other than manufacturing. Many also argue that structural unemployment in advanced industrial nations results from a permanent shift of labor-intensive production to lesser developed countries and NICs, where wages are low. In the longer term, this might be a positive force; if international specialization takes place, the more advanced nations should be able to concentrate on capital- and knowledge-intensive industries, and expand their employment in these sectors, But in the short run it leads to severe dislocations, already evident, for example, in consumer electronics or steel.

The same causes and effects—technological change, productivity growth, shifts in international comparative advantage, technology gaps—are thus viewed differently by the optimists and the pessimists. The latter see them as signals of persisting unemployment. Unlike the optimists, they emphasize obstacles to adjustment such as mismatches between the skills and capabilities of workers and the requirements of industry (ch. 8), They argue that employment statistics for the United States already underplay the extent of *real* unemployment, not to mention underemployment.[3]

The debate between the optimists and pessimists ranges far beyond the electronics industry. But electronics technology has been a natural locus of concern because it so clearly embodies labor-saving advances by which machines perform tasks that people did in the past. No wonder labor unions—in the United States but particularly in Western Europe—have continued to raise questions about automation and electronics, and sometimes actively resisted new production methods,

The question: "How will electronics technology affect employment?" is unanswerable, Posing the question more narrowly helps a little: Will continued developments in electronics drastically reduce the number of workers needed in the manufacturing sectors of advanced economies? Will the effects be beneficial through elimination of burdensome tasks while creating new and more interesting jobs? These phrasings still cannot be treated with any precision, but at least are more suggestive. The problem is that no methods exist for determining employment shifts caused exclusively by technical change. Too many other forces are at work, A second analytical problem relates to the type of employment impact. Advances in electronics may eliminate a job in one plant—but a similar job may open in a nearby firm or in a distant city, Alternatively, a displaced worker might be able to find employment only after retraining, or even reeducation.

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[1] R. Rothwell and W. Zegveld, *Industrial Innovation and Public Policy: Preparing for the 1980's and the 1990's* (Westport, Corm,: Greenwood Press, 1981), p. 207, In Europe, the term "jobless growth" has come to describe this phenomenon.

[3] One study has claimed that 80 percent of American workers are "misemploy ed''-i.e., are doing jobs for which they are ill-suited. See W. W. Harman, "Chronic Unemployment: An Emerging Problem of Postindustrial Society, " *The Futurist,* August 1978, p. 213,

Leontief paints a grim picture of the effects of technological change, mismatch, and misemployment:

> To argue that workers displaced by machines should necessarily be able to find employment in building these machines does not make more sense than to expect that horses displaced by mechanical vehicles could have been directly or indirectly employed in various branches of the expanding automotive industry.

See W. Leontief, "Employment Policies in the Age of Automation," *Science and Public Policy,* December 1978, p. 452.

From the perspective of the individual, geographical moves or retraining can aggravate what is already a severe blow on psychological as well as more tangible grounds.

Factors Affecting Employment Levels

Directly or indirectly, the ability of American firms to compete internationally links many of the forces that affect employment, Increasing sales here and abroad provide the foundation for a growing labor market, with aggregate expansion creating new job opportunities unless labor productivity goes up even faster. Conventional methods of forecasting labor market demand begin with output projections, In a given sector, output and employment will depend in complex fashion on aggregate demand; in a period of economic downturn, job opportunities can still increase in some industries. While this has often been true in electronics, recessionary pressures during 1981 and 1982, as in 1974 and 1975, show that the semiconductor industry is far from immune from sales slumps and layoffs.

For years, the interrelation between employment and inflation was pictured in terms of the well-known Phillips curve, which showed that high rates of inflation tended to correspond to low rates of unemployment, and vice versa. But by the end of the 1970's, the American economy seemed prone to simultaneous inflation and unemployment—another gloomy portent to those on the pessimistic side of the structural unemployment question. One reason is wage and price rigidity. When demand falls, companies are reluctant to cut prices as a means of expanding output, workers reluctant to accept pay cuts to reduce costs. Rather than greater output and employment at lower wage and price levels, prices stay high—aggravating inflation-sales drop, output must be cut, and workers are laid off. Nonetheless, recent wage concessions in the steel and automobile industries show that adjustment is possible if the slump is serious enough.

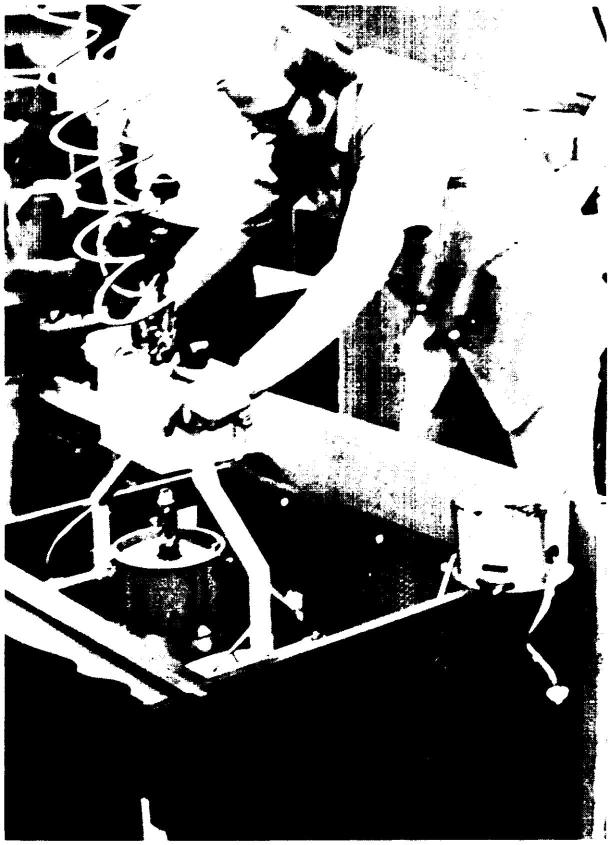

Photo credlt *RCA*

Final adjustments during color TV assembly

Employment is closely linked to labor productivity—commonly measured in terms of output per man-hour. If firms can produce more with the same amount of labor, the economy as a whole expands and so does individual purchasing power. Growth in purchasing power can create new demand which will in turn create new jobs; thus *increases in productivity do not of themselves result in employment losses.* But if the overall economy is stagnant or growing only slowly, productivity growth in a given industry can well lead, not only to decreasing job opportunities in that industry, but to net job losses within the economy.

As this implies, sectoral shifts must be considered. A worker displaced by rising productivity and foreign competition in consumer electronics finds little solace in growth elsewhere in the economy. Similar patterns appear at higher levels of aggregation. As pointed out in chapter 5 (see fig. 32), employment in both manufacturing and agriculture has shrunk relative to services in the OECD nations. The service sector makes an ever-growing contribution to U.S. GNP, and the rate of job expansion there has been high. What of productivity in services? Since productivity has grown less rapidly in services than in manufacturing [although productivity in many service sector categories is notoriously difficult to measure), overall employment levels have been maintained in part by transfers of labor from manufacturing to lower productivity service sector jobs. Of course, factory workers cannot always quickly move to service jobs, nor may they want to—particularly if the jobs available are low-paying or menial. The point is that sectoral shifts always imply some degree of dislocation.

The impacts of technological change take several forms. Automation, interpreted broadly as extending to jobs outside the traditional manufacturing sector, cuts into the need for labor. Computers eliminate jobs for file clerks; banking machines displace tellers; instead of three people in the cockpit, new commercial aircraft need two. Great Britain's telephone system provides a quantitative example: when electromechanical equipment was phased out in favor of electronic switching during the 1970's, employment dropped from over 90,000 to 65,000.[4]

The effects of new technology depend in large measure on the motives for its introduction. Investments aimed at rationalizing the production process by cutting costs, improving efficiency, or adjusting to new conditions tend to cause net declines in job opportunities. The British telephone system is a case in point. On the other hand, technical change may expand output or create new markets, resulting in many more jobs. Henry Ford's moving assembly line is a classic historical example; labor productivity increased and costs were cut to the point that vastly greater numbers of people could afford to buy cars. Likewise, the introduction of color television cut into sales of black-and-white sets but expanded overall demand for TVs. Many examples could be drawn from the computer industry.

The export competitiveness of domestic firms, as well as market penetration by imports, directly affect employment. Greater sales in export markets mean more jobs at home. On the other hand, an influx of foreign goods may put Americans out of work. In recent years, considerable attention has focused on jobs lost to foreign low-wage industries making products such as TVs or textiles and apparel. Nevertheless, competition with advanced nations can be equally important—evident in products ranging from automobiles and machine tools to integrated circuits and aircraft, As industries like electronics become more thoroughly international in character, it is seldom easy to disentangle the costs and benefits flowing from shifts in competitive strength. Overseas production by American firms can be viewed as a loss in domestic job opportunities; it can also be seen, in at least some cases, as an entree into new and expanding foreign markets (see app. B on offshore manufacturing for an outline of the complexities of such judgments).

Finally, employment levels always depend to some extent on the fit between the demand for manpower and the skills and capabilities of the work force. Structural shifts affect not only the employment levels in various economic sectors, but the kinds of people needed. In the United States, the unemployed Youngstown steelworker may neither be qualified nor desire to move into a Silicon Valley electronics company, especially since the pay is unlikely to be very high. In advanced economies, growth in services has led to a variety of changes in labor markets. In Sweden, for example, as the economy has grown and the service sector expanded, labor force participation among older men has declined. One explanation is that this group has become redundant—older men do not bother to look for work because they be-

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[4] R. Roth well and W. Zegveld, *Technical Change and Employment* (New York: St. Martin's Press, 1979), p. 152.

lieve that none is available. ' At the same time, women have joined the labor forces of the industrialized nations in greater numbers, taking many of the service sector jobs.

The match between supply and demand in the labor market—never perfect—is thus an intrinsic part of the employment question, To some extent, problems of skills and training are those of response time; people's choices may lag new opportunities, as may programs of study in educational institutions (ch. 8). Shortages of entry-level electrical engineers in the United States have reflected, not only rapid growth in demand for the products of the electronics industry, but slow response within the educational system to new labor market demand. This is one way in which employment is affected by public policies, at least to the extent that schools and universities depend on governments (including State and local) for resources. Government programs can also help men and women who find themselves unemployed or underemployed develop new skills and find new jobs. Adjustment is but one of several avenues; during the 1930's, the Federal Government instituted many programs to ex*pand* employment. These massive public works efforts drew support from Keynesian theory, which held that demand stimulation could help ensure full employment.

Despite the experiences of the Depression, and the many job programs since, the United States does not have a comprehensive manpower policy at the national level. Although some States have set up worker training programs to help attract industry, retraining has never been approached systematically, in striking contrast to nations such as West Germany; in addition to the vocational programs mentioned in the preceding chapter, the German Labor Market Office matches unemployed workers with openings through a nationwide computer survey.[6] There are no parallels in the United States.

This brief review illustrates the difficulty of assessing the consequences of changes in technology 01 competitive position even in a single industry like electronics. First, many of the factors are interrelated. How can shifts in competitiveness be isolated from the effects of aggregate economic growth, which determines demand for the industry's products? How directly must gains or losses of jobs elsewhere in the economy be linked to changes within the electronics industry (e. g., new technologies] to justify an attribution to electronics? Should vir*tual* employment and unemployment—jobs that would or would not exist in the *absence* of changes in electronics technology—be included? Finally, which impacts are most significant? Those on individuals? On companies? On entire industries? Or are all three of comparable importance? What of regional dislocations? There can be no easy answers to the general question of whether continuing developments in electronics will have positive or negative consequences for employment in the United States,

The following sections look in more detail first at changes within the electronics industry, then at effects on other sectors.

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[5] H. Berglind, "Unemployment and Redundancy in a 'Post-Industrial' Labor Market, " *Work and Technology,* M. R. Haug and J. Dofny (eds.), *Sage Studies in International Sociology* 10 (Beverly Hills: Sage Publications, 1977), p. 201,

[6] L. **Dobyns,** "America Works When America Works, " *NBC White Paper,* June 25, 1981,

Employment Trends in the U.S. Electronics Industry

Changes in employment within any one industry take place in a larger context. Employment in U.S. manufacturing as a whole has been essentially static since the late 1960's. Over the period 1972-82. manufacturing jobs declined from 26.0 to 21,8 percent of the nonagricultural work force.[7] Of course, these broad trends tell little about employment on a

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[7] *Economic Report of the President* (Washington, D.C.: U.S Government Printing Office, February 1983), p. 205.

sectoral basis; the number of jobs in the U.S. consumer electronics industry has declined, while in computers and semiconductors expanding output has brought rising employment.

Analysis of such trends depends on how the industry is defined and subdivided. For instance, data published by the Electronic Industries Association (EIA) show 1.6 million workers in the entire industry in 1982.[8] EIA, however, bases its tabulation on very broad SIC (Standard Industrial Classification) categories. Among these is SIC 367, "electronic components and accessories, " which has nine subdivisions. Only one–3674, "semiconductors and related devices''—is among the portions of the electronics industry that OTA has focused on, others—e.g., "electronic coils, resistors, and capacitators" —being less illuminating in terms of international competition. Therefore, discussion of employment in the rest of this chapter is limited to the following four SIC categories?

- 3651—Radio and Television Receiving Sets, Except Communication Types, (Despite the title, this SIC group includes more than just radios and TVs, extending to nearly all home entertainment or consumer electronic products; consumer audio equipment, public address systems, and amplifiers for musical instruments all fall within SIC 3651.)
- 3674—Semiconductors and Related Devices. (This category includes virtually all types of microelectronic components, ranging to solar cells and bubble memories, those manufactured by captive plants as well as merchant firms,)
- 3671—Radio and Television Receiving Type Electron Tubes, Except Cathode Ray. (Virtually all vacuum tubes are included except for TV picture tubes and other cathode ray tubes, and special purpose devices such as klystrons or X-ray tubes.)
- 3573—Electronic Computing Equipment. (Processors and peripherals of all types fall into SIC 3573.)

In referring below to these SIC categories, more inclusive names—e.g., consumer electronics for SIC 3651—have been adopted. Both semiconductors (3674) and the vacuum tubes they have largely replaced (3671) are examined, so that growth in the first category can be compared to contraction in the second.

During the 1970's, employment grew in two of these four SIC categories, as table 74—based on data gathered by the Bureau of Labor Statistics (BLS)—shows. In microelectronics, employment has doubled, and in computers it has gone up even faster, while the consumer electronics category has shrunk, (Most of the contraction in vacuum tube production predates 1972.) In 1982, the nearly 800,000 workers covered by the SIC codes in table 74 totaled slightly more than 4 percent of the 19 million men and women in the U.S. manufacturing

Table 74.—Employment in Selected Portions of the U.S. Electronics Industry

	Number of employees and percentage of production workers (in parentheses)		
SIC category	1972	1980	1982a
3651, consumer electronics.	114,500 (740/.)	85,900 (70°/0)	74,400 (670/o)
3674, microelectronics	115,200 (51%)	226,900 (44°/0)	230,000 (40°/0)
3671, vacuum tubes	46,400 (70°/0)	42,600 (620/o)	43,400 (61 '/0)
3573, computers and peripherals	182,300 (360/.)	350,200 (40°/0)	418,300 (380/.)
	458,400	705,600	766,100

[a] First 10 months.

SOURCE Bureau of Labor Statistics

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[8] *Electronic Market Data Book 1983* (Washington, D. C.: Electronic Industries Association, 1983), p. 144. This is the total of Labor Department employment figures for four Standard Industrial Classification categories: SIC 3651 (radio and TV receivers), 366 (communications equipment), 367 (components), and 3573 (computers). Communications, with more than 550,000 employees in 1982, makes up one-third of the total.

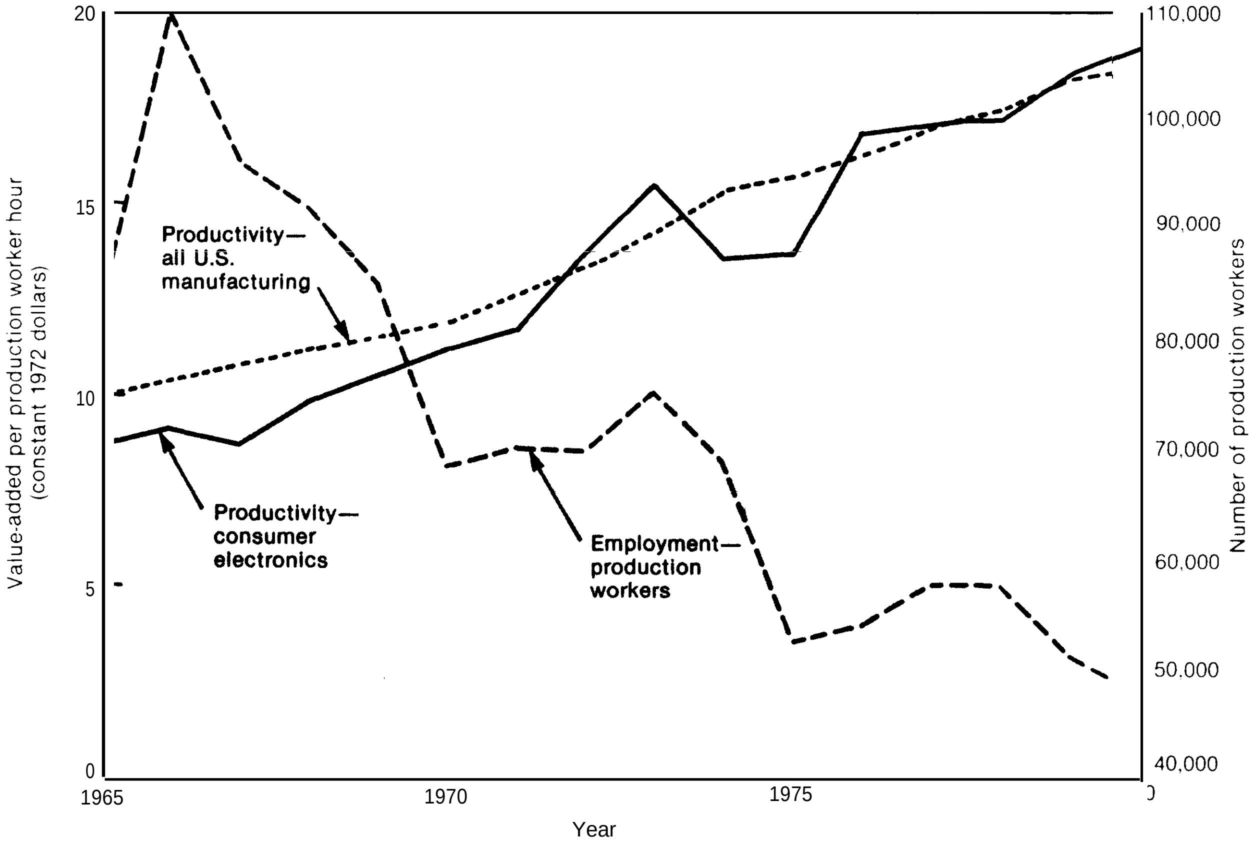
[9] Defined in *Standard Industrial Classification Manual 1972* (Washington, D. C.: Office of Management and Budget, 1972), pp. 190 (SIC 3651), 193 (SIC 3674), 192 (SIC 3671), and 180 (SIC 3573).

work force, making even this portion of the electronics industry larger than, say, steelmaking—which employs half a million. *

Figure 56 compares trends in labor productivity and employment (for production workers only) over the past decade for each of the categories except vacuum tubes, In all three charts, productivity is given as value-added per production-worker hour in real, inflation-adjusted terms. Productivity growth in consumer electronics, figure 56(a)—where employment declined—has paralleled the all-manufacturing average, growing slightly faster in earlier years. In contrast, computer manufacture–fig. 56(c) —shows the most rapid rise in employment; the number of jobs doubled, with productivity rising almost as fast until the mid-1970's. Past this point productivity growth has slowed—but, as pointed out in chapter 5, productivity trends in terms of value can be misleading when technical change is as rapid as it has been in the data processing industry. Even so, value-added productivity in computer manufacturing has risen much more rapidly than for U.S. manufacturing as a whole. Many jobs have also been created in semiconductors, fig. 56(b), where productivity gains were again substantially above the all-manufacturing average. The cyclical nature of employment in the semiconductor industry distinguishes it from both consumer electronics and computers; the sensitivity of semiconductor production to recession is magnified by the tendency of purchasers to quickly cut back on orders when their own out-

Figure 56.—Labor Productivity and Employment by Sector of the U.S. Electronics Industry

(a) Consumer Electronics (SIC 3651)



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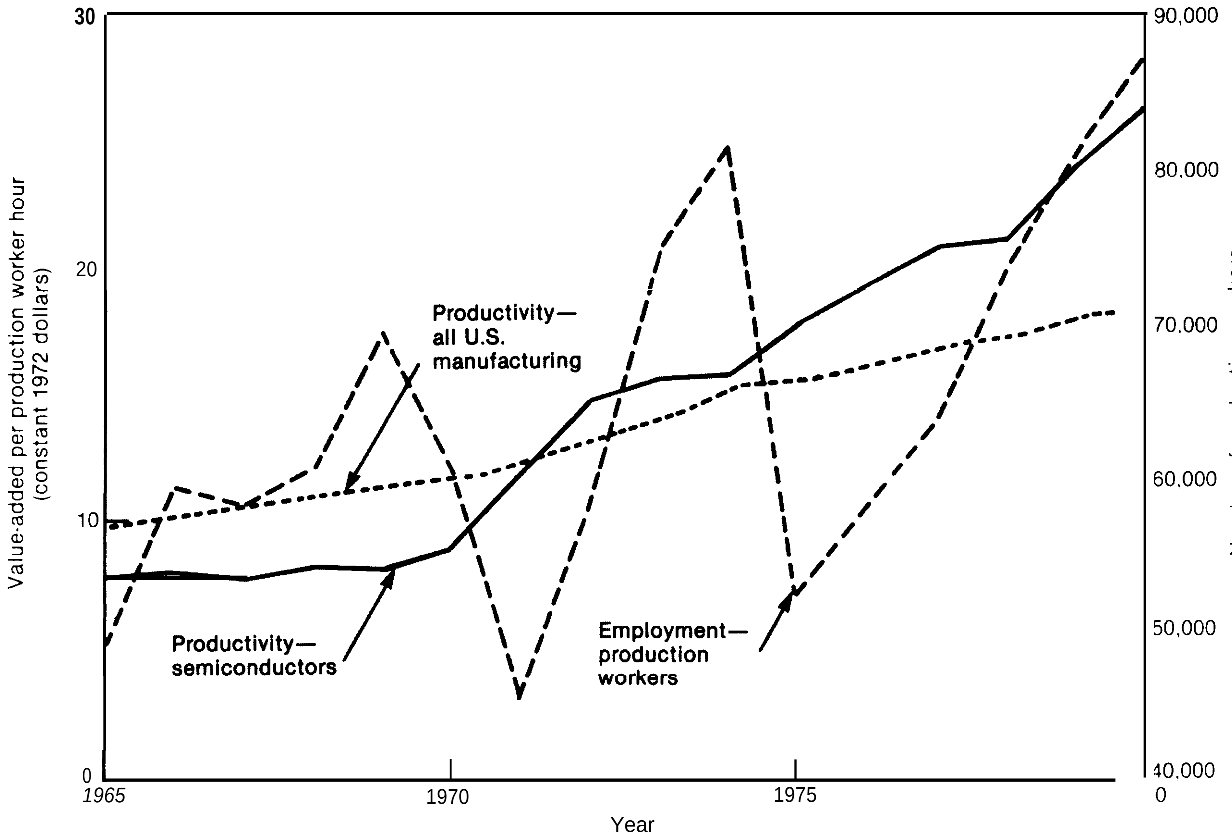
*BLS figures for the first 10 months of 1982 show 18.9 million workers in manufacturing—11.2 million in durable goods, 7.7 in nondurables.



(b) Semiconductors (SIC 3674)

put drops, sometimes to double-order in upswings for fear of shortages.

As the plots in figure 56 demonstrate, the portions of the electronics industry that showed the highest rates of productivity growth also experienced the highest rates of employment growth. Increases in productivity were associated with the creation of jobs, not their elimination. The reason is simple: output in computers and semiconductors grew at very high rates, spurred by exports as well as domestic sales. The domestic market for radios and TVs grew more slowly, exports were small, and import penetration has been severe.

As the cases of computers and microelectronics illustrate, when rates of change in technology and productivity are high, employment may rise. Similar correlations sometimes follow at the aggregate level; unemployment may drop while productivity climbs, particularly if coupled with rapid technical change and high investment. But as the examples from electronics in figure 56 illustrate, there can be a great deal of variation across sectors: productivity rises at different rates; sometimes employment goes up, sometimes down. Still, over time, technologically progressive U.S. industries have generally experienced—not only above-average productivity gains, decreasing real prices, and increases in sales—but relative increases in employment as well.[10] While an increase in em-

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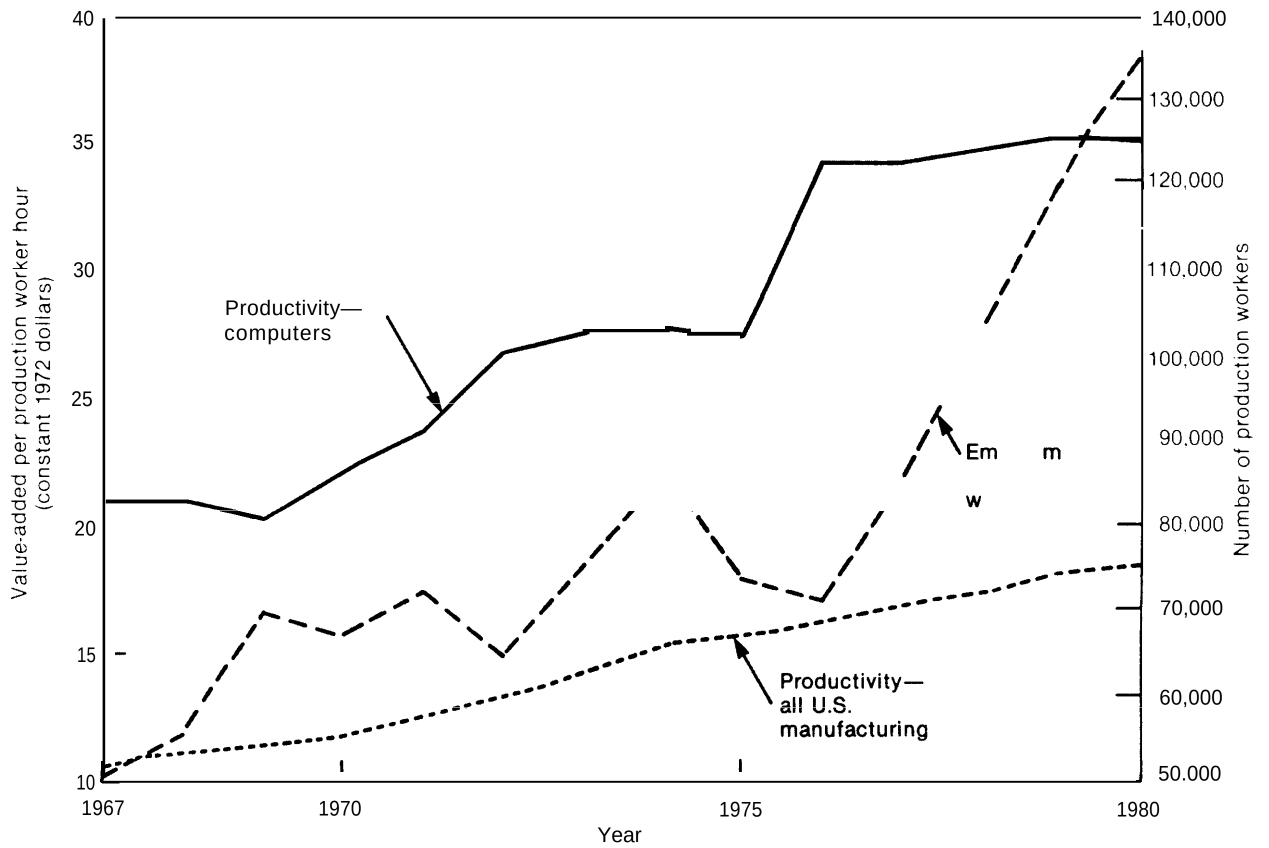
[10] Denison and others have studied the contributions of technological change to economic expansion—for example, E. Denisen, *Accounting for United States Economic Growth* (Washington, D. C.: Brookings Institution, 1974). For an analysis of trends in electronics, see W. Kendrick, "Impacts of Rapid Technological Change in the U.S. Business Economy and in the Communications, Electronic Equipment and Semiconductor Industry Groups," *Microelectronics, Productivity and Employment* (Paris: Organization for Economic Cooperation and Development, 1981], pp. 25ff.

(c) Computers (SIC 3573)



NOTE Census Bureau figures for employment may not agree exactly with BLS figures cl fed elsewhere in this chapter BLS figures are collected at the plant level and may include some workers from other SIC categories if a plant makes products that fall under several categories Census figures are used in these charts for consistency with productivity data from the Census Bureau Value-added figures have been converted to constant dollars using the implicit price deflator for consumer durables

SOURCES 1965.77— 1977 *Census of Manufactures 1978.80— 1980 Annual Survey of Manufactures*

ployment is not inviolably associated with the development of new technologies and productivity growth, the pattern is not an uncommon one. That employment goes up does not, of course, mean that adjustment problems disappear—but it can provide leeway to deal with them. The next sections examine employment by sector in more detail.

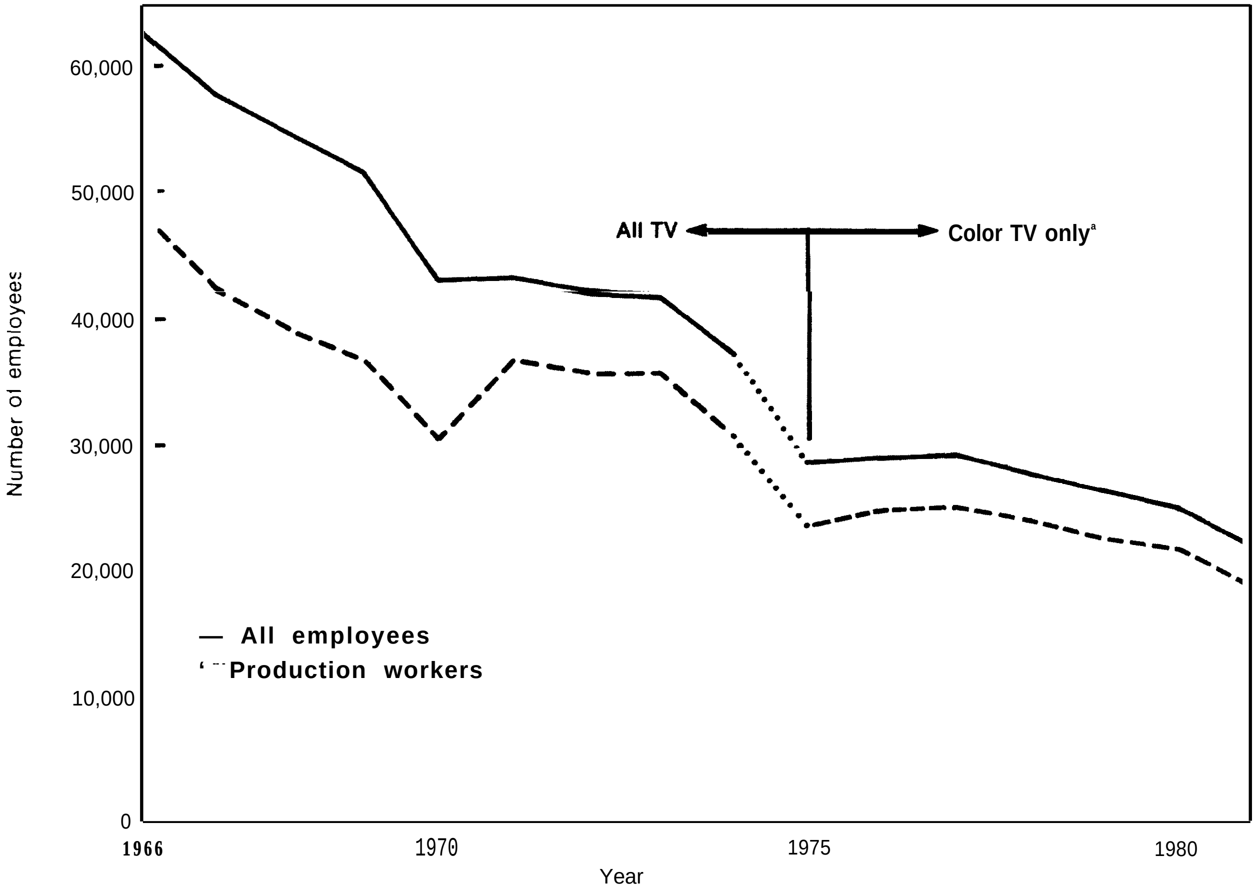
Consumer Electronics

Trends in Employment

Domestic employment levels in TV manufacturing have been falling rather steadily since the mid-1960’s, despite a doubling of production volumes. Figure 57 illustrates the decline, which was especially precipitous over the early 1970’s (as noted on the plot, the data cover TVs only, not consumer electronics as a whole]. Jobs for production workers dropped by half between 1971 and 1981. Over these years, a number of U.S. manufacturers either merged with Japanese or European producers or left the business. On the other hand, the industry now includes more than 10 foreign companies with assembly operations in this country that contribute to the employment totals in the figure,

For reasons discussed in more detail below, and ranging from automation to simpler chassis designs, labor productivity in U.S. TV manufacture is much greater now than a few years

Figure 57.—U.S. Employment in Television Manufacturing



a Monochrome production in the United States had dropped to low levels by 1975

SOURCES 1966-70— *Television* Receivers *and Certain Parts Thereof* (Washington, D C U S Tariff Commission Publication 436 November 1971) p A 70 1971 -75— *Television Receivers, Color and Monochrome, Assembled or Not Assembled, Finished or Not Finished and Subassemblies Thereof* (Washington, D C U S International Trade Commission Publication 808, March 1977), p A-117 1976, 1977– *Color Television Receivers* U S *Production, Shipments, Inventories Imports, Employment, Man Hours, and Prices, Fourth Calendar Quarter 1977* (Washington D C U S International Trade Commission Publication 866 March 1978), table 5 1978, 1979— *Color Television Receivers* U S *Production, Shipments, Inventories, Imports, Employment, Man-Hours, and Prices, Fourth Calendar Quaffer 1979* (Washington, D C U S International Trade Commission Publication 1036 February, 1980) p A 7 1980, 1981 —*Color Television Receivers" U.S. Production, Shipments, Inventories, Exports, Employment, ManHours, and Prices, First Calendar Quarter 1982* (Washington, D.C U.S International Trade Commission Publication 1245, May 1982), table 5

ago; the causes of the employment declines in figure 57 extend well beyond import competition or offshore assembly, with technological change a major force. Although the contributions of the various factors cannot be quantified with any precision, the spread of solid-state chassis designs and associated manufacturing methods dramatically reduced employment requirements in the industry.

Figure 57 includes only those people involved in TV manufacturing. Television accounts for roughly half the U.S. consumer electronics market (ch. 4, table 8), and rather less in terms of jobs. Total employment in SIC 3651—which covers many other consumer electronics products—is considerably greater, as shown in figure 58. Still, the number of workers here has been in decline since 1973, for similar reasons.

Productivity

As domestic output of TVs grew over the years covered by figure 57 (see ch. 4, table 9), apparent productivity—measured by annual

Figure 58.—U.S. Employment in Consumer Electronics (SIC 3651)

SOURCES 1960-1 965— 1977 Census of Manufactures 1972-82—Bureau of Labor Statistics

output divided by the number of production workers—jumped from 150 sets per worker in 1971 to 560 in 1981, In terms of value-added per production worker, productivity was up by about 40 percent during the decade—a trend not far different from that for the broader consumer electronics category seen in figure 56(a). * During this period, the proportion of domestic value-added dropped as American manufacturers shifted labor-intensive operations to developing countries; whether made by American- or foreign-owned companies, TVs produced in the United States now include more imported components and subassemblies. Because of these trends (table 13 in ch. 4 illustrates the rise in imports of incomplete sets and subassemblies over the latter part of the 1970's) simply dividing the total output of TVs by the number of employees considerably overstates productivity y gains. However, the value-added productivity measures adjust for this.

Thus, there is no question that productivity increased considerably during the 1970's, the result of design changes and automation driven by competitive pressures (ch. 6). As manufacturers moved from monochrome to color production, they shifted to more highly automated manufacturing facilities. Somewhat later, redesigned solid-state chassis cut the number of parts, hence the labor content; only 6 percent of the color TVs made in the United States were solid-state models in 1970, but by 1976 essentially all had been redesigned around transistors.[11] A good part of the productivity growth over the 1970's resulted from changes

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***In** terms of constant 1972 dollars, annual value-added per production worker in TV manufacturing went from $22,2oo in 1971 to $31,600 in 1977, falling to $27,300 in 1981. See 1977 *Census of Manufactures: Communication Equipmen t, Including Radio and TV,* MC77-I-36D (Washington, D. C.: Department of Commerce, June 1980), p. 36 D-5 and 1982 U.S. *Industrial Outlook* [Washington, D.C.: Department of Commerce, January 1982), p. 343. Conversions to **1972** dollars **were made using the implicit** price deflator for consumer durables—*Economic Report of the President* (Washington, D (;.: U.S. Government Printing Office, February 1 982), p. 236.

[11] Data presented at International Trade Commission hearing on Investigation No. TA-201-19, January 1977.

in chassis design and associated manufacturing methods.

Although productivity gains in consumer electronics have contributed to declining employment, the *composition* of the work force has not changed greatly. As table 74 and figure 58 both illustrate, the ratio of production workers to nonproduction workers has decreased relatively slowly. In TV manufacture rather than consumer electronics as a whole, the shift has been greater, mostly taking place by the mid-1970's (fig. 57). The semiconductor industry, for one example, has seen more rapid changes in skill mix (table 74).

Imports and Offshore Manufacture

Earlier chapters described the inroads made by imported TVs, both monochrome and color, Few black-and-white sets are now manufactured here. Orderly Marketing Agreements (OMAs) restricted imports of color sets during the period 1977 to mid-1982, but figure 57 shows that the quotas did not arrest employment declines. Still, jobs would have been lost even faster without OMAs.

American consumer electronics firms relocated many of their manufacturing operations to low-wage offshore locations during the 1970's, While there are no precise figures on foreign workers employed in these plants, the Department of Labor believes that the number may be over 30,()()&-more than employed in domestic TV operations.[12] These people substitute quite directly for American workers.

Semiconductors

Since the mid-1950's, employment in semiconductor manufacture has grown rapidly, from a few thousand when production of semiconductor devices was just getting underway, to well over 200,000—figure 59. These totals include captive manufacturing. During two periods—1969-72 and 1974-76—employment dropped sharply as a result of recession.

As figure 59 also shows, the proportion of production workers in the domestic industry has declined–from 66 percent of the total work force in 1963 to 40 percent in 1982. Major causes include the transfer of production operations offshore and advancing technology. More complex manufacturing methods—including automation—have increased the relative need for technicians and other nonproduc-

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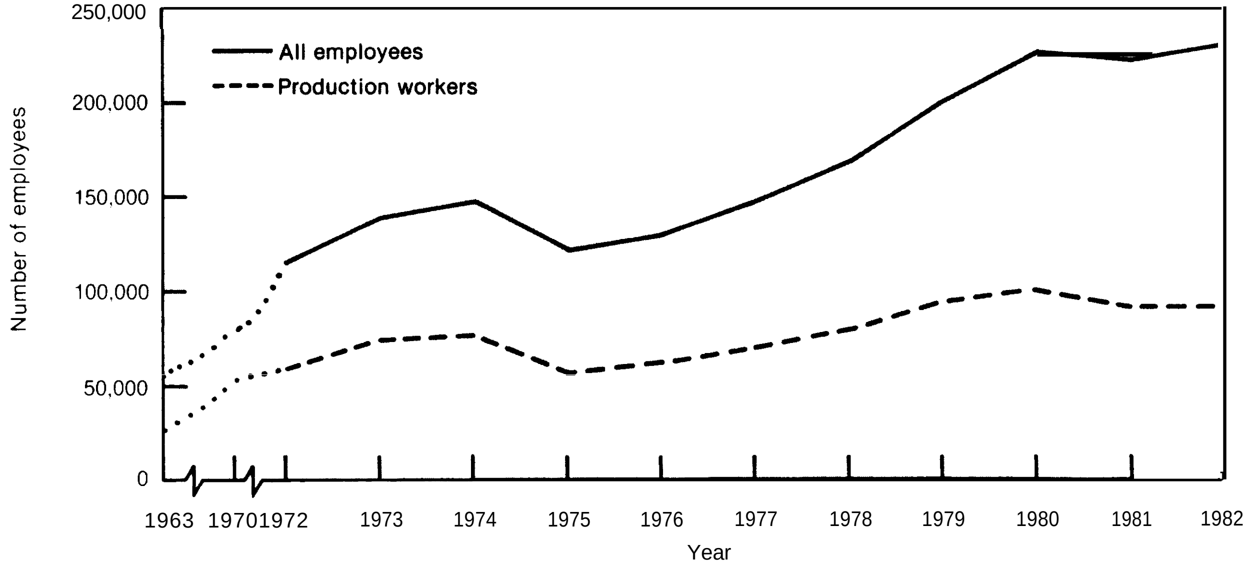
[12] Information from Department of Labor.

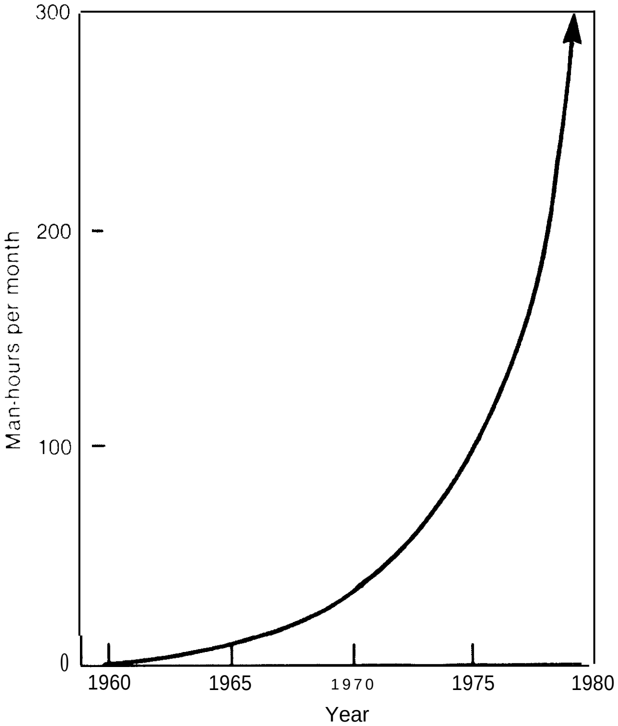
Figure 59.— U.S. Employment in Semiconductors and Related Devices (SIC 3674)



SOURCES 1963, 1970— 1977 *Census of Manufactures* 1972-82—Bureau of Labor Statistics tion workers. High levels of research and development have contributed to expansion in nonproduction ranks; the number of man-hours devoted to integrated circuit design has been increasing exponentially—figure 60. Technological advance in microelectronics has thus been paralleled by a decrease in semiskilled and unskilled employees relative to skilled workers and professionals in U.S.-based manufacturing. The result has been an "upskilling" of the domestic labor force. Employment opportunities for technical personnel—engineers, scientists, technicians—have grown rapidly. As these trends continue, the proportion of production workers in domestic semiconductor operations will fall even more,

American semiconductor firms transferred "back-end" operations overseas at a rapid pace during the 1960's, with more than 50 foreign manufacturing plants established during the decade.[13] While point-of-sale plants have arguably small impacts on domestic employment, offshore investments driven by lower wages directly displace American workers, just as in consumer electronics. Offshore manufacturing also contributes to the declining proportion of production employees in the United States. Unskilled assembly labor accounts for most of the jobs overseas; U.S. firms employ about three-quarters as many people in their foreign plants as they do here: around 180,000, of which more than 80 percent—as many as 150,000—are production workers.[14] Among U.S. merchant semiconductor firms, perhaps 90 percent of all assembly work is performed overseas. 15

Figure 60.— Effort Levels Associated With Product and Process Design for Integrated Circuits



SOURCE VLSI Some Fundamental Challenges —Scoping Its Future *IEEE Spectrum*. April 1979 p 35

Many U.S. companies make semiconductors solely for internal use, but no disaggregation of employment data is available for these captive facilities. While most produce specialized devices in relatively low volumes, with considerable variation in month-to-month levels, IBM is a large producer and large employer. Because some of the overhead and administrative tasks associated with captive manufacturing may be performed elsewhere in the firm, the proportion of production workers is probably higher than in merchant manufacturing.

As semiconductor production grew, the vacuum tube industry (excluding cathode ray tubes, hence TV picture tubes) declined—figure 61, While tubes still find specialty applications, by the early 1970's, substitution of semiconductors had caused domestic employment to drop by one-third from the peak level of 1966. Although jobs in tube manufacturing have been lost to technical change, far more people are now employed in making semiconductors than were *ever* employed in making vacuum tubes.

Computers

Computer manufacturing, like microelectronics, has seen rapid employment growth with simultaneous productivity improvement —although, as emphasized in chapter 5, productivity measures can be misleading where

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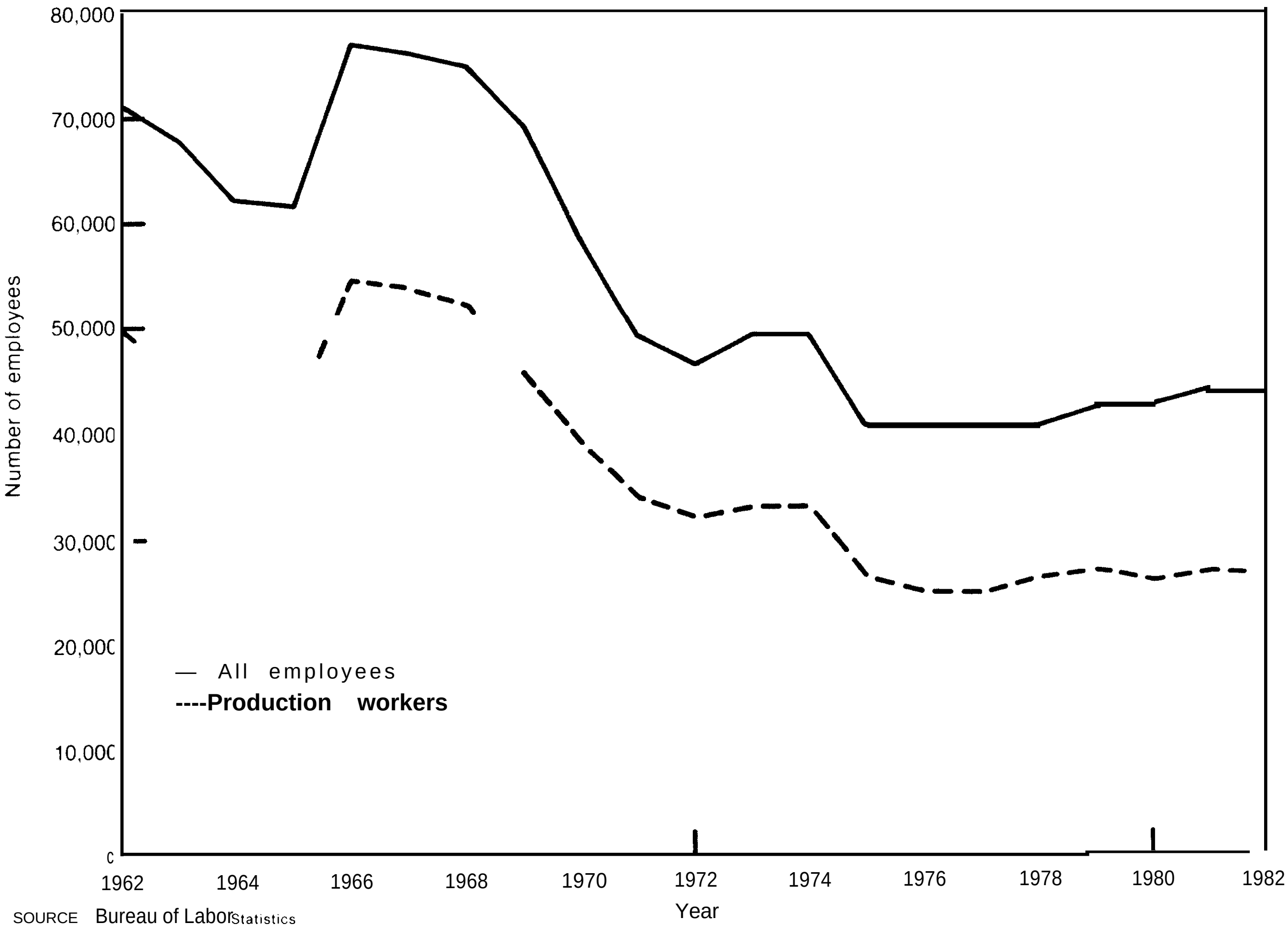
[13] *A Report on the U.S. Semiconductor Industry* (Washington, DC; .: Department of Commerce, September 1979), p. 84.

[14] *Summary of Trade and Tariff Information, Semiconductors* (U.S. International Trade Commission Publication 841, Control No. 6-5-22, July 1982], p. 8.

[15] J. R. Lineback, "Automation May Erase Offshore Edge," *Electronics*, Apr. 21, 1982, p. 94.

Figure 61.—U.S. Employment in Vacuum Tube Manufacturing (SIC 3671)



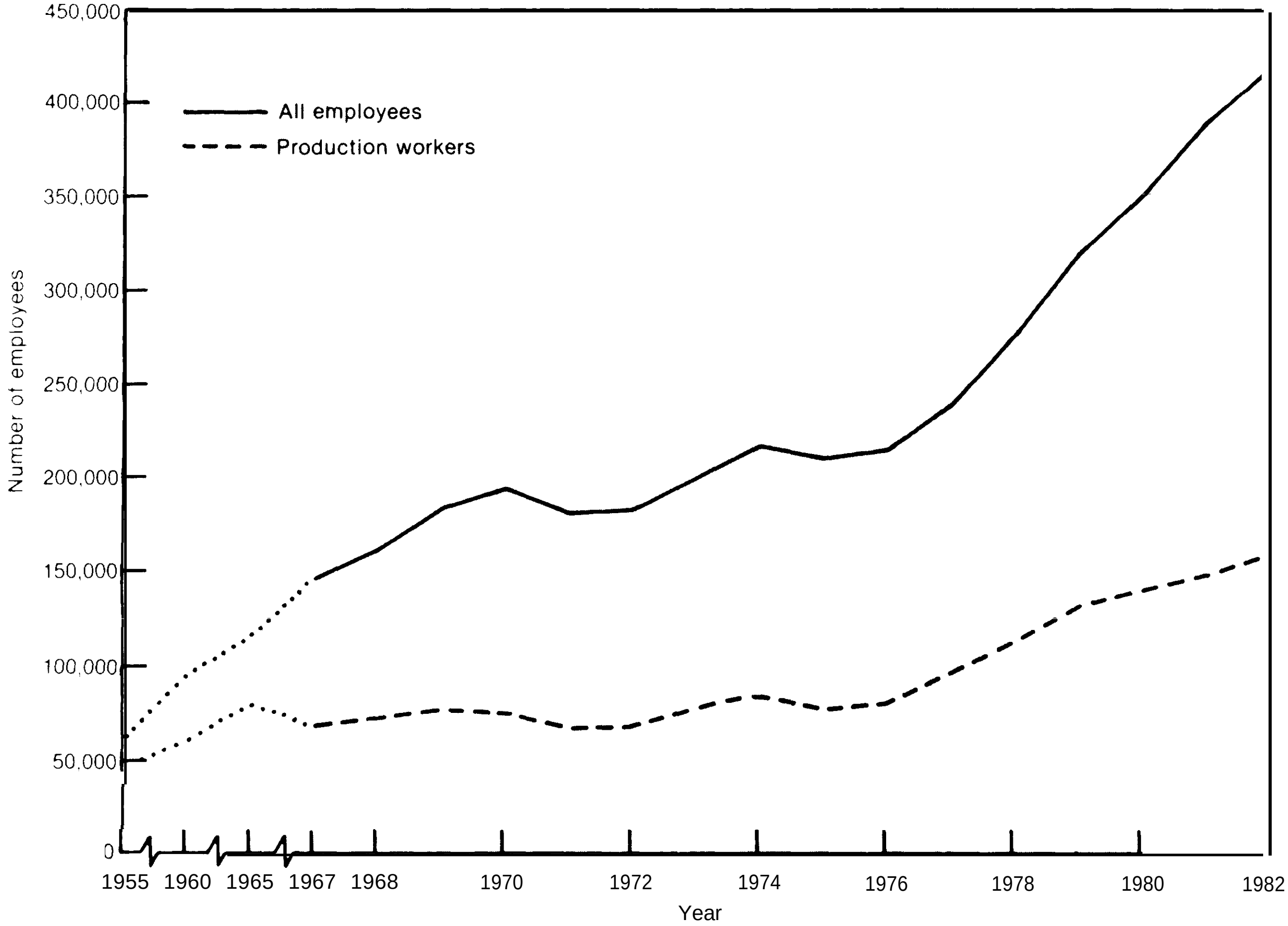
SOURCE Bureau of Labor Statistics

the product changes so much. Regardless, advances in computer systems have *created* vast numbers of jobs—not all in computer manufacturing. Many of these new jobs have originated in the user community, and in software production. Figure 62 illustrates job growth in the industry itself, including peripherals, Even more so than in microelectronics, the trend has been away from production employees and toward skilled workers and white-collar professionals.

Unlike either semiconductors or consumer electronics, employment in computers and peripherals has not been greatly affected by import penetration or offshore production. Many American computer firms have invested overseas, but foreign manufacturing facilities have generally served foreign markets. As in semiconductors, some of this foreign production may substitute for exports from the United States, but overseas sales are often tied to local production, limiting the extent to which point-of-sale plants displace domestic jobs.

The summary above of employment trends by sector in the domestic electronics industry shows that the number of jobs has increased, but not everywhere or uniformly. Increases in semiconductors and computers have more than offset—in magnitude—the declines in consumer electronics and vacuum tubes. The composition of the work force has changed; *employment gains have been greatest for nonproduction workers.*

Figure 62.—U.S. Employment in Computer (and Peripheral Equipment) Manufacturing (SIC 3573)



SOURCES 1955-65— 1977 Census *of Manufactures* 1988-82-Bureau of Labor Statistics

Effects of Import Penetration and Offshore Assembly

An increase in imports or a transfer of manufacturing operations offshore can cut into domestic job opportunities. The United States is importing more manufactured goods of all types, not only consumer electronics and semiconductors, making the import penetration question especially timely. Moreover, to labor unions, offshore production amounts to the export of jobs. For policy makers, both phenomena—but especially imports—have been a growing concern.

The employment consequences of import penetration and offshore assembly are felt in a context of global shifts in market structure, implying long-term changes as well as immediate impacts on people, firms, and industries. The dynamics are important on both time scales. In expanding markets, firms that can respond quickly to new opportunities anywhere in the world may be able to increase exports and consolidate their positions, aided by products that take advantage of new technologies. This happened during the 1970's, when American semiconductor firms capitalized on the shift toward metal oxide semiconductor integrated circuits ahead of their overseas rivals. Today, Japan's avowed goal of capturing more than 30 percent of the world computer market by 1990 (along with 18 percent of the U.S. market) reflects a belief that longstanding patterns can be disrupted when growth is rapid,

This section looks more closely at the effects of imports and offshore production on employment in consumer electronics and semiconductors (neither is important at the moment in computers). As pointed out in chapter 5, industries do not rise or decline in competitiveness simultaneously; looking at employment on a sectoral basis gives only part of the picture, and then an equivocal one. Still, the sectoral approach is a valid starting point, for reasons that are discussed in some detail in appendix B.

The first question is: What are the *causes* of import penetration? Imports may rise because demand exceeds domestic capacity or consumer preference shifts to foreign-made goods. Japanese penetration of U.S. markets for dynamic random access memories (RAMs) is an example of the first case, TV imports at least in part the second (imported automobiles are a more obvious example). In the first case, jobs may not be lost because of imports, but the rate of increase in domestic job opportunities may slow. In the second case, immediate decreases in employment are likely.

The full consequences of import penetration depend on the industry, Declining output in some industries—a prominent recent instance again being automobiles—can have major spillover effects elsewhere in the economy. As sales of domestic cars lagged, jobs were lost in firms making steel, tires, and components. Sometimes companies can limit impacts on individuals by allowing employment to decline through attrition rather than layoffs; even so, the overall pool of job opportunities shrinks.

The effects of offshore production are no more straightforward. On the one hand, all wages and salaries paid overseas could be viewed as a loss to American labor and the U.S. gross domestic product. But what if firms can only lower their costs and maintain or expand their markets by moving offshore—whether to take advantage of low-cost labor and be better able to compete with imports, or simply to manufacture their products nearer the ultimate market? Firms weigh a variety of such factors in deciding whether to invest overseas, although ultimate decisions generally turn on cost savings. From the standpoint of the Nation as a whole, rather than a particular company, the costs and benefits may be quite different. Appendix B discusses the impacts of offshore manufacturing on the aggregate economy and outlines the range of effects compared with alternatives available to the firm. This appendix includes a case study drawn from the experience of an American company which invested in a subsidiary in Taiwan. Briefly, the conclusion of the case illustration is that the offshore plant—established to assemble automobile radios—helped maintain competitiveness vis a vis Japanese manufacturers and prevented even more U.S. jobs from eventually being lost. As this suggests, in consumer electronics the movement offshore by American producers can be viewed as a defensive reaction to imports. In contrast, the motivation for overseas manufacturing in the semiconductor industry has been cost reduction and market expansion driven by domestic competition. The consequences for employment have been much different.

Consumer Electronics

Almost half the consumer electronics market in the United States has been taken by imports; in addition, many products assembled here depend heavily on imported components and subassemblies. Penetration of consumer electronics markets has coincided with employment decline, as shown in figures 57 and 58. Imports of black-and-white TVs rose from one-quarter to three-quarters of U.S. sales over the period 1967-77. Color TV imports peaked in 1976 at a level nearly tenfold greater than in 1967, then dropped because of OMAs. A third round of imports followed, the influx of video cassette recorders from Japan.

Today, all U.S. TV manufacturers operate foreign production facilities. In addition to the attraction of low-wage labor, Items 806.30 and 807,00 of the U.S. tariff schedules encourage offshore assembly (ch. 11). During the last half of the 1970's, 30 to 45 percent of all color TV imports entered under Item 807, although final assembly remains concentrated hem-in part because of foreign investments to avoid the OMA-imposed quotas.

Despite limits on imports, employment in TV manufacturing did not recover. In testimony before the U.S. International Trade Commission, the International Brotherhood of Electrical Workers reported that 20,000 workers had lost their jobs in the TV industry due to imports.[16] To what extent are imports to blame, given that domestic productivity improvements and offshore investments by U.S. firms have also contributed to employment decline?

It is oversimple to argue that the total number of foreign workers engaged in production for shipment to the United States—whether employed by U.S. or foreign firms– represents domestic employment loss, In most cases, U.S. consumer electronics firms had little choice concerning offshore production. Movement abroad was a defensive reaction, not a strategy aimed at expanding markets and improving profitability. To assume that jobs overseas substitute directly for U.S. employment is tantamount to assuming a stable competitive environment--which was not the case. Rather, employment declines followed losses in competitiveness; American firms had higher costs than their rivals, and little scope for developing strategies that would preserve domestic jobs. They pursued the obvious route: increased automation to raise productivity at home, combined with transfers of labor-intensive operations offshore, Only some companies survived; the others were purchased by more successful manufacturers or left the industry. In this sense—as part of a more complex chain of *events—import competition must indeed be counted as the primary cause of job losses in consumer electronics.* [17]

But this is not the whole story: Is it possible that the ready availability of Item 807.00 reduced incentives for American managers to cut costs and improve labor productivity at home? Might U.S. firms have avoided offshore production by adopting more capital-intensive automated manufacturing processes here? Jobs still might have been lost, but the costs and benefits would have shifted. The behavior of American executives is often contrasted with that of their Japanese counterparts, who recently have faced similar difficulties-i. e., competition from countries with much lower labor costs. Some observers have claimed that Japanese consumer electronics firms have invested more rapidly and more boldly in mechanized production technologies such as automatic component insertion (see ch. 6 for a further discussion of rates of adoption of automation).

As with many such questions, the truth probably lies somewhere between. The availability of Item 807 reduces the pressure to find cheaper manufacturing methods at home. It is also true that the Japanese, when themselves confronted with the rather sudden emergence of competition from other Far Eastern countries, transferred some of their production to lower wage sites. In part, such transfers were also caused by the 1977 OMA—which, by limiting shipments from Japan, created incentives for Japanese firms to move to export platforms--but Japanese managers exhibit little reluctance to take whatever steps seem necessary' for preserving hard-earned market positions. Along with developing new production methods-–an uncertain business —Japanese firms would probably have shifted labor-intensive production abroad in any case, simply for insurance. In this respect, Japanese managers have behaved much like Americans.

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[16] "Testimony Before the U.S. International Trade Commission on TV Receivers (TA-201-19), International Brotherhood of Electrical Workers, 1977. See also "Petition for the Extension of Import Relief," submitted to the U.S. International Trade Commission, Dec. 11, 1979.

[17] For a generally contrary view, see A, O. Krueger, "Restructuring for Import Competition From Developing Countries, I: Labor Displacement and Economic Redeployment in the United States," *Journal of Policy Modeling* vol 2, 1980, p. 165

Photo credit: Control *Automation*

Robot set up for assembling electronic components

While U.S. employment would have dropped even faster without OMAs, the lesson—repeated in other industries—is that controlling levels of imports to provide companies a respite during which they can take measures to enhance their competitiveness is unlikely to improve employment prospects, Indeed, just the opposite tends to be true, as manufacturers strive to cut costs by improving labor productivity, To the extent that they succeed, employment probably will decline, even in situations where modest growth in output takes place. As a result, trade protection seldom functions as a substitute for assistance to displaced workers.

Semiconductors

U.S. imports of semiconductor devices have increased steadily, exceeding imports by 1982 (ch. 4, fig. 24); in earlier years, the United States exported many more semiconductors than it imported. Do such trends portend job losses? More to the point, with Japanese manufacturers holding half or more of the burgeoning 64K RAM market, will employment in this portion of the electronics industry suffer as in consumer electronics? There is a major difference: semiconductor production is still expanding rapidly, Furthermore, American semiconductor manufacturers have exported much more actively than consumer electronics firms.

Figure 59 showed the steadily growing employment in the U.S. semiconductor industry. Domestic jobs more than doubled during the **1970's**; offshore employment probably expanded even faster. The question again is: Do imports, or foreign workers employed in the overseas operations of U.S. firms, stand for job opportunities lost to Americans? Imports and offshore manufacturing are more closely coupled for semiconductors than for consumer electronics. Nearly 40 percent of U.S. semiconductor sales are classed as imports, but more than three-quarters of these are re-imports by American firms under Items 806 and 807 of the tariff schedules. Offshore production is central to the U.S. industry. Still, shipments from Japan have also risen swiftly over the last 5 years.

The offshore facilities of U.S. semiconductor manufacturers concentrate on the labor-intensive steps in the production process—primarily assembly. In the mid-1970's, Finan estimated that manufacturing costs for integrated circuits could be cut in half through offshore assembly.[18] Cost/price competition has thus been the primary motive for foreign investments; *American semiconductor firms moved offshore to reduce costs and expand markets*. Moreover, the competition has been largely among domestic firms; investments predate Japanese competition by a decade and more. If in the case of consumer electronics, offshore manufacturing was a reaction to import competition, in semiconductors the primary motivations were offensive. Capital investment requirements have been one of the forces at work. In order to keep up with demand, semiconductor firms have been under continual pressure to add new capacity (ch. 7). Offshore assembly offered flex-

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[18] W. F. Finan, "The International Transfer of Semiconductor Technology Through U.S.-Based Firms, " Working Paper No. 118, National Bureau of Economic Research, December 1975, p. 60. The savings are greater for simpler integrated circuits and discrete devices than for complex circuits—as illustrated in app. B—because the assembly cost is a larger fraction of the total cost for simple devices.

ibility; firms could avoid the risks of investments in automated equipment that might soon be outdated, expanding capacity without taking funds from capital-intensive wafer fabrication and testing equipment.

What are the implications for job opportunities? As the case study in appendix B illustrates, these depend in part on the time horizons. Given rising foreign competitiveness in microelectronics, offshore production now helps meet international as well as intranational competition. If overseas manufacturing helps U.S. firms maintain their competitiveness, the net impact on domestic employment might be positive over the longer term. Furthermore, point-of-sale plants are sometimes able to sell in markets to which the U.S. parent would have difficulty in exporting because of trade barriers. In some instances at least, American firms may thus be able to strengthen their long-term competitive position by investing overseas, enlarging domestic as well as foreign employment. Still, in the short term, offshore investments cut the number of job opportunities for Americans. In this respect, questions of the impact of Items 806 and 807 of the tariff schedules are similar to the more general problem—isolating the consequences of foreign direct investment of any type on employment. Such matters have been investigated extensively over the years. The most common conclusion is that direct investment by American corporations has increased net employment in the United States; nevertheless, the opposite result is sometimes reached, again depending on the particulars. In the end, implications—both short and long term—can only be evaluated on a case-by-case basis, and depend on assumptions concerning the future competitive environment for American firms.

Foreign Investment in the United States

Foreign investments here bring yet another dimension to questions of domestic employment. Japanese investment in the United States has grown rapidly, from a cumulative $152 million in 1973 to $4.2 billion by 1980.[19] The desire to open new markets and to ease trade frictions are among the forces behind this influx. Japanese-owned firms now assemble nearly 4 million color TVs here each year. North American Philips adds well over a million.

As this suggests, most of the past investments in electronics have been limited to consumer products, Japanese interests seem bound to widen, however, with plants for assembling integrated circuits the next step. In typical foreign-owned manufacturing plants, only a few upper management slots are reserved for executives from headquarters. Viewed strictly from an employment perspective, therefore, onshore manufacturing has positive consequences for the United States. Viewed more broadly, the picture becomes mixed: many of the skilled and professional jobs remain overseas.

Generalizations about employment that would apply to all parts of the electronics industry are impossible. In the case of consumer electronics, import penetration is closely associated with job loss. In contrast, employment has grown steadily in both domestic and foreign operations of U.S. semiconductor firms; overseas investments have helped cut costs, expand markets, and increase competitiveness. Simply in terms of numbers of jobs, expansion in semiconductors and computers has more than offset declines in consumer electronics. This does not mean, of course, that such trends will persist indefinitely. Nor is it any consolation to people who find themselves out of work. The rest of the chapter looks to the future.

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[19] "Japanese Manufacturing operations in the United States," Japan External Trade organization, September 1981.

Projections of Employment Within the Electronics Industry

Before examining impacts on other parts of the economy, this section treats the industry itself, in the context of Bureau of Labor Statistics (BLS) employment projections to 1990. The perspective is much broader than the discussion of possible shortages of engineers and skilled workers in the previous chapter.

Ideally, projections of future trends would be based, not only on a model for aggregate economic expansion, but also on sector-specific variables—growth in particular product markets, demand for workers with certain kinds of skills, levels of imports and exports. Unfortunately, this much detail is seldom attempted. BLS projections, virtually the only analyses available with industry-specific output, are based on an econometric model—a limited tool, although representative of the state of the art.[20]

BLS began making econometrically based employment projections two decades ago, introducing a macroeconomic demand model in 1975. Their current procedure includes five basic steps: 1) projections for the economy in the aggregate; 2) disaggregation of GNP by demand categories; 3) distribution of demand by categories to producing industries; 4] output projections by industry sector based on an input-output table; and 5) forecasts of labor productivity, total labor hours, and number of people employed at the sectoral or industry level. A critical input in terms of employment is the estimated gross demand for the products of an industry, This gross output is divided by an estimated productivity level (output per employee-hour) to yield the labor hour projection for the industry, and thus employment. The model as a whole is sensitive to a wide range of assumptions, most fundamentally those for GNP growth. BLS's recent projections have been based on GNP increases ranging from 2.4 percent annually (the "low trend") to 3,8 percent (the "high trend"). These assumptions compare with a 1973-79 average of 2.8 percent per year. BLS has assumed growth in labor productivity to stabilize at the rather low levels of recent years.[21]

On this basis, BLS predicts that aggregate growth in U.S. employment will range from 1.6 to 2.0 percent annually over the decade of the 1980's, considerably below the 2.7 percent yearly rise for 1975-79. Women will get two-thirds of the new jobs. The durable goods portion of manufacturing is expected to grow faster than the all-industries average, nondurable slower.

Output increases in computers and related equipment should lead all other manufacturing industries; employment in the computer industry will grow from about 420,000 in 1982 to perhaps 600,000 by the end of the decade. If these projections prove realistic, employment in the computer and peripherals sector will comprise as much as 3.1 percent of the total manufacturing work force by 1990, compared to 1.6 percent at the end of the last decade. Employment in the electronic components sector (SIC 367) is expected to grow at about 2.2 percent per year in both low- and high-growth scenarios, well above projections for manufacturing as a whole. In the low-growth scenario, 33 of the 150 industries examined show employment drops, One of these is radio and TV manufacturing, with an anticipated decline averaging 1.4 percent per year over the period 1979-90. Thus, if BLS projections prove realistic, past employment trends in electronics will persist: there will be continuing decline in consumer electronics, rapid growth in computer manufacturing, and con-

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[20] "Methodology for Projections of Industry Employment to 1990, " Bulletin 2036, Department of Labor, Bureau of Labor Statistics, February 1980.

[21] For more; detail, see v. A. Personick, "The outlook for Industry Output and Employment Through 1990, " *Monthly Labor Review*, August 1981, pp. 28ff. Also *Occupational Outlook Handbook*, 1982-83 *Edition*, Bulletin 2200" (Washington, 1), C.:Department of Labor, Bureau of Labor Statistics, April 1982).

siderable expansion in components. Together, these three portions of electronics might, under the most favorable circumstances, account for more than 7 percent of U.S. manufacturing employment in 1990. The projections are all conditional, needless to say, and BLS's approach shares the principal limitation of virtually all forecasting techniques: current trends are expected to continue, breaks with the past seldom anticipated.

BLS also estimates employment by occupational category across industries; in all scenarios, white-collar jobs grow faster than total employment, blue-collar jobs slower. White-collar workers will make up slightly more than half the 1990 labor force—the fraction is slightly less now—with notable increases in the professional and technical category.[22]

Table 75 lists occupations in electronics for which BLS predicts the greatest percentage increase during the 1980's. All are grey- or white-collar jobs. The nonelectronics categories are included for comparison; 5 of the 10 fastest growing occupations in the complete BLS listing are electronics-related. Despite the high growth rates, categories starting from a modest base will not account for large numbers of new jobs.

Table 75.—Predicted Growth Rates by Occupational Category Over the 1980's

Occupation[a]	Predicted increase in employment (1980-90)
Paralegal	109°/0
Data processing machine mechanic	93
Computer operator	72
Computer systems analyst	68
Business machine service technician	60
Computer programer	49
Employment interviewer	47
Computer peripheral operator	44
Psychiatric aide	40

[a] Noninclusive fastest growing occupations in electronics are listed together with selected occupations outside of electronics (in italics) for comparison

SOURCE Testimony Before the Senate Subcommittee on Employment and Productivity, March 26 1982 by Ronald E Kutscher, Assistant Commissioner, Office of Economic Growth and Employment Projections Bureau of Labor Statistics *Productivity in the American Economy 1982* hearings Subcommittee on Employment and Productivity Committee on Labor and Human Resources U S Senate, Mar 19 and 26 Apr 2 and 16 1982 p 327

Photo credit Western Electric Co

Semiconductor wafers being loaded into furnace

As shown earlier, the electronics industry experienced a more-or-less gradual shift toward fewer production workers and more white-collar workers during the *1970's*, with the biggest change in semiconductor manufacturing (fig. 59). Table *76* gives occupational breakdowns in consumer electronics, components, and computers according to BLS data for **1980.** While BLS expects some further upskilling during the 1980's, the projections (not shown)--which may or may not be well-founded-indicate these to be mostly matters of a percentage point or two. Note that the SIC categories in table 76 are broader than used earlier; the consumer electronics data cover SIC 365, rather than the "home entertainment" subdivision, 3651; electronic components, SIC 367, includes all types of components, not just microelectronics; and the computer category referred to earlier, 3573, is a subdivision of SIC 357. Moving the boundaries of these categories outward probably makes little difference for consumer electronics and computers, but components as a whole are not nearly as skill-intensive as microelectronics; thus the proportions of technical professionals in table 76 are considerable underrepresentations for semiconductor firms (compare table 74).

Table *76* points quite graphically to the high skill requirements of the computer industry, where about 60 percent of the work force falls

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[22] M. L. Carey, "Occupational Employment Growth Through 1990," *Monthly Labor Review*, August 1981, p. 45.

Table 76.—Occupational Distributions in Electronics as of 1980

	Consumer electronics (SIC 365)	Electronic components (SIC 367)	Computers (Sic 357)
White- and gray-collar workers	***27.90/.***	***32.00/.***	***59.00/0***
Professional and technical:			
Engineers (and scientists)	3.6	6.2	11.3
Engineering technicians	2.8	6.1	9.3
Computer specialists	0.6	0.6	6.2
Other	3.0	2.8	5.7
Managers	4.7	5.4	9.4
Salesworkers	0.7	0.7	1.0
Clerical	12.5	10,2	16.1
Blue-collar workers	***62.1 0/0***	63.60/o	38.20/o
Craft	17.3	14.8	12.1
Assemblers and machine operators	44.8	48.8	26.1
Service ***workers and others.***	10,0 ”/0	4.3 ”/0	2.90/o

SOURCE: Bureau of Labor Statistics

in the ranks of white-collar workers (not all with high levels of education or training) or skilled, grey-collar technicians—in contrast to consumer electronics and components, where these jobs make up less than a third of the total. Employment expansion in computers will continue to be most rapid in skilled categories (table 75); numbers of service and repair technicians and systems operators will increase, while jobs for keypunch operators—whose skills are becoming obsolete—will dwindle, as will work for those without special training. Likewise, in components, BLS estimates that the number of professional and technical workers will grow from 87,700 in 1980 to over 117,000 in 1990. In the more mature consumer electronics industry, the absolute number of blue-collar workers is likely to decline, as well as the proportion. Taken together, the trends indicate a continued shift toward more highly skilled jobs in electronics. Computer manufacturing, in particular, will be a leader in employment growth and in demand for new skills over the next decade; the picture for this industry foreshadows trends expected elsewhere in the U.S. economy,

Future Employment Patterns in Other Industries

If analysis of past trends in electronics is problematic, looking ahead to the impacts of electronics on other industries is a still more tenuous exercise. Yet it is a vital one, for future developments in electronics have far-reaching implications for the entire economy, Useful policy guidance could flow from an understanding of how technological change affects employment patterns. Public and private training and retraining programs would benefit if vulnerable job categories, as well as those for which demand will rise, could be more reliably identified, unfortunately, there are no substitutes for painstaking case-by-case analysis based on disaggregated data and carefully defined occupational categories, This is expensive and time-consuming, demanding a sophisticated appreciation of how industry uses technology; in consequence, such studies are seldom attempted.

Uncertainties abound. First, past trends—including examples of technical change in industries other than electronics–can offer only a general guide; there are no guarantees that current employment patterns—outcomes of large numbers of incremental and evolutionary changes—will persist. Second, many impacts will be several levels removed from the electronics industry itself. Computer-controlled production of consumer goods such as clothing—to take one example—may increase employment in firms designing and building the equipment used, decrease employment in the apparel industry, but perhaps have positive impacts on employment at the retail level (one reason might be that custom design would become cheaper, with smaller runs of styles and sizes sold in specialty shops). Attempting to trace such second and third level effects involves the interplay of business decisions, economic and product cycles, imports and exports—not to mention the unpredictable nature of consumer demand. The following sections do not attempt to answer the question of whether electronics technologies will have net positive or negative impacts on U.S. job opportunities, but simply illustrate some of the forces at work.

European governments, sensitive to the potentially negative employment consequences of electronics and automation, have commissioned numerous reports on the subject, with uniformly disappointing results, Micro-level analyses exploring impacts on a particular craft or industry are difficult to integrate with macro-level studies and aggregate economic forecasts. Yet this coupling–the complex and evolving interplay among technical advance, utilization within various economic sectors, and the response of the labor market—is critical on both supply and demand sides. For example, companies typically install labor-saving equipment in periods of economic expansion, when workers can be transferred to other jobs rather than laid off. Over the longer term, then, a given firm can often use normal attrition to help manage the size of its work force. Where this is the case, direct attribution of decreases or increases in employment opportunities to new technology can be difficult to defend. [23]

While forecasting methods do a reasonable job of predicting employment within either aggregate or disaggregate categories as long as change is slow and past trends supply precedents, the unexpected consequences of new technologies escape forecasting methodologies virtually by definition. Examples *from the past illustrate little beyond the seeming randomness of the impacts of technological change.* This in itself is an important lesson, but means that the state of the art is such that even well-documented historical case studies can seldom provide direct policy guidance.

The basic problem is that, even if it were possible to predict how technical change in electronics would affect some other industry, there is no necessary relationship between these findings and the consequences for the economy as a whole. Building up the picture on a detailed, sector-by-sector basis would be a vast undertaking. Most of the past attempts—whether dealing with manufacturing or services or both—have been more limited, falling into one of two categories: 1) elaborate but abstract analytical frameworks, typically econometric; or 2) case studies outlining impacts on particular sectors. The first, exemplified by the BLS analyses discussed earlier, have seldom been very illuminating in terms of real-world experience. The second often yield insights that are useful but limited to relatively narrow segments of the labor force–bank tellers, coal miners, postal workers—as illustrated by the case examples that follow.

Manufacturing

Many of the studies addressing manufacturing begin by distinguishing between product and process applications. These overlap in the sense that computer-based process control systems, to take one example, can be viewed in either light. As a “product, ” they are developed and sold by firms in the capital goods industry. In the alternate view, automated process control is one aspect of an ongoing transformation of production in many industries. Employment impacts follow in both views, although typically of very different magnitudes.

As a further organizing principle, it helps to consider employment effects by product and

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[23] The authors of a British study write: “ Mic roelectronics technology will affect manufacturing industry in so many ways that it is impossible to be exhaustive, and difficult even to find a coherent framework for analysis. ” See J. Sleigh, B.Boatwright, P. Irwin, and R.Stanyon, *The Manpower Implications of Micro-Electronic Technology* (London: Her Majesty’s Stationery office, 1979), p. 14.

by market.[24] In theory, the greatest gains come where new *products* are introduced into new *markets*. Pocket calculators and video games are examples. While they may replace other goods—electromechanical calculators, for example—to the extent that new products expand markets or create new ones, employment will rise. *Existing products* introduced into new *markets* have parallel effects. The "personal" computer is not a new technology or a new product so much as an adaption of microprocessor-based data processing systems to the needs of individual households and small businesses. Low-end minicomputers of the early 1970's, such as the PDP-8, were similar in many respects to current personal computers, but the PDP-8 was never marketed as such. In contrast, the introduction of new or replacement technologies into *old* markets often cuts into job opportunities. Recent and well-publicized illustrations include electronic switching in telecommunications—principally telephone systems—and electronic typesetting in the printing industry. In essence, these technologies caused step changes in labor productivity, with subsequent employment declines, In such cases, output may expand, but not rapidly enough to compensate, In between the extremes of the examples above fall many which have more moderate impacts on employment.

Several case studies are outlined below, including those of telecommunications and typesetting, to illustrate typical impacts of electronics-related technologies on employment patterns,

The British Telecommunications Industry

The introduction of electronic switching in the British telephone system exemplifies the replacement case. Employment dropped from 90,000 in 1973 to 65,000 by the end of the decade, Jobs were lost both in manufacturing and among those employed running the system. Declining export sales contributed to job loss in the manufacture of telecommunications equipment; within the system, fewer installers, service personnel, and operators were needed. Further reductions may be in store, with fully electronic equipment—expected around 1990—cutting the work force to as little as one-tenth its former size.[25]

Printing

Computerized typesetting provides a second example of the introduction of new products into old markets. High-speed photo-typesetting equipment, along with typesetting computers, have transformed the printing industry. The equipment is much less labor-intensive than the hot-metal typesetters that have been replaced, and productivity has jumped. With electronic typesetting, an operator selects type size and style, column width, spacing, and other layout specifications on a video screen, composing an entire page at a time; the older linotype machines, stemming from the end of the 19th century, produced one line of type at a time. After electronic photocomposition had been introduced at the *New York Times*, the Sunday classified section could be completed in 20 minutes rather than 3 days, Over the mid-1970's, the staff in the composing room declined from 830 to 685 employees, and would have dropped much further except for the ability of the printer's union to maintain many jobs that were in fact redundant.[26] (Of course, if one looks at media as a whole, electronics has created vast numbers of jobs.)

Unfortunately, while productivity is now much higher, demand for books and newspapers has not changed much, Between the mid-1960's—when only about 2 percent of all typesetting in the United States was performed

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[24] Following M, McLean and H. Rush, "The Impact of Microelectronics on the U. K.: A Suggested Classification and Illustrative Case Studies," Occasional Papers Series, No. 7, Science Policy Research Unit, University of Sussex, June 1978.

[25] M. Wilkinson, "System X: The Need to Shake-up the 'Phone-makers, " *Financial Times*, Oct. 18, 1978.

[26] The union at the *Times* was more successful than most at holding on to jobs for its members. For a detailed treatment of this case, see "The Impacts of Robotics on the Workplace and Workforce, " Carnegie-Mellon University, School of Urban and Public Affairs, June 14, 1981, pp. 35ff. Other examples of applications of electronics technologies in printing can be found in J. R. Werner, "The Role of Electronics in The Modern Newspaper, " and J. L. Boyd, R. E. Robey, and J. S. Richards, "Automating Newspaper Production, " sess. 21, The Role of Electronics in the Graphic Arts, 1979 Electro Professional Program, New York, Apr. 24-26, 1979.

by the new machines—and the end of the 1970's, penetration rose until about 90 percent of all newspapers were composed using computerized equipment. The impacts on printers as craft workers have been severe. Not only are fewer people needed for photocomposition, but they must have different skills, Few printers have found jobs as computer programmers or service personnel. Unions have been less concerned with the total number of job opportunities than with protecting individuals. Work forces have been reduced through attrition; the pension system created incentives for early retirement. Printers, proud of their traditional craft skills, were not very receptive to retraining, although this had always been a central part of the union's philosophy. While the strategies adopted by organized labor when confronted with such problems have varied, the example of the printing industry is not untypical of instances where replacement technologies have been introduced into existing markets; labor-management relations tend to be critical factors in coping with job-displacement effects.

Electronic Watches

In the watchmaking industry, an example from consumer goods manufacturing, electronically based products took more than half the total market within the space of a decade. In Switzerland alone, 20 to 30 percent of existing assembly labor was displaced.[27] Skill requirements for assembling electronic watches are negligible. Along with deskilling of the production work force, international shifts occurred as firms in the Far East took over markets for lower priced watches; most of the relatively simple integrated circuits needed are also made in Asia. Managements of Swiss watchmakers reluctant to switch to the new technology found their firms rapidly losing ground, with effects on employment that were even more devastating than among manufacturers choosing to embrace electronics.

Computer-Aided Manufacturing and Design

Continuing integration of computer technology into manufacturing operations—computer-aided manufacturing (CAM)—will eventually have major consequences for employment (ch. 6). Nonetheless, such developments--including robots and software-programmable automated equipment of many kinds—should generally be viewed as evolutionary steps in the automation of the workplace, continuing down paths originating many years ago. Much the same is true of computer-aided engineering design (CAD), which consists in part of automating tasks—ranging from drafting to numerical analysis-formerly done manually. In addition, both CAM and CAD make possible work that could not be performed at all in earlier years. Examples include machining parts without the aid of drawings, continuous balancing of rotors with material removed by lasers, or finite-element analyses of stresses and deflections.

As computers spread through manufacturing, impacts on employment will be, at least at first, incremental and random-seeming. In the longer run, productivity will be greatly improved; labor-intensity will drop, and large numbers of manufacturing jobs will disappear, particularly those with lower skill levels. In this sense, the long-term effects will in fact be revolutionary. The work force will face continuing structural shifts, and labor-management relations will be under strain as accommodations are sought. Changes in employment patterns in a given industry will depend on the characteristic production processes--how susceptible they are to automation—as well as growth in markets and shifts in competitiveness. Computers will have their greatest impacts when accompanied by large-scale reorganization of the work place, as happened in continuous process industries with the introduction of computerized process control.

Numerically Controlled Machine Tools

The diffusion of numerically controlled (NC) (ch. **6]** machine tools illustrates the results of incremental improvement in manufacturing

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[27] *Technical Change and Employment,* op. cit., p. 136.

technology. A survey of 24 American firms revealed comparatively limited impacts on employment.[28] NC machines were generally purchased when business was good and output expanding; the new equipment helped firms produce more without hiring extra workers. Nor were many employees displaced; most moved on to other production jobs, although skilled craftsmen sometimes found the transition to NC machines difficult. Management also had to learn to operate in a new environment. Overall employment remained more-or-less static, but the skill mix changed and some individuals were faced with entirely new jobs. If the impacts of NC machine tools have been mild, it would be misleading to generalize this to future developments in CAD/CAM. NC machining is a major step in metal cutting, but a much more modest development from the viewpoint of manufacturing technology as a whole; the next two or three decades of advances in CAD/CAM will bring more radical change to the factory floor.

Pet Foods

In an example of automated process control, a British firm with a large share of the pet food market invested in a computer-controlled production system.[29] Instituted with the goal of rationalizing the production process, the system was expected to cut employment by three-quarters over a 5-year period. The proportion of unskilled production workers dropped precipitously, while more management and engineering personnel were needed. An absence of unions, combined with an extensive campaign to convince workers that the new equipment would eliminate the least desirable jobs, appear to have been critical factors in the acceptance of the new equipment. The small group of workers selected by management to run this equipment expressed considerable satisfaction with their greater responsibilities, The rest of the production work force lost their jobs.

Are the Case Studies Typical?

None of these examples can be taken as representative. They are anecdotal accounts of events that have followed the introduction of electronics-related technologies. Technical change generally proceeds in piecemeal fashion, with pace and impact that vary from case to case; given hindsight, of course, such seemingly random and incremental events may show patterns invisible at the time.

In the examples recounted, the jobs created generally called for different skills. Typical new openings were for computer operators, or service and repair personnel trained to work on the latest generation of equipment. While patterns of job loss and job creation vary across industries, production jobs—unskilled, semiskilled, or skilled—disappeared in all cases except NC machining. Future employment impacts will be influenced, not only by the technology itself, but by the general state of the economy at the time new technologies are introduced, by the attitudes of workers and unions to automation, and by the choices of corporate managers, In some cases, job losses will be mitigated by expanding markets, particularly if workers are retrained, Overall, however, *a shrinking work force in manufacturing points to continuing displacement and adjustment problems.*

Services

The service sector has been growing more rapidly than manufacturing. Can the U.S. economy continue to generate new jobs in services at a high rate? Office work has been a major source of past expansion. With the electronic office on the horizon, will this source dry up? If office automation begins to cut deeply into employment opportunities, the ability of the service sector to compensate for losses in manufacturing will be seriously impaired.

Office Automation

Fortunately, this seems unlikely—at least in the near term. Office work, breeding ground for Parkinson's Laws, will probably continue to expand. At least some white-collar jobs seem

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[28] R. T. Lund, et al., "Numerically Controlled Machine Tools and Group Technology: A Study of U.S. Experiences, " Report CPA 78-2, Center for Policy Alternatives, Massachusetts Institute of Technology, Jan. 13, 1978.

[29] K. Dickson, "Petfoods by Computer: A Case Study of Automation, " *The Microelectronics Revolution*, T. Forester (cd.) (Cambridge, Mass.: MIT Press, 1981).

relatively impervious to automation in the sense that people can find other things to occupy their time. This is partly a consequence of the lack of output indicators or other measures of white-collar productivity. Nevertheless, beyond office work, electronics may reduce job opportunities (or the rate of job creation) in sectors like transportation, retailing, banking, and the postal system.

Less is known about the effects of automation in services than in manufacturing. Over the past two decades, the xerographic copier has probably had greater impacts on office work than any other piece of technology, yet these seem hardly to have been studied. Has the office copier created jobs? What have been the effects on organizational efficiency? No one seems to know. It has saved so much drudgery, however, that few are likely to care.

More concretely, studies of the application of electronics to services generally find—not revolutionary change, but gradual evolution best viewed as an extension of computer applications already in place. Such studies emphasize the extent to which workers such as typists or clerks whose job skills may become obsolete can be redeployed, seeing, for example, word processing as a straightforward extension of typing.

The central features of the electronic office—expanded applications of data processing equipment, including communications and word processing—have thus far been introduced into existing or conventional office environments, In this respect, the analogy with NC machines and industrial robots is close. While office automation promises to reduce staffing needs in conventional jobs, new tasks are at the same time created in operating and maintaining the systems, as well as using them. Since office work is seldom very efficient or well-organized, computerization is likely to have its first effects at the margins of these people-centered activities, rather than leading to sudden and major shifts. Wholesale reorganizations of the workplace will be slower than in manufacturing.

Photo credit Wang Laboratories

Word processing: one of the early steps in office automation

Examining occupational categories makes it clear that the mode of utilization of the new technology is just as important as the speed of adoption, again as in manufacturing. If new technology is instituted primarily as a substitute for narrowly defined functions such as inventory recording, bank telling, or filing, employment is likely to drop over the longer term unless jobs expand in other areas (such as sales). Where computers facilitate more effective and extensive information processing, new jobs may be generated. Where demand for new types of services is created, employment will rise.

Consider the proliferation of word processing equipment, which affects the tasks now performed by **a** well-defined group of employees. Based on the results of work-measurement tests conducted in organizations that have switched from typewriters to word processors, productivity often more than doubles. While this might suggest that half the typing work force faces unemployment, in practice nothing like this has happened, Indeed, some firms have invested in word processors in response to a shortage of typists. In other instances, where typists have been made redundant they have moved to other parts of the organization. In many cases, people just write more words.

In fact, since word processors make it easier to produce multiple revisions of the same document, productivity cannot be measured simply in terms of words or drafts typed, The characteristics of the technology lead directly to an increase in the number of slightly modified versions prior to a final copy, whether this is a short letter or a report hundreds of pages in length, While the benefits of this maybe questioned, the point is that oversimple estimates of productivity gains—achieved or potential—overstate the probable employment consequences.

Eventually, offices will be structured in substantially different ways, Some jobs will be eliminated, others modified. Interactions among people, individually and in groups, will change. Matters of timing and approach to the installation of new office equipment will, as in the case of factory work, affect employee support or resistance, thus the effectiveness with which the equipment is utilized, and people's satisfaction with their work.

Other Services

Service sector jobs outside the office include health care, retailing and selling of all types, banking, transportation, and postal services (more broadly, communications). In principle, electronics could alter many of these, but where and when—or whether— is another matter.

In banking, computer processing of magnetically encoded checks has made it possible for the same number of employees to handle an ever-growing volume of transactions. Electronic funds transfer remains costly, and thus far has seen only limited use in retail banking; applications to interbank transactions have been much more prominent, Such developments have not led to work force reductions; during the 1970's, the number of people employed in banking in the United States grew by half, confounding predictions of employment losses.[30] Two interpretations are possible: the first is that growth in job opportunities slows under these circumstances; the second, that electronics allows banks to expand their functions in ways that would otherwise be precluded, These interpretations are not mutually exclusive; both have some validity. Clearly, electronics technology has modified and extended banking functions—an obvious example is the automated 24-hour teller. Nonetheless, in Europe, employment growth in banking and insurance has already begun to slow; a well-known report to the French Government predicts that one-third of all jobs in banking and insurance might be eliminated over the decade ahead.[31] While perhaps overly dramatic, such predictions point to the concern these issues have aroused, particularly in Western Europe.

Like electronic funds transfer, electronic mail has been viewed with some apprehension. The U.S. Postal Service has made notable strides in productivity over the past decade, even reduced its labor force—but seldom as a result of electronics. In the future, electronic mail may cut deeply into job opportunities for postal workers; employment could drop by 20 to 25 percent over the next 20 years.[32]

Summary and Conclusions

Examples from both manufacturing and services can be interpreted either optimistically or pessimistically; in the absence of more systematic studies, the question of employment impacts resulting from technical change in electronics on the economy as a whole cannot be answered. But regardless of the view one takes, *unprecedented adjustments lie ahead for*

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[30] See J. Henize, "Evaluating the Employment Impact of Information Technology," *Technological Forecasting and Social Change, vol. 20,* August 1981, p. 41.

[31] *Microelectronics* at *Work: Productivity and Jobs in the World Economy,* op. cit., pp. 36-37. The French report is S. Nora and A. Mine, *The Computerization of Society* (Cambridge, Mass: MIT Press, 1980).

[32] *Implications of Electronic Mail and Message Systems for the U.S. Postal Service* (Washington, D. C.: U.S. Congress, office of Technology Assessment, OTA-CIT-183, August 1982), ch. 6. The postal service employed nearly **700,000** people in **1980.**

both individual and firms. Should aggregate employment increase, the introduction of new technology will alter the jobs that people do and change their interactions with one another. should total employment increase only slowly compared to growth in the labor pool, or decrease, the adjustment problems will be extraordinarily severe, more so in a country like the United States which has little experience with manpower policies, and where many people have come to view adjustment assistance as a failure.

In recent years, the number of new job opportunities generated by the U. S. economy has slowed, A good deal of the future expansion will be in computer-related fields; only those with appropriate training and skills will be in a position to take advantage of these opportunities. Upskilling in the computer industry has been going on for years, as indicated by the increasing proportion of white-collar employees compared to production workers. In fact, the white collar-blue collar distinction no longer carries much meaning; the labor force is becoming increasingly stratified. Distinguishing those with specialized skills from those without is only a starting place for examining the many new gradations.

A common notion, for example, is that computers will bring "user-friendliness" to many jobs so that unskilled workers can perform them, This is potentially misleading. User-friendliness permits people with *good* skills to work with complex and sophisticated systems that otherwise would demand highly specialized expertise. User-friendliness also tends to change the abilities required in the labor force. Efficient utilization of a word processor depends on different skills than manual typing. Mistake-free entry is not so important, but taking advantage of the full range of capabilities of the system requires a certain grasp of its logic and capabilities-mental skills, not manual (and different from the spelling and grammar now learned in school). Productivity in many types of jobs will increasingly depend on such abilities; it would be doubly unfortunate if the U.S. electronics industry were to suffer shortages of trained people at the same time that large numbers of Americans find themselves without work because they lack the capabilities that this and other industries depend on.

Like all technical change, advances in electronics will bring a mix of positive and negative effects; at present, there is little factual basis for either an optimistic or a pessimistic view of the longer run impacts, Firms manufacturing electronics products will, for some years, continue to create substantial numbers of new jobs. In U.S. manufacturing as a whole, the rate of growth of job opportunities has already slowed, and jobs may go down in absolute terms. A major source of declines will be computer-assisted automation. Will job growth elsewhere compensate? Anticipating events in the service sector, where productivity growth has been low, is more problematic than in manufacturing. While there may be only a few cases of employment impacts as severe as in newspaper printing, there will be a multitude of adjustment problems for individuals; these are likely to accelerate as electronics technology continues to permeate both manufacturing and services. in the end, much will depend on overall rates of economic growth.

Job opportunities also depend on competitiveness. Employment typically falls when industries lose ground in either domestic or international markets. Even if aggregate economic growth brings greater demand, only the more efficient companies can take full advantage. Generally speaking, *firms and industries that make effective use of new technologies will generate new jobs, or if jobs are lost, this will come more slowly;* indeed, companies seldom have any choice but to adopt new technologies if they wish to remain competitive. Those that move quickly (but not too quickly) can often gain an edge over their competitors via new products or productivity improvements in existing lines of business. Ultimately, the greatest numbers of jobs may disappear where firms, industries, or nations do not keep pace with technological advance.

Firms or industries whose competitive position is already in decline may be forced to automate or pursue other routes to lower costs and higher productivity simply to survive, In some cases, then, declining employment is associated with attempts to revive competitive advantage, particularly when an industry or firm is threatened with competition from low-wage countries. But it would be a mistake to attribute the accompanying job losses solely to imports. In consumer electronics, U.S. corporations have automated their production facilities and moved offshore; this costs U.S. jobs in the short term, but may expand or help maintain the total market for American products over the longer term. Moreover, as the electronics industry becomes more and more international—with American firms producing goods overseas for foreign markets as well as re-importation, and foreign firms setting up assembly plants here—it becomes increasingly difficult to evaluate impacts on the American labor force in isolation.

Most fundamentally, only by using labor efficiently—which often means investments in automation—can U.S. firms maintain their international competitiveness. Improvements in *productivity-a path way to increased competitiveness—can have serious employment impacts on particular groups of workers, graphical regions, and industrial sectors.* The essential question is: How can the negative impacts on employment be minimized while capitalizing on the potentials of new technology?

Only where the market is expanding rapidly can employment growth parallel productivity advances. This has been the case in the semiconductor and computer industries, but not in consumer electronics. To the extent that the American economy continues to grow only slowly, many of the productivity gains flowing from applications of electronics and computers will have negative first-order effects on employment, Still, few practicable alternatives exist; once robots or other automated technologies become cost effective, the pressures to use them become virtually irresistible. More jobs could ultimately be lost through failure to adopt such technologies than by pursuing them,

The implication is straightforward: *some* people, companies, industries, and regions will lose competitiveness and lose jobs. The relationships between technical change, employment, and international competition may be complex, but *from the standpoint of public policy, the negatives are wholly predictable.* They cannot be avoided, but *the country could prepare for them, both to ease the inevitable adjustments and to help maintain U.S. competitiveness,* Because changes in industrial structure bring new job requirements, policy measures aimed at encouraging both public and privately funded education and training are central to effective adjustment policy.

CHAPTER 10

National Industrial Policies

Contents

List of Tables

CHAPTER 10

National Industrial Policies

Overview

Government policies directly and indirectly affect the international competitiveness of industrial sectors. The impacts can be positive or negative, tangible or intangible; they may fall on domestic firms or foreign enterprises. The American electronics industry has claimed that the policies of the U.S. Government sometimes damage its competitiveness, while foreign industrial policies—particularly those of Japan–also place it at a disadvantage. This is a familiar argument: many U.S. business leaders assert, on the one hand, that U.S. policies are counterproductive and that they would be better off without Government interference, and on the opposite hand, that in other countries government polices, far from being counterproductive, give their competitors powerful advantages in international trade. Such questions turn on the general tenor of relations among government, business, and other interest groups (consumers, organized labor) as well as the details of policy.

As the importance of electronics became obvious and competition intensified, foreign governments sought policies that would promote the growth and development of their own industries. These trends seem bound to continue, not only in industrialized nations like Japan but in developing economies. Questions of central concern for American policy makers include: How do industrial policies differ among nations? To what extent can the effectiveness of these policies be evaluated? Do actions taken by foreign governments give the electronics industries of these countries significant competitive advantages? Can industrial policies ‘‘create’ comparative advantage? These are hard questions. The monetary value of subsidies can seldom be approximated accurately. Even where this is possible, it does not tell whether the money was well spent or wasted. More important, the industrial policies of countries like Japan work in large part through intangibles. When counting the yen does not suffice, how does the United States countervails subsidies?

This chapter treats industrial policy in comparative fashion, with special attention to institutional context and the evolution of industrial policymaking, as well as the place of electronics in strategies for economic development. Policies in the United States are covered only briefly; the next chapter treats U.S. trade policies in greater detail, while chapter 12 examines policy alternatives for this country.

Industrial policy means different things to different people. To some, the term brings to mind government programs for supporting and promoting targeted industries, typified by the French “plans” or Japan’s government-funded research and development projects—sector-specific attempts to assist industry. Beyond sectoral measures, a vast array of public policies—dealing with taxation, trade, human resources, science and technology, antitrust, labor markets and economic adjustment, government procurement—also influence the development and viability of industries like electronics. OTA prefers to view industrial policy broadly, as encompassing both sectoral targeting and the many policy measures with aggregate rather than sector-specific aims that often have less direct effects on private firms. [1]

International competitiveness, at root, depends on the efforts of private firms—this is as true in countries like Japan with relatively comprehensive and well-developed industrial policies as in the United States—but public policies help shape the environment within which corporations operate and managers

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[1] *U.S. industrial Competitiveness: A Comparison of Steel, Automobiles, and Electronics* (Washington, D, C.: U.S. Congress, Office of Technology Assessment, OTA-ISC-135, July 1981], p. 151.

make decisions. The decisions of government officials are important too. Nations have approached industrial policy differently; government intervention is more common and viewed more positively in France or Japan than in West Germany or the United States. Sometimes public policies are clearly defined and consciously developed, sometimes they evolve in ad hoc fashion—the traditional pattern here.

Still, such generalities can mislead: in all major industrial nations, policies toward the electronics industry have changed over time; in several, debates over new approaches are underway. Furthermore, policies often differ across an industry. More than 20 years ago, Japan began a series of programs intended to foster the growth of an indigenous computer industry—but the government did little by comparison to directly promote consumer electronics. In the United States, public policies toward the automobile industry have centered on regulations, while trade issues have been stressed in the context of steel. U.S. agricultural policy has been much more highly developed than policies toward manufacturing.

Why then have some nations—France, Japan, Taiwan, for examples—moved toward well-defined and rather comprehensive policies directed at electronics, while countries like the United States have not? There is no simple answer, but historical and institutional factors as well as stages of economic development and the exigencies of day-to-day politics play a part,

Where government has for years promoted industrial development—France rather than Britain—public sector involvement in the economy is more widely accepted as legitimate. In such countries, policies directed at a single industry such as electronics have usually reflected overall economic objectives. Institutional mechanisms that facilitate coordinated policymaking—central banks or development banks, respected planning councils, centralization of responsibility within one or a few bureaucratic ministries–enhance the ability of government officials to implement industrial policies. These features are lacking in the United States. During the greater part of the postwar period—when American industries such as electronics and aircraft were clear leaders in world competition—public policies here were directed, not at economic development, but at regulation.

As this chapter demonstrates, industrial policies will be a prominent feature of the international competitive environment for the foreseeable future. While other countries are busy developing them, the United States is still groping for a response.

The Context for Industrial Policy

Public policies directed at electronics should be viewed in light of a nation's overall economic development strategy. Table 77 gives in summary form a number of indicators of economic position and industrial policy for five countries, Electronics and other high-technology industries grow more important as manufacturing and services displace agriculture, In Japan, agriculture accounted for more than 20 percent of the gross domestic product (GDP) in 1955, when the electronics industry was insignificant by international standards; by the end of the 1970's, the agricultural sector had receded to less than 5 percent of GDP, From 1976 to 1980 alone, the share of Japan's exports accounted for by electronics went from 9 to 14 percent.[2]

Such shifts, the results of complex economic currents, form part of the policy context. Major changes have also been occurring within electronics. Continuing the example of Japan, con-

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[2] *"I'rends in the Electronics Industry in 1980* (Tokyo: Electronic Industries Association of Japan, 1981), p. 49; "Industrial Review of Japan—1981 ," Japan Economic Journal, p. 33.

Table 77.—Economic and Industrial Policy Indicators

	United States	Japan	West Germany	United Kingdom	Taiwan
1. Services as a proportion of gross domestic product (GDP)	63°/0 (1980)	550/0 (1 979)	49 ”/0 (1979)	630/o (1980)	380/o (1979)
2. R&D expenditures as a percentage of GDP	2.39°/0 (1981)	1 .970/0 (1 979)	2.320/o (1980)	2.11 (1978)	0.650/o (1981)
3. Government as a source of R&D funds	47.20/, (1982)	27.40/o (1980)	49 ”/0 (1 979)	550/0 (1979)	43%[a] (1980)
4. Civilian (rather than military) R&D as a percentage of total R&D	70.0% (1981)	97.40/0 (1977)	92.40/o (1979)	69.70/o (1978)	NA
5. Electronics R&D as a percentage of total R&D (1975)	22°/0	28.40/o (1979)	30 ”/0	26	NA
6A. Government R&D spending on electronics as a percentage of total government R&D spending (1975)	30°/0	320/o	31 %	340/0	NA
6B. Industry R&D spending on electronics as a percentage of total industry R&D spending (1975)	21 °/o	260/o	30 %	2170	NA
7. Percentage of 1978 government R&D funds going to:					
Economic development	9°/0	220/0	15%	13 %	NA
Defense	49°/0	2%	12 %	52	NA
8. Organization of industrial policymaking system	Fragmented	Centralized	Decentralized	Fragmented	Centralized
9. Government-business relations	Adversarial	Cooperative	Structured representation of business and labor views	Semi adversarial	Cooperative
10. Patents granted (1981)	65,770	50,904	13,429	22,924	NA
11. Balance of trade in electronics with the United States (1981) (millions of dollars)	+$4,235[b]	- $5,878’	+ $1,592	+ $1,696	-$1 ,635’
12. Overall policy and strategy	Ad hoc	Leapfrog: indigenous technology development	Adaptive: stresses technology development	Adaptive: stresses commercial applications	Catch-up

NA not available

[a] Excludes expenditures for military R&D

[b] United States with all nations

[c] Negative sign denotes exports to the United States exceeding imports from the Un ited States

SOURCES Ten Year Economic Development Plan for Taiwan, Republic of China,' Taiwan Council for Economic Planning and Development March 1980
Technical Change and Economic Policy (Paris Organization for Economic Cooperation and Development, 1980) p 31
Denshi Sangyo no Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku (Survey Report on Trends in the International ization of the Electronics Industry and Their Influence Part II on East and Southeast Asia) (Tokyo Nihon Denshi Kikai Kogyokai (Electronic Industries Association of Japan), March 1981), p 121
K Schott, *Industrial Innovation in the United Kingdom, Canada and the United States* (London Contemprint July 1981) p 9
J Baranson and H B Malmgren,' Technology and Trade Policy Issues and An Agenda for Act Ion '' report prepared for Department of Labor and Off Ice of the U S Trade Representative. October 1981 P 158
'Survey of R&D Activities in the Year 1980 Republic of China, ” National Science Council, Republic of China 1981
Science Indicators—1980 (Washington D C National Science Board National Science Foundation 1981), pp 210-214
Electronics Jan 13, 1982
C J Mosbacher Will R&D Funds Be More Than $77 Billion in 82 *Industrial Research & Development* January 1982 p 106
National Patterns of Science and Technology Resources— 1982 (Washington D C National Science Foundation 1982) p 33
World Development Report 1982 (New York Oxford University Press 1982) P 114
Outlook for *Science* and Technology, National Research Council (San Francisco W H Freeman, 1982), p 519
Electronic Market Data Book 1982 (Washington D C Electronics I ndustries Association 1982) P 111
Information from U S Patent Off Ice Embassy of Japan, Science Division Coordination Council for North American Affairs Republic of China

sumer products declined from two-thirds of that country's exports of electronics in 1971 to about half by the end of the decade, while semiconductor and computer exports increased. Many of Japan's consumer electronics shipments to the United States have been displaced by products from other Asian nations, partly a result of rapid industrialization in countries like Hong Kong and Korea.[3]

These changes in the composition of Japan's exports reflect shifts in the international division of labor—developing economies are now producing more consumer electronic goods, while advanced nations concentrate on higher technology products. Industrial policies can be viewed as responses to such structural changes; they may attempt to modify or resist them, to smooth adaptation to change, to complement or even induce it. "Success" is most likely when policies work to accommodate or reinforce rather than impede changes in industrial structure—provided the policies are based on sound judgments concerning the strengths and weaknesses of a country's industries, both domestically and in the international marketplace. This is no easy task; still, policies toward electronics in other countries, if not the United States, should be viewed in these terms—as components of national economic strategies based at least in part on perceptions and projections of structural shifts in the world economy.

International economic conditions now favor American corporations less than in the earlier postwar years; this is one reason for the growing interest in industrial policy for the United States. This country, along with the rest of the industrialized West, has experienced low rates of economic growth, rising inflation, and high unemployment over the past decade. Competition has intensified among firms here and abroad, all seeking to maintain or enhance their positions in markets that maybe growing only slowly. Under these conditions, governments have turned to industrial policy as a way out of persistent economic problems, Moreover, aggressive industrial policies in one country breed responses elsewhere. The turn toward industrial policies, particularly in nations lacking a tradition of government involvement in economic affairs, is partly a reaction to these new circumstances; in other countries, industrial policy is nothing new, just a continuation of past practices under a different name.

Policy Orientations

As part of a nation's overall development strategy, industrial policies can be directed at catching up, leapfrogging, or staying ahead in worldwide competition (table 77), Absence of a clearly defined industrial policy may indicate general satisfaction with the situation, the case in the United States until recently; lack of a well-defined industrial policy could also reflect a belief that it is improper for government to concern itself with such issues—a widespread attitude here. In contrast, during the 1960's the French and Japanese began supporting and defending their computer industries against what they viewed as an American challenge.

In many countries and at many times, *defensive industrial policies* have been devised—intended to preserve existing economic structures, maintain employment, and protect beleagured firms and industries.[4] Often defended as temporary (ch. 11), protective measures frequently turn out to be persistent if not permanent.

Adaptive industrial policies seek to encourage structural change by facilitating shifts of resources to growing and productive industries—those in the process of becoming more competitive. In contrast to the defensive approach, adaptive industrial policies begin with the assumption that some sectors will eventually decline in size and importance. In practice the boundaries between various sorts of industrial policies are vague; for instance, subsidies or protection for a given sector may be rationalized as a means of encouraging adap-

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[3] *White Paper on International Trade-1980* (Tokyo: Ministry of International Trade and Industry, September 1980), p. 32. As discussed elsewhere, Orderly Marketing Agreements have also contributed to this shift.

[4] See W. Diebold, Jr., *Industrial Policy as an International Issue (New* York: McGraw-Hill, 1980), pp. 7-8, for an outline of types of industrial policies.

tation, while in practice they function as defenses against decline.

More ambitious than adaptive policies are those that attempt to induce change, This implies moving beyond a response to economic forces—here government takes the lead in *initiating industrial change,* with the object of improving the competitiveness of some sectors of the economy. Both this approach and the adaptive strategy tend to be associated with notions of dynamic comparative advantage and the belief that governments can anticipate and plan for shifts in the structure of advantage,

As pointed out in chapter 5, the competitiveness of all sectors of an economy cannot improve at once. To pursue a positive development strategy, a nation must begin with at least the implicit acknowledgment that some of its industries will likely decline. Common ground concerning the prospects for industry is easier to find in economies with simple structures. Nations that are still attempting to catch up have an easier time in formulating policy; they face fewer choices, fewer possibilities,

The Tools of Industrial Policy

In market economies, governments bring a more or less standard set of policies to bear on industrial development—measures used for purposes ranging from improving competitiveness to encouraging regional development or strengthening the national defense, Regardless of whether a country is attempting to pursue an integrated policy, a wide variety of government actions will inevitably affect the industrial portion of its economy.

In the case of electronics, many countries have instituted policies affecting costs and supplies of capital—for R&D as well as for investment in plant and equipment. R&D *supports* can take the form of low interest loans, direct subsidies, or government contracts. In West Germany, government funding supports basic research as well as projects aimed at commercialization carried out by the laboratories of the Fraunhofer Gesellschaft; the German Ministry of Science and Technology also subsidizes contract research undertaken by smaller enterprises, along with cooperative R&D in industrial research associations. The Very High-Speed Integrated Circuit program of the U.S. Department of Defense is aimed at integrated circuits (ICs) for military applications, but will have commercial spinoffs. The Economic Recovery Tax Act of 1981 included a tax credit for R&D spending, as well as accelerated depreciation of equipment used in research, Japan also offers tax credits to firms that increase their spending for R&D over past levels. Beyond this, the Japanese Government directly supports projects aimed at commercial microelectronics and computer technologies.

Many countries assist regions, small businesses, perhaps entire industries through *investment grants and subsidies.* The United Kingdom's National Enterprise Board provided 50 million pounds to capitalize the semiconductor firm Inmos. In the United States, the Small Business Administration loans money at favorable interest rates and with lengthy repayment periods. Regional development loans have stimulated investment by American and Japanese semiconductor firms in Ireland and Scotland. National banks, particularly industrial development banks, have been important vehicles in many countries for channeling funds to particular sectors.

Government procurement is widely used to support national firms. Military procurement has been much more important in the United States, France, and Great Britain than in countries like West Germany. The "Buy Japanese" policies of public corporations such as Nippon Telegraph and Telephone (NTT) were for years an integral part of Japan's policies in electronics. In 1980, NTT—which purchases sizable amounts of communications and electronics products—agreed, after lengthy negotiations, to open some procurements to foreign bidders. American firms have made only limited progress in selling to NTT, but the attention given the case indicates that government procurement is becoming more subject to international negotiation, perhaps less usable as a tool for the promotion of domestic industries (nontariff barriers to trade, of which this is an example, are discussed more extensively in the next chapter).

Still another category of policy measure includes those bearing on the *regulation of industrial structure*. Nations can influence the structure of their industries by encouraging or discouraging mergers, not to mention nationalizing firms or industries as the Mitterrand government in France has done. American competition policy has emphasized the regulatory side—i.e., antitrust enforcement—while in France and the United Kingdom, governments have steered companies into mergers (e.g., the computer manufacturers CII-Honeywel] Bull in France and ICL in Britain) intended to create "national champions. " Encouraging mergers, often through financial incentives—sometimes referred to in Europe as structural policy—has been a common feature of policies toward electronics in most developed nations.

Some countries use *foreign investment controls* to restrict inward flows of capital, and thus preserve domestic markets for local firms. In years past, such regulations, as well as restrictions on imports and technology from abroad, played a central role in the industrial policies of Japan; several examples in electronics were outlined in chapter 5.[5]

Finally, *tariffs and other varieties of trade policy* are an ever-present force in international competition. Countries erect tariff walls to protect new or old industries; the European Economic Community, for instance, maintains a tariff of 17 percent on ICs to discourage imports and stimulate domestic production. The United States negotiated import quotas on color televisions with Japan, Taiwan, and South Korea during the 1970's in an attempt to deal with the problems of this industry (as discussed in ch. 11). Trading nations all maintain export promotion measures intended to help local firms sell in the world market. In the United States, the Export Trading Company Act (Public Law 97-290) passed in the fall of 1982 is one of the most recent examples; modifications to the Foreign Corrupt Practices Act likewise intended to support U.S. firms in foreign markets passed the Senate but not the House of Representatives in 1981.

Policy measures of the types outlined above have been deployed by governments everywhere in their attempts to influence the development of industry and improve competitiveness. Generally speaking, tariff barriers, controls on foreign investment, and competition policies were the tools of first choice during earlier postwar years; since the late 1960's, as trade liberalization gained momentum and direct trade barriers were dismantled, R&D policies and investment stimuli have come to the fore. In the wake of intensified competition in a wide range of industries, trade negotiations—both bilateral and multilateral—have increasingly centered on subsidies and indirect barriers.

While the typical mix of industrial policy measures has shifted over time, the group of policy tools from which they are chosen has not changed very much. The industrial policies of various nations draw on the same basic ingredients—R&D supports, investment grants and subsidies, public sector procurement, merger policy, controls on foreign investment, tariffs and other trade policies. Nations combine these depending on their assessments of the strengths and weaknesses of their own industries and the objectives of their economic development programs.

The key to effective national policies has lain, not in the individual policy tools but in their combination—in the extent to which the policies chosen complement one another and work toward a more or less consistent set of objectives. The timing of policy initiatives and the receptivity of private firms to government programs are also important, but the success or failure of industrial policies is determined to a large extent by the ability of policy makers to develop and implement a consistent framework and approach, one appropriate to that nation's position in the international economy.

The remainder of the chapter reviews industrial policy in a number of countries, with particular attention to electronics,

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[5] See also R. S. Ozaki, *The Control of Imports and Foreign Capital in Japan* (New York: Praeger, 1972).

Industrial Policies Compared

The failures of industrial policy are much more evident than the successes. How does one weigh the contributions of government policies to economic development—either on a general or a sectoral basis—when a country has been in the “take-off” stage, with many forces working more or less in concert to speed industrialization? This was the pattern in the Japanese steel, shipbuilding, and petrochemical industries in earlier years, when a skilled labor force and rapidly expanding markets were aided by the government’s push. It is now the case in other nations that have begun to experience rapid economic growth.

Developing Countries

The past decade has seen a striking rise in the electronics industries of a number of newly industrializing countries (NICs), most of them in Asia. Many of these nations—Taiwan, South Korea, Brazil—have chosen paths of government-guided economic development, albeit with many gradations in the extent of government involvement. With the exception of China, which has emphasized “self-sufficiency,” the Asian nations have relied heavily on imported technology while capitalizing on cheap labor. In countries like Singapore, Hong Kong, and Taiwan, economic development policies have relied more heavily on encouraging diversified exports of manufactured goods than protecting local industries against import competition. The typical attitude toward foreign electronics firms has been pragmatic, with American and Japanese involvements tolerated or encouraged because of benefits in technology transfer and infrastructural development.

In years past, the electronics industries in most NICs centered on relatively simple consumer products—radios and black-and-white TVs, pocket calculators, electronic watches, toys and games. Now, policy pronouncements from these countries are calling for shifts toward more sophisticated goods, In Taiwan, which has perhaps the most ambitious government programs, the stated aim is a more knowledge-intensive industrial structure, much as in Japan. Chinese planners, also reconsidering their traditional approach, have become more open to technology exchanges and business ventures involving foreign firms. While the industries in countries like Taiwan and South Korea have already become major producers of middle-range products like color TVs, simpler microelectronic devices, and computer peripherals, it is far from certain that such nations can succeed in advanced electronics technologies. Manpower limitations are the most severe constraint.

South Korea

The Korean Government has consistently sought rapid industrialization; the public sector presence has perhaps been more pervasive than in any of the other NICs. Policy instruments have ranged from money to guidance: rebates of indirect taxes, raw materials subsidies and loans to exporters, target figures for exports, funds for R&D. Korea’s export financing programs have also been unusually comprehensive compared to other NICs.[6]

For many years the Korean economy expanded at a high rate, with annual increases in gross national product (GNP) averaging 10 percent over the period from the early 1960’s into the mid-1970’s. Labor-intensive manufactured goods provided the foundation for this growth; exports have become much more important to South Korea’s economy over the past decade, growing from 12 percent of GNP to 35 percent.[7] Electronics has been an export leader, the most rapidly growing sector. Korea’s electronics industry is still small compared to Japan’s, but it accounts for more than 10 percent of Korean exports.

More recently, South Korea’s economic miracle has fallen on the same hard times that have

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[6] “Korea’s Eximbank Provides Incentives To Diversify Export Mix, Destination, ” *IMF Survey, Nov.* 26, 1979, p. 366.

[7] P. Hasan and 11. C.Rao, *Korea, Policy Issues for Long-Term Development* (Baltimore: Johns Hopkins University Press, 1979), p. 20.

afflicted the rest of the world. The slump was sudden: whereas Korea's output of electronic products grew at the astounding rate of 40 percent per year during the 1970's, production actually fell in 1980, although rebounding strongly in 1981,[8] South Korea's Government considers continued growth in electronics necessary for recovery, and the industry remains a focal point of development strategy. Korea's fourth economic plan (1977-81) concluded that long-term export viability would depend on structural changes in manufacturing. The plan called for rapid increases in exports of electronic products.[9] Korea's Government assumes that other developing economies will provide stiff competition in sectors like textiles and apparel, where Korean industry has in the past been strong; thus, the country needs to continue moving into durable manufactures for export. The government also intends to deemphasize petrochemicals and heavy industries like steel—sectors that helped lead Korean economic growth in past years. The fifth and latest plan released by South Korea's Economic Planning Board proposes dramatic cuts in investments in these portions of the economy, with expenditures on electronics boosted substantially.[10] Table 78 summarizes projections by the Korean Government; electronics exports are expected to climb to $14.5 billion in 1991. The most rapid growth is projected in industrial electronics products, including computers and communications equipment, with a heavy emphasis on microelectronics. The share of total electronics output accounted for by consumer products is expected to begin shrinking by the latter part of the decade, with a pronounced move away from the less sophisticated components that are currently a staple of the Korean industry, Such a reorientation will entail shifts in R&D emphasis, with increases in funding for both product and process technologies. To this end, the Ministry of Commerce and Industry has begun channeling funds to Korean electronics firms for developments in semiconductors and computers.[11]

Table 78.— Korean Electronics Production

	Output (millions of dollars)	
	1981	1986[a]
Consumer	$1,600	$5,800
Industrial[b]	490	2,700
Components	1,710	4,800
	$3,800	$13,300
Total electronics exports	$2,200	$7,000

[a]Proiected
[b]Includes computers and telecommunications equipment

SOURCE A Spaeth, "Korea's Electronics Industry Making Rapid Gains in Shift to HighTechnology Products," Asian *Wall Street Journal Weekly*, Dec *20, 1982*, p. 1 The projections come from South Korea's Ministry of Commerce and Industry

To help focus research efforts, the Korean Institute of Electronics Technology—established with government support in Gumi, the country's Silicon Valley—is to be built into a centerpiece for research in electronics. The institute has been installing production lines for very large-scale ICs; the equipment will be used for commercial production as well as engineering development.[12] While the staff of the $62 million institute remains small, planners hope that it will eventually house more than a thousand research workers.[13]

In addition to R&D assistance, the South Korean Government has provided investment funds to electronics firms and supported them through procurements, For instance, Gold Star Semiconductor—a joint Korean-U.S. venture—will receive a loan of more than $40 million from both foreign and domestic sources, including the Korea Development Bank, to manufacture telephone switching equipment which

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[8] *Denshi Sangyo no Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku* (Survey Report on Trends in the Internationalization of the Electronics Industry and Their Influence, Part II on East and Southeast Asia) (Tokyo: Nihon Denshi Kikai Kogyokai (Electronic Industries Association of Japan), March 1981), p. 103; A. Spaeth, "Korea's Electronics Industry Making Rapid Gains in Shift to High-Technology Products," *Asian Wall Street Journal Weekly*, Dec. 20, 1982, p. 1.

[9] *Denshi Sangyo no Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku*, op. cit., p. 56,

[10] N. Thorpe, "South Korea's Economic Program Reduces Expansion of Several Major Industries, " *Wall Street Journal*, July 24, 1981, p. 24.

[11] One report states that $800 million has already been invested by the government–''Fourth Five-Year Plan," *Electronics Weekly*, Apr. 25, 1979, p. 19.

[12] "Korea's Electronics Industry Making Rapid Gains in Shift to High-Technology Products, " op. cit. Eventually, the institute expects to sell the production facility to a private firm.

[13] "South Korea Seeks Electronics Rebound," New *York Times*, Mar, 24, 1981, p. D5.

will be purchased by the Ministry of Communications.[14] A second major Korean electronics firm—Samsung, also partly U.S.-owned—is involved in the project as well. When the government decided to begin color TV broadcasting in 1980, Samsung won loans to aid in the production of color receivers. Foreign firms have also benefited from investment incentives, although South Korea's electronics industry has been less dependent on overseas capital than most others in Asia. Foreign-owned companies are exempt from Korean income, property, and corporate taxes during the first 5 years of operation.[15]

Government generosity has not prevented bottlenecks such as rising labor costs and skill shortages among the 180,000 employees of Asia's third largest electronics industry. The recent push toward indigenous technological capability implies heavy R&D commitments, but most South Korean firms have only limited human and financial resources to devote to these ends. Furthermore, other countries are likely to be cautious in transferring electronics technology to Korea now that the country's competitiveness is apparent. Japanese firms have refused repeated requests for licenses covering video cassette recorder (VCR) technology.[16] Korean producers have already demonstrated their ability to compete in the color TV market, but if they cannot get foreign technology in other areas their progress in electronics will be slowed.

In view of these obstacles, does South Korea's development strategy seem feasible? There is no question that Korean firms are well placed to expand their shipments of products like color TVs, passive components, discrete transistors, and small-scale ICs to more advanced countries. Korea is already the world's biggest producer of black-and-white TVs, and Korean firms have been among the leaders as Asian nations have taken over much of the world's production of consumer electronics products—table 79. But developing the capability for designing and developing new products based on domestic technology and resources is a more ambitious and less certain undertaking than manufacturing commodity-like products using standardized, well-understood techniques.

Taiwan

The Taiwanese electronics industry runs a close second in sales to Korea (ch. 4), and employs more people. Both governments have followed the Japanese pattern in emphasizing electronics. At the center of Taiwan's current 10-year economic plan (1980-89) is the development of the machinery, electronics, and information industries—favored because of high value-added, modest demands for energy, and comparatively high technology content. Taiwan has the best trained corps of engineers and scientists in the Far East outside of Japan, mak-

Table 79.— Market Shares in Consumer Electronics for Japan and Other Asian Nations

	Share of total world market, 1979		
	Japan	All other Asian nations	Total Asian share
Video cassette recorders	93.2%	0	93.2%
Color TVs	27.7	3.8	31.5
Monochrome TVs	16.3	49,6	65.9
Radios	5.2	71.8	77.0
Audio tape recorders	38.2	52.8	91.0
Auto radios and tape players	48.6	18.7	67.3
Other home audio equipment, stereos	40.1	12.1	52.2

SOURCE *Denshi Sangyo no Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku* (Survey Report on Trends in the Internationalization of the Electronics Industry and Their Influence, Part II on East and Southeast Asia) (Tokyo Nihon Denshi Kikai Kogyokai (Electronic Industries Association of Japan), March 1981), p 2

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[14] "Gold Star Semiconductor Raising Loan for Move Into Advanced Electronics," *Asian Wall Street Journal Weekly*, Apr. 13, 1981, p. 8. The company is owned 44 percent by Western Electric and 56 percent by the Korean Lucky Group.

[15] C. Webb, "South Korea," *Electronics Weekly*, Apr. 25, 1979, p. 19.

[16] M. Inaba, "Koreans Press Japan To Share Video Cassette Profits," *Electronic News*, Nov. 30, 1980, p. F. Nonetheless, several Korean firms already produce VCRs of their own design,

ing the more technology-intensive sectors natural targets. The country's development plans encompass ICs, computers and peripherals, and high-end consumer products such as VCRs. The Taiwanese, like the South Koreans, are not satisfied with their image as manufacturers and assemblers of components, producers of cheap TVs and consumer goods. According to the current government plan, electronics output is to double over the decade.[17]

For some time, the Government of Taiwan has been encouraging shifts from labor- to knowledge-intensive industries. One vehicle has been the Electronics Research and Service Organization (ERSO), which gets about 40 percent of its funding from public sources, ERSO, established in 1974, is one of four divisions of the Industry Technology Research Institute (ITRI); projects have included computerized industrial control systems, Chinese language computers, and semiconductor development. The organization also negotiated the technology transfer agreement with RCA that helped Taiwanese firms produce c-MOS ICs for the country's watch industry.[18] ERSO is engaged in manufacturing as well as R&D, and has helped introduce improved quality control procedures in Taiwan's electronics industry,

Wage increases have rendered Taiwan's labor-intensive industries increasingly vulnerable to competition from other developing countries, an important motive for the government's stress on knowledge-intensive sectors and another parallel with Korea. Policy pronouncements call for greater use of computer-based automation to increase productivity and export competitiveness. ITRI leaders hope that Taiwan will be able to independently develop small computers and the associated software for both domestic and export markets. Government planners believe that Taiwan will have the best chance of success if, instead of attempting to challenge IBM or the Japanese, the country's efforts are concentrated on special-purpose machines compatible with the Chinese language, along with minicomputers, peripherals, and software.[19] Examples of the initiatives being discussed include joint ventures with Western firms in which government-sponsored training efforts would provide skilled workers for software development.[20]

Along with other Asian electronics industries, Taiwan depends heavily on exports (table 19, ch. 4; Taiwan exported 80 percent of its electronics production in 1979, South Korea 70 percent), with the bulk of these shipments going to U.S. markets. Taiwanese firms such as Tatung and Sampo have already set up color TV production facilities in the United States. With an economy that has been growing at an annual rate of about 8 percent, unemployment at less than 2 percent, and a persistent trade surplus with the United States, Taiwan's electronics industry is well positioned for further expansion. But Taiwan faces many of the same problems policy makers in Korea are grappling with. The country will need greater numbers of well-trained technicians and engineers, higher levels of spending on R&D, and continued improvements in labor productivity—the latter of growing significance as wages rise.

As for South Korea, Taiwan may not have the financial and human resources needed for rapid development in electronics based on indigenous technology, And again, foreign patent holders fearful of new competitors appear reluctant to negotiate agreements with Taiwanese companies, particularly in more advanced products such as VCRs, Some leaders within the Japanese electronics industry have urged "accommodation" with emerging Asian economies—meaning that Japan should concentrate on leading-edge technologies while importing less sophisticated goods from elsewhere in Asia; but if Taiwan's government is

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[17] " Ten-Year Economic Development Plan for Taiwan, Republic of China, " Taiwan Council for Economic Planning and Development, March 1980, p. 39.

[18] R. Neff, "Taiwan pushes High Technology, *Electronics,* May 8, 1980, p. 100,

[19] D. Ying, "Taiwan is Counting on Its Computer Industry to Boost Exports and Bolster the Economy," *Asian Wall Street Journal Weekly,* Oct. 20, 1980, p. 1; "Upgrade or Perish: Electronics Makers Get the Message, " *Trade Winds,* October 1980, p. 11.

[20] "Hewlett-Packard Weighs Software Center in Taiwan, " *Asian Wall Street Journal Weekly,* Mar. 15, 1982, p. 4.

serious about its commitment to high technology, such an accommodation would probably not be acceptable.[21]

China

More strongly committed to self-sufficiency than other industrializing economies, China's progress in electronics and other industries has been uneven—in part because of longstanding conflicts between the development of science and technology and the quest for revolutionary social change, China's desire for self-sufficiency has also created obstacles to efficient mass production; as a case in point, components are still soldered into circuit boards by hand, while in the West wave soldering has been employed for more than 20 years. This is not to say that the country's electronics industry is unrelievedly primitive: the People's Republic of China (PRC) builds mainframe computers as well as ICs roughly comparable to mid-1970's U.S. products, Nonetheless, until recently most of the computers were one-of-a-kind machines, lacking even transportable software.[22]

The picture has changed in the last half-dozen years as a new consensus on the importance of science and technology—one of the "four modernizations" advocated at the Fourth National People's Congress in 1975-emerged among China's leaders.[23] In the National Plan for Development of Science and Technology, announced at a nationwide science conference in 1978, eight technical areas were singled out for special emphasis, among them computers. In calling for the development of China's capability in a wide range of electronics technologies, including large-scale ICs, microcomputers, peripherals, software, and computer networks, the plan termed computer science and technology "a conspicuous hallmark of the level of modernization of a country. " The reestablishment of the Science and Technology Commission, a central agency for policymaking and implementation, is a further indication of the government's new direction.

Ten factories in China now produce computers, ranging from microcomputers to machines similar to PDP-11s and IBM 360s.[24] The State Administration of Computer Industry (SACI) has programs underway to utilize the nation's existing computing capability more efficiently, and intends to move toward smaller machines rather than relying on large mainframes. As one route to such objectives, SACI is establishing joint ventures with foreign concerns. In 1981, the China Technical Services Corp. and the Japanese firm NEC (Nippon Electric Co,) signed an agreement for a computer center in Beijing. NEC will provide a medium-sized machine free of charge, and an annual 4-month training course for 30 to 40 Chinese software specialists. The Chinese will supply other facilities, along with the center's staff, including interpreters. A similar agreement has been signed with Sperry Univac, while negotiations have taken place with other U.S. firms, including Wang Laboratories and Honeywell.[25] Both Japanese and Western firms hope to establish themselves in the potentially lucrative PRC market.

As such ventures indicate, China is putting a good deal of effort into training computer specialists as a basis for more effective utilization of information processing technologies. Electronics and computer technicians will study at an Information Processing and Training Center, established in 1979 with funding from the United Nations. Among the plans for the center, to be equipped with a Burroughs mainframe, as well as five Hewlett-Packard 3000 series minicomputers, are development of a world patent index, collection of information on food supplies, a data base on power generation and distribution for the Electric Power Ministry, studies of urban traffic flows, and macroeconomic modeling.[26] Such endeav-

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[21] See the summary of the Electronic Industry Association of Japan's report on Asian electronics in *Asian Wall Street Journal Weekly*, June 8, 1981.

[22] K. Berney, "Computer Sales to China, " *China Business Review*, September-October 1980, p. 25.

[23] R. P. Suttmeier, *Science, Technology and China Drive for Modernization* (Stanford, Calif.: Hoover Institution Press, 1980),

[24] D. Burstein, "Chinese Foment Another Revolution, " *Electronics*, Jan, 13, 1983, p. 115.

[25] K. Berney, "China's Computer Resolution, " *China Business Review*, November-December 1981, p. 14.

[26] "U.N. Aid for China's Computer Modernization, " *China Business Review*, September-October 1980, pp. 33-34.

ors imply that China—at least at present—may be more interested in applications than in building production capacity, not only in computer equipment but in electronics more generally,

Other NICs

Rapid growth in the Asian electronics industry extends well beyond Taiwan and South Korea. Hong Kong's companies, which have been basically assembly-oriented suppliers of products like watches and calculators, accounted for 13 percent of the colony's exports in 1980.[27] In Singapore, which has also been a major assembly site, the government has introduced policies intended to encourage semiconductor manufacturing, as well as production of computer hardware and software; the government, for example, owns 25 percent of Tata Elxsi, a joint venture involving U.S. and Indian interests formed to make mainframe processors.[28] Government policy in Hong Kong has been less intrusive than in Singapore, but the electronics industry there has also been moving toward high technology.

Clearly the Asian NICs are all, in one way or another, attempting to learn from and emulate Japan's approach to industrial policy, In the earlier postwar years, Japanese companies imported technology, while government decisions favored heavy industries; newly in*dustrializing nations in Asia have already abandoned this approach for one more like Japan current industrial policy*. The question is whether South Korea, Taiwan, and other NICs have, at this juncture, the resources to support technological self-sufficiency. But even if their progress in developing home-grown technologies proves slow, these countries will be increasingly competitive in world markets for less sophisticated electronics products, well able to challenge manufacturers anywhere that fail to maintain a technological edge,

The discussion above does no more than sketch in a few of the outlines of industrial policy toward electronics in developing Asian economies (Japan is treated in some detail below). Outside Asia, governments in countries like Brazil and Mexico have also nurtured rapidly expanding electronics industries. Brazil, for instance, has used access to its rapidly growing market as the carrot for acquiring U.S. minicomputer technology.[29] In all these countries, foreign investments by American and/or Japanese firms have been one of the starting points for indigenous development. Today, these nations are aggressively attempting to strengthen their own capability and reduce their dependence on more advanced countries. None of the policies employed—the establishment of government-supported R&D facilities, tax breaks and financial subsidies for local firms, preferential procurement, government encouragement of or participation in joint ventures with foreign firms—are unique or even unusual. Such measures are part of the standard list. Still, government planners in NICs have often pursued them more consistently and forcefully—South Korea is especially striking in this regard–than have developed economies. This is partly because the paths are well marked for NICs in comparison to advanced nations with complex industrial structures. The explicit focus on strengthening domestic technical know-how—a recent shift in emphasis —has led to increased demands for transfers of technology as a condition for sales or investment by foreign firms. Countries making such demands—or alternatively, offering incentives to attract technology inflows-see them as a prerequisite for building their own capabilities. Some multinational electronics firms have accepted these conditions—which at times have been a prerequisite for market entry, a tactic that Japan employed in years past—more readily than others. The draft UNCTAD (United Nations Council on Trade and Development) code on technology transfer

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[27] "Says Electronics Could Lead as Hong Kong Export Earner, " *Electronic News,* Oct. 26, 1981, p. FF.

[28] "See CPU, Software Mfg. Leading Singapore's Future, " *Electronic News,* Dec. 7, 1981, p. Q.

[29] J. Baranson and H. B. Malmgren, "Technology and Trade Policy: Issues and an Agenda for Action, " report prepared for Department of Labor and Office of the U.S. Trade Representative, October 1981, pp. 125-126.

illustrates the strong desire among developing nations everywhere for technology acquisition on more favorable terms.

A problem that the developing Asian economies all share—some more so than others—is expanding their pools of engineers and technicians. Countries like India, Taiwan, and Korea have labor forces containing substantial numbers of engineers and scientists, many of them educated in the West. Nevertheless, while some of these nations have managed to mobilize their human resources more effectively than others, none of the NICs have enough skilled people to move rapidly into high-technology electronics production. They do have one advantage: their engineers are not paid nearly as well as in the advanced countries. With salaries perhaps one-quarter those in the United States, the industrializing Asian economies are striving to capitalize on lower R&D costs as they earlier did with unskilled labor.[30] While it is unlikely that any of these countries will quickly bridge the commercial and technological gaps separating them from Japan and the West, and while their approaches to industrial policy differ in style of government intervention and reliance on market mechanisms, all seem committed to some variety of coordinated industrial policy as a means of supporting local electronics manufacturers in both domestic and world markets.

United States

The U.S. Government has not developed a consistent, systematic set of policies directed at industry—a task that, even if judged desirable, would be much more difficult for the world's most complex economy than one that was still industrializing. It has become a commonplace to note that, while numerous public policies exert direct or indirect effects on firms and industries, the American approach is ad hoc. In this sense, then, U.S. industrial policy also differs from that in Japan or many of the European nations, While the Federal Government has paid more attention to some industries than others, this has most often been a result of political pressures, as in the case of textiles, or national security considerations. And not even in the Department of Defense could one find anything like an "electronics industry policy. " Following World War II, U.S. foreign economic policy centered on an ambitious recovery program in Western Europe and Japan–the Marshall Plan. But despite this embrace of economic planning for other parts of the world, domestic economic policies have revolved around macroeconomics and regulation. The United States has avoided promotion, planning, and targeting—the common tools in other countries.

In electronics, microlevel involvements, leaving aside national defense, have generally had regulatory thrusts—witness the lengthy antitrust prosecution of IBM. One reason the U.S. Government has been willing to endorse economic planning overseas but not at home lies in the unrivaled strength of American corporations during most of the postwar period. In light of the success of American firms such as Boeing, IBM, or General Electric in world markets, the focus of policy makers here on free-market competition is quite understandable; for the Federal Government to consider policies that would promote "national champions''—as the French did—when these champions already existed, would have seemed superfluous if not counterproductive.

Public policies have, nonetheless, exerted considerable influence on the American electronics industry. Military procurements stimulated developments in computers and semiconductors. Since the 1960's, trade policy has been a persistent concern in consumer electronics. Taxation, regulations of many kinds (particularly in the telecommunications sector), patents, protection of computer software–all have been debated in various contexts. But in total, the Federal Government's policies have been a patchwork, often based on objectives quite different from those motivating the industrial policies of other countries. Antitrust enforcement stands out especially.

‘A, Spaeth, "Asian ‘NICs' Rely on Cheap Brainpower To Plan Output of More Advanced Goods, " *Wall Street Journal*, Jan. 5, 1983, p. 25.

Antitrust

Where competition policies in other countries have been vehicles for mergers, joint ventures, and consolidation, notably in the computer industry—the rationale being to create companies big enough to compete effectively—antitrust enforcement in the United States has aimed at breaking up large enterprises.[31] Despite the common association of bigness with badness, American law does not prohibit oligopoly (industries dominated by a small number of firms), but limits predatory or exclusionary tactics. Therefore, antitrust violations tend to be difficult to prove, cases lengthy and expensive .32

How has antitrust enforcement influenced the international competitiveness of American electronics firms? As has been the case so often with U.S. industrial policy, the side effects may have had the greatest impact—in this instance, uncertainty over the intentions of the Department of Justice and the Federal Trade Commission. Business and industry in the United States claim—perhaps with justification—that antitrust enforcement is ambiguous and threatening, that Government officials, knowing the line to be vague, try to keep companies far back. Instances in which enforcement intentions have been known to actually stop mergers, joint ventures, or acquisitions in electronics are few. One case arose at the end of the 1970's, when GE and Hitachi proposed a joint venture to manufacture TVs in the United States. The two companies suspended their negotiations after the Justice Department threatened to sue under provisions of the Clayton Act.[33] More frequently, the possibility—even if remote—of costly and protracted litigation seems to have caused American firms to steer clear of cooperation in R&D.[34] While much of the complaining by the business community over antitrust reflects no more than the usual antagonism toward Government regulation, it does appear that companies have been little inclined to explore the bounds of the permissible, simply because the risks have been seen as far greater than the rewards. Largely as a result of repeated expressions of concern, the Department of Justice issued a set of written guidelines covering joint R&D ventures, but a good deal of ambiguity nevertheless persists.[35] Even where no single project has great import, a general discouragement of joint R&D efforts could eventually have a large cumulative impact. Moreover, if joint international research projects proliferate, American antitrust law—in the absence of more concrete guidance—may present an obstacle to participation by U.S. firms .38

Trade and Foreign Economic Policies

If antitrust has recently been at the forefront of U.S. industrial policies as they have affected

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[31] On U.S. antitrust law and enforcement, see *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles,* op. cit., pp. 184-185. Also ch. 12 of the present report; J. W. McKie, "Government Intervention in the Economy of the United States," *Government Intervention in the Developed Economy, P.* Maunder (cd.) (London: Croom Helm, 1979), p. 75; and M. Keller, "Regulation of Large Enterprise: The United States Experience in Comparative Perspective, " *Managerial Hierarchies: Comparative Perspectives on the Rise of the Modern Industrial Enterprise,* A. D. Chandler, Jr., and H. Daems (eds.) (Cambridge, Mass.: Harvard University Press, 1980), p. 161.

[32] The Department of Justice initiated its suit against IBM in 1969, with the trial beginning in 1975. A decision—which would certainly have been appealed regardless of the verdict—was still well in the future when the case was dropped by the Government in January 1982. At the same time, the Justice Department resolved a 7-year antitrust suit asking that AT&T divest itself of Western Electric, the communications company's manufacturing arm. On the settlements, see "Statement of William F. Baxter, Assistant Attorney General, Antitrust Division, on Recent Actions of the Department of Justice in U.S. v. AT&T and U.S. v. IBM, Before the Committee on the Judiciary, U.S. Senate, " Jan. 25, 1982.

[33] J. Crudele and J. Hataye, "Fear for TV Jobs as Justice Blocks GE-Hitachi Venture," *Electronic News,* Dec. 4, 1978, sec. I, p. 1.

[34] See, for example, D. H, Ginsburg, "Antitrust, Uncertainty, and Technological Innovation, " *Antitrust Bulletin,* winter 1979, p. 635.

[35] *Antitrust Guide Concerning Research Joint Ventures* (Washington, D. C,: Department of Justice, November 1980). At the end of 1982, the Justice Department announced that it would not seek to bar the formation of Microelectronics & Computer Technology Corp., the joint venture involving a dozen U.S. firms intended to pursue R&D in advanced electronics technologies (ch. 5].

[36] For a proposal that foreign enterprises be allowed to participate equally in the government-sponsored R&D efforts of all nations, see *Report of the U.S.-Japan Economic Relations Group,* January 1981, p. 80. Japan has recently agreed to open its fifth-generation computer project, and others like it, to Japanese subsidiaries of U.S. companies. See U. C. Lehner, "U. S., Japan Pact Would Bolster Joint Research," *Wall Street Journal, Nov.* 1, 1982, p. 35.

the computer industry—via the IBM case—trade policies concerned with dumping and other unfair practices have been central in consumer electronics, Trade policies and their effects are treated in detail in chapter 11; the point here is simply to note their significance as part of U.S. industrial policy. After years of litigation, the competitive battle in color TV is still proceeding in the courtroom as well as the marketplace. A legalistic thrust analogous to that in computers has dominated public policy impacts.

To take a somewhat broader perspective, as world competition in electronics has increased, U.S. policy makers have renewed their attempts to reduce overseas trade barriers. Nontariff and indirect barriers restricting the entry of American products into foreign markets have been particular targets. A new flurry of activity came in 1982; the many bills introduced in Congress that could be loosely grouped as dealing with trade reciprocity illustrate the depth of concern. Progress on such questions will be slow; since most countries view subsidies and other tools of industrial policy as internal matters, they are difficult to address via international negotiations.

Procurement and R&D

In contrast to the antitrust and trade orientations visible in computers and consumer electronics, American semiconductor firms have seldom, since the 1960's, been directly affected by public policies. Through the 1950's and 1960's, the Federal Government stimulated developments in microelectronics by purchasing semiconductors for military and space programs, as well as by supporting R&D (much the same was true for the computer industry in its early years). During this period, the Government purchased a large fraction of U.S. semiconductor output—e.g., for the Minuteman II missile. In 1965 the Department of Defense accounted for about 70 percent of U.S. IC sales, while by the end of the 1970's, the figure had dropped to around 7 percent.[37]

Because the military market is now so small compared to commercial sales, specialized contractors do much of the work on devices for defense systems. Largely in response to the slow rate of introduction of advanced microelectronics technologies into military hardware, the Department of Defense initiated an R&D program directed at very high-speed integrated circuits (VHSIC) beginning in fiscal 1979. With an initial 6-year budget of more than $200 million–since expanded substantially–the VHSIC program is intended to speed the development of ICs that meet military needs. Involving all three services, VHSIC has been structured around bidding by firms and groups of firms for contracts covering a variety of well-defined R&D tasks. Although the ICs themselves will be tailored to military applications, research results in areas such as processing technology, computer-aided circuit design, and system architectures will find their way into the commercial efforts of U.S. merchant firms. While most of the VHSIC contracts are closer to development than basic research, the Defense Department has also initiated a program entitled Ultrasmall Electronics Research intended to support R&D that will pay off 10 or 20 years in the future.[38]

Even with the increases stemming from the VHSIC program, Federal support of R&D in semiconductor-related technologies remains a much smaller fraction of total U.S. semiconductor R&D than in the 1960's. While the comparisons are less than straightforward because allocations of spending to R&D categories tend to be rather arbitrary, and disaggregated data seldom available, an idea of the current significance of Federal funding can be pieced together.

For 1980, the latest year for which data is available, total U.S. R&D spending by the "electronic components" sector—which is considerably larger than microelectronics alone—has been put at $1.354 billion.[39] For the same

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[37] *An Assessment of the Impact of the Department of Defense Very-High-Speed integrated Circuit Program,* National Materials Advisory Board Report NMAB-382 [Washington, E). C.: National Research Council, January 1982), p. 6. Also see ch. 4.

[38] *The 5-Year Outlook on Science and Technology 1981* (Washington, D.C.: National Science Foundation NSF 81-40, 1981], p. 33.

[39] *Electronic Market Data Book 1982* [Washington, D.C.: Electronic Industries Association, 1982), p. 121. The figure, from data collected by the National Science Foundation, is for SIC category 367, which has nine subdivisions. Of these, semiconductors (SIC 3674) is certainly the largest performer of R& Il.

year, tabulations of R&D spending by U.S. merchant semiconductor firms from sources such as annual reports give totals in the range of $800 million. It is more difficult to determine spending on microelectronics by captives, which seldom report such data separately. Allocation of software development costs also leads to ambiguity; as microelectronic devices become more complex and more like complete systems, software becomes a major part of the research, design, and development effort.

In any case, given that IBM—largest of the captive producers—no doubt spends several hundred million dollars annually on microelectronics, total U.S. R&D expenditures on semiconductor-related technologies in 1980 must have been well over $1 billion. How much of this did the Federal Government provide? For fiscal year 1980, Government expenditures for R&D related to ICs have been reported as $61 million, rising to $71 million in fiscal 1981.[40] Evidently, then, the Federal Government contributes something between 5 and 10 percent of the total. This estimate illustrates the continuing decline in the Federal presence; over the period 1958-76, Government spending accounted for about 15 percent of all U.S. semiconductor R&D.[41]

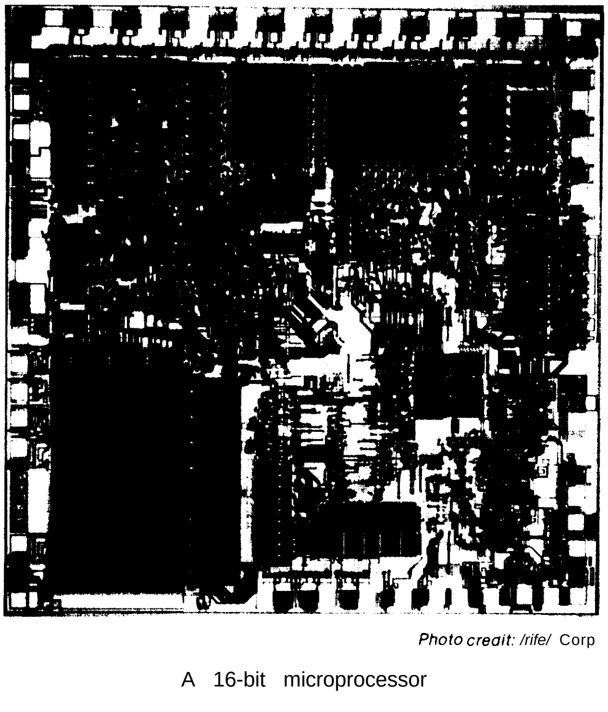

Photo credit: /rife/ Corp

A 16-bit microprocessor

Indeed, it appears that even in the early years, Government purchases were a greater spur to the industry than R&D contracts.[42] By providing a guaranteed market, Government procurement—mostly for military purposes—stimulated the growth of the industry at a critical stage in its development. At the time, semiconductor manufacturing was a far different business than today; it **was** part of the defense sector of the economy, whereas sales to the Government are now dwarfed by sales to computer manufacturers and other nondefense customers.

Taxation

The Economic Recovery Tax Act of 1981 (ERTA) **was** supposed **to** speed economic growth and build U.S. competitiveness by increasing incentives for saving and investment.

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[40] *An Assessment of the Impact of the Department of Defense Very-High-Speed Integrated Circuit Program,* op. cit., pp. 20-22. For purposes of this rough comparison, R&D related to ICs can be taken as equivalent to R&D related to microelectronics. The Federal contribution includes work performed in Government laboratories, but this accounts for less than 10 percent of the total—the rest being contracts and grants to industry, universities, and independent research laboratories. About 10 percent of the Government money comes from the National Science Foundation (NSF), most of the rest from the Department of Defense, NSF's share of *basic* research support is closer to 30 percent. In fiscal **1980, the VHSIC program accounted** for 40 percent of the Government's total spending on microelectronics R&D. As table 77 indicates, overall R&D spending by the U.S. Government is heavily skewed toward military needs compared to countries like Japan or Germany.

IBM spends well over $1 billion annually on R&D; the company's R&D spending on very large-scale ICs has been reported to total about $1 billion over the period **1977-80—G.** Gregory, "The U.S. Wages Micro-War, " *Far Eastern Economic Review,* Mar. 16, 1979, p. 124.

[41] *A Report on the U.S. Semiconductor Industry* (Washington, D. C.: Department of Commerce, September 1979), p. 8. The estimates are those of the Semiconductor Industry Association. In 1958, Department of Defense contracts and grants accounted for nearly a quarter of the industry's R&D spending–N. J. Asher and L. D. Strom, "The Role of the Department of Defense in the Development of Integrated Circuits, " Institute for Defense Analyses paper P-1271, May 1977, p. 3, The percentage has thus been falling more or less steadily for many years.

[42] Asher and Strom, op. cit.; J. M. Utterback and A. E. Murray, "The Influence of Defense Procurement and Sponsorship of Research and Development on the Development of the Civilian Electronics Industry," report CPA-77-5, Center for Policy Alternatives, Massachusetts Institute of Technology, June 30, 1977.

The wholesale changes in U.S. tax policy embodied in ERTA have affected all industries; perhaps most significant are the altered depreciation schedules discussed in chapters 7 and 12. ERTA also extends a tax credit—amounting to 25 percent of any increase in R&D spending over a base figure—as part of a package of incentives for research. Although young high-technology companies may not have profits to set against the tax credit, at least some electronics companies will benefit from the R&D provisions more than from accelerated depreciation.

As pointed out elsewhere, the ERTA package has thus far had little perceptible effect on investment. Moreover, it appears that, in comparison with other U.S. industries, the *relative* attractions of investments in electronics may have been diminished, The telling point in the context of U.S. industrial policymaking is this: *such outcomes have been neither intended nor anticipated, instead resulting from the unexamined give-and-take of the political process.*

Industrial Policymaking

As many of the examples above indicate—from antitrust through taxation (many others could be adduced)—public policies influencing the American electronics industry have lacked a framework and sense of direction, The very notion of objectives or "goals" for policy, in any but the most immediate sense, has been anathema for policy makers here. In contrast, other countries have pursued economic development quite consistently, making use of numerous policy tools. While in the United States there has been no one agency to serve as a focal point for industrial policies, other nations have developed policymaking approaches involving more or less permanent industrial advisory councils, ministries accountable for well-defined policy areas, mechanisms for coordination. Here, many agencies participate in policy development—sometimes on a regular basis, sometimes infrequently.

More often than not, policies affecting electronics have been formulated with little consideration of possible impacts on international competitiveness. National security, antitrust, macroeconomic policy have taken priority—competitiveness and economic efficiency have seldom been at the forefront, or even in view. Trade policy complaints in consumer electronics have come from domestic firms and their employees, with Federal agencies—ill-equipped to take an independent view—reacting to these pressures. Short-term response to political pressures has in fact been the common denominator of U.S. industrial policy.

Yet as competition has intensified—in computers and microelectronics, jet aircraft and telecommunications systems—both Congress and the executive branch have begun to debate the question of a more explicit industrial policy for the United States.[43] In addition, the Department of Defense through VHSIC and other programs, the National Science Foundation, and the Department of Commerce have all studied—even attempted to design, often under rubrics such as innovation—policies that would stimulate basic as well as applied research, and

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[43] To give only a few examples, and leaving aside such related topics as innovation or productivity, late in 1980 the Subcommittee on Trade of the House Ways and Means Committee issued the *United States-Japan Trade Report* (Sept. 5, 1980), calling for overall improvement of the economy rather than trade protection as a response to Japan's growing challenge in high-technology industries. A report by J. Gresser—*High Technology and Japanese Industrial Policy: A Strategy for U.S. Policymakers* (Oct. 1, 1980)—recommending a more focused U.S. response was published soon thereafter under the auspices of the same committee, The Subcommittee on Trade's *Report on Trade Mission to the Far East* (Dee. 21, 1981) reiterates many of the same themes, More recently, the Joint Economic Committee has released a study by M, Borrus, J. Millstein, and J. Zysman entitled *International Competition in Advanced Industrial Sectors: Trade and Development in the Semiconductor industry* [Feb. 18, 1982) which stresses the importance of electronics for overall economic development.

Dozens of hearings in Congress over the past several years have covered such issues, two examples being *Industrial Policy,* hearing, Joint Economic Committee, Congress of the United States, May 18, 1982; and *U.S. Industrial Strategy,* hearing, Subcommittee on Economic Stabilization, Committee on Banking, Finance and Urban Affairs, House of Representatives, Sept. 22, 1982.

Trade and tax policy debates inside the Reagan administration have dealt at least peripherally with electronics, as has an interagency stud y on high-technology trade—see *An Assessment of U.S. Competitiveness in High-Technology Industries* (Washington, D. C,: Department of Commerce, February 1983). The Commerce Department has begun work on an inventory of industrial policy measures employed by other countries, while the Department of Labor has a long-standing interest in industrial policies, particularly as they deal with adjustment.

encourage productive investments by the private sector. There is no dearth of concern over policies affecting industries like electronics, but little consensus as yet on the direction that policy initiatives should take.[44]

Chapter 12 addresses policy alternatives for the United States in some detail; here the point is that—in contrast to ongoing debates over industrial policy in other countries, which tend to focus on review and redirection of measures already in place—there is still no consensus in this country on the need for a more coherent industrial policy, much less on the form it might take. In a sense, the United States is *starting off behind in the race to develop effective industrial policies simply because U.S. industries like electronics led the competitive race for so many years.*

France

Perhaps more than any other advanced Western nation, France has centralized and coordinated its industrial policymaking as one of the primary ingredients in an interventionist approach to economic policy. While the tools and tactics have shifted over time, the policies adopted by the current Socialist Government trace their origins to the planning process adopted by France in the aftermath of World War II. The continuity of the French system, like that of Japan, is one of its salient characteristics.

The Setting

The French have accepted government involvement in the economy as legitimate and necessary. Industrial policies are part of a context that includes extensive public ownership of both manufacturing organizations and financial institutions; under Mitterrand, the electronics firms CII-Honeywell Bull, Thomson, and CGE (Compagnie Generale d'Electricity) have joined the roster of national enterprises, together with a number of banks. The goal has been not only to increase the financial resources and market power of French corporations, but to create prestigious flagships that can lead the economy. Saving jobs in threatened industries—e.g., steel—has also been an important motive; furthermore, the government's plan for the electronics industry promises to create 80,000 new jobs over the 5-year period 1982-86.[45] "National champion" firms were a capstone of French industrial policy during the 1960's, when France became the first nation to mount a direct challenge to IBM. Aircraft, nuclear power, and telecommunications have been other government favorites. The idea of national champions never really died, and has simply been revived in slightly different form under Mitterrand; electronics—computers, semiconductors, consumer products, communications, office automation—is to be at the core of France's future industrial policy.

Policymaking mechanisms in France—centered on the ministries of Industry and of Economy and Finance—differ greatly from those in the United States, as might be expected in a country where the idea that the state can and should play a role in industrial development has been widely affirmed. In the policymaking system that has evolved, the Ministry of Economy and Finance takes the lead in channeling funds to favored sectors (ch. 7), while the Ministry of Industry is more heavily involved in day-to-day matters, as well as technology and microlevel planning. Within the Ministry of Industry, the Directorate of the Electronics Industries and Data Processing is responsible for efforts such as the Government Program for Development of Electronics, announced late in 1982. Since the Socialists took power in 1980, the Ministry for Research and Technology has taken a larger role in industrial policy—not only the design of policies for high-technology industries like electronics, but

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[44] OTA's comparison of U.S. competitiveness in three industries led to the suggestion of a "macroindustrial" policy. The intent would be to provide infrastructural support for American industries, rather than moving toward explicit Government decisions favoring some sectors over others. Examples would be policies directed at labor markets, technological development, human resources, taxation, and economic adjustment. See *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles,* op. cit., pp. 157-165.

[45] " Government Funding for Electronics Industry Discussed," *West Europe Report, Science and Technology, No. 118,* Joint Publications Research Service JPRS 81678, Aug. 31, 1982, p. 3.

also restructuring elsewhere in the French economy. Broad 5-year economic plans continue to be part of the policymaking process, although they have receded into the background compared to 30 years ago.

The staffs of French ministries tend to share similar educational backgrounds, typically the prestigious grandes ecoles. Not only the public sector, but large industrial enterprises as well, are managed by a small and homogeneous elite; the Socialists placed at the head of nationalized firms by the Mitterrand Government are in most respects indistinguishable from the men they replaced. The closed nature of this system helps the French bureaucracy wield authority more like that granted public officials in Japan than in the United States, Distinguishing features of French industrial policy—an emphasis on sectoral measures, perhaps stronger even than in Japan, and the encouragement of corporate consolidation—reflect not only the power of the bureaucracy but the community of interest binding industry and the state.

Planning

Much has been written on indicative planning in France, which can be traced to the immediate postwar period and the Monnet Plan for reconstruction. As the term "indicative" suggests, the country's 5-year economic plans have not been imperative, but based on concerted actions mutually agreed on. In earlier years especially, officials in the Planning Commission played key roles in bringing together leaders in government and industry.

A major function of the planning process has simply been to gather information about past progress and future prospects by sectors in the economy. The hard decisions have been made elsewhere, with the role of the Planning Commission largely facilitory. While the rapid postwar recovery of the French economy cannot be attributed solely to planning and industrial policy, the planning exercise has helped crystallize perceptions among the bureaucracy, as well as decisionmakers in private industry, creating a shared referent for government and industry. Business has been able to operate within a fairly predictable context.

Finance

The French financial system, like the planning mechanism, enhances government influence over economic development. Capital allocations—see chapter 7—are controlled to considerable extent by administrative fiat rather than market forces, A rather small number of financial institutions—closely tied to the bureaucracy whether or not actually nationalized—link government policy makers and companies seeking funds. The Treasury determines interest rates on bonds; through the Ministry of Economy and Finance, as well as a variety of semipublic lenders and the banks, the government can exert considerable leverage over credit decisions. Specialized institutions such as the Institut de Developpement Industriel (IDI), funded from both public and private sources, provide risk capital to medium-sized firms; ID I has also made equity investments in the computer firm Compagnie International pour l'Informatique (CII). Even in light of the French Government's traditional use of financial channels, Mitterrand's investment plans for electronics are extraordinarily ambitious. The industry—which is now roughly half nationalized—is to invest $20 billion over the period 1982-86, with the government providing about 40 percent of the total .[46] It is not clear where the money will come from.

Le Plan Calcul

French policies as they have affected electronics have been shaped, as elsewhere in Europe, by historical circumstance—i.e., the relative weakness of French industry compared to American corporations. The result during the 1960's was a concerted thrust in computers known as Le Plan Calcul—not unlike what the French are now undertaking in electronics as a whole.

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[46] Ibid. The 5-year investment plan calls for the government to provide 55 billion francs of the 140 billion total.

By the early 1960's, the enormous strength of IBM—combined with the comparative weakness of European firms—was perceived as a serious threat to the viability of the French electronics industry. It was the "American challenge''–viewed as a technological lead, but in reality just as much commercial superiority—that stimulated an ambitious effort by the French.[47] The well-known Plan Calcul came in 1966, on the heels of serious difficulties for the French computer industry. In the "Affaire Bull" of 1964, the American firm General Electric had purchased Machines Bull, a faltering French computer manufacturer. At about the same time, the U.S. Department of State refused to grant export licenses for two of Control Data's largest processors. These were to have been used in the development of fusion weapons; the refusal helped convince French policy makers of the need for an independent computer industry. Since then, if not before, the French military, although taking some care to stay in the background, has had a major say in industrial policy decisions affecting electronics and telecommunications.

Le Plan Calcul was intended to build an industry capable of challenging IBM; to do this, the bureaucracy engineered the merger of two existing manufacturers, forming a new public corporation—CII. The government provided capital to the fledging champion, but as the product of a union between two firms which together held no more than 7 percent of the French computer market, the new company had a long way to go.

CII's efforts were directed first and foremost at medium to large mainframes—the rise of the minicomputer was just beginning and had not been widely recognized. CII was to be an export leader, as well as providing for France's own needs, of which national security was at the forefront. Although CII was attacking IBM at the latter's point of greatest strength, French planners hoped—by providing export and other subsidies, encouraging shipments to the Soviet bloc and developing countries, protecting CII against foreign competitors, and guaranteeing domestic procurements for the company's products—to enable the firm to challenge IBM. A related series of measures over the late 1960's and early 1970's comprising Le Plan des Composants (Plan for Components) was to help with the development of semiconductor devices, primarily for computer applications.

Despite the support provided CII, the firm never approached its targets. American companies continued to dominate sales in France, and CII's chief market turned out to be the government, By 1975 Le Plan Calcul had effectively been abandoned, as a variety of factors combined to defeat the best efforts of French policy makers (who now insist that their efforts at least prevented further erosion of the nation's indigenous capabilities), Some critics emphasize the contradictions inherent in a protective strategy within a highly competitive industry, and a policy designed and implemented by technocrats with little experience of commercial realities.[48] Hindsight shows the effort to have been overambitious, an attempt to confront American firms across a broad line of products rather than in selected niches. In this sense, national goals took precedence over sound business strategy. Finally, the money that the French Government pumped into CII—perhaps $350 million between 1966 and 1976—looks rather insignificant next to, say, IBM's resources.[49]

Into the 1970's, then, French policy toward the electronics industry centered on one company—CII. By 1975, when the failure of Le Plan Calcul was clear, the government encouraged CII to merge with Honeywell Bull—the descendant of Machines Bull that emerged from the sale of General Electric's computer business to Honeywell. The new company, CII-Honeywell Bull (CII-HB), was majority French-owned; it quickly received further government

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[47] This interpretation of the "challenge" is elaborated by N. Jequier, "Computers," *Big Business and the State,* R. Vernon (cd.) (Cambridge, Mass,: Harvard University Press, 1974), p. 193.

[48] J. Zysman, *Political Strategies for Industrial Order* (Berkeley, Calif.: University of California Press, 1977), p. 99.

[49] The $350 million estimate is from *Technical Change and Industrial Policy: The Electronic Industry* (Paris: Organization for Economic Cooperation and Development, 1980), p. 46. Jequier (op. cit., p. 217) gives a figure of $120 million between 1966 and 1970.

assistance totaling perhaps $700 million, so In 1982, after prolonged discussions, the Mitterand government effectively nationalized CII-HB, which will become a subsidiary of a government-controlled holding company taking up the old name Machines Bull.[51] Machines Bull will be the centerpiece of Mitterrand's computer thrust, discussed below, with CII-HB responsible for mainframes,

Le Plan des Composants

Recognition that CII-HB needed infusions of semiconductor technology led to a new 5-year components plan in 1977. Military requirements were also a strong motive, Since the 1950's, France had maintained a small but high-quality semiconductor research effort. However, this had never been translated into a commercially viable merchant industry. By the early to mid-1970's, perhaps a hundred French engineers and scientists were engaged in R&D on advanced microelectronic devices; the country did not have the capability for mass-producing ICs. French engineers had little background in microprocessors, nor in MOS (metal oxide semiconductor) ICs, most of their expertise being in bipolar devices for communications and consumer products. Le Plan des Composants—designed by the ministries of Industry and Defense, plus the PTT (responsible for postal services and telecommunications)—was intended to rectify these deficiencies. In contrast to Le Plan Calcul, France did not attempt to keep foreign participants out, but sought to build on American technology, In this way, French planners hoped to move toward self-sufficiency in microelectronics, with the eventual goal of a major share of the European market,

The vehicles included three joint ventures linking American semiconductor firms with French partners. France would get technology, the U.S. participants access to the French market—particularly the lucrative telecommunications sector, well protected by the PTT. These joint ventures, in which the French partners held controlling interests, tied Thomson to Motorola, Saint-Gobain to National Semiconductor (in a firm named Eurotechnique), and Matra to Harris. In addition, the plan supported two more firms: Radiotechnique, a Philips subsidiary in France, and EFCIS, originally owned by the French atomic energy authority (Thomson purchased a majority interest in EFCIS in 1977).

Le Plan des Composants was developed at a time when France's Government was rediscovering market forces, Attempting to learn from Le Plan Calcul, French planners decided to support a number of firms. Rather than funnel the money set aside for the program to a single champion, the five companies would compete with one other. Although an element of competition was thus built in, each participant was assigned certain technologies in which it was to take the lead. Matra-Harris, for example, would specialize in c-MOS since this was Harris' strength; later the joint venture negotiated a further agreement with Intel, largely to gain the latter's n-MOS technology. ICs were new technologies for both Matra and Saint-Gobain, which were picked for the program in part because of their success in other fields–in the case of Matra, its high-technology experience in aerospace was a particular attraction, Saint-Gobain-Pont-a-Mousson, a major producer of glass and chemicals, had decided of its own accord to diversify into electronics; in addition to participating in Le Plan des Composants, the company purchased substantial interests in CII-HB and the Italian computer and office equipment firm Olivetti during this period, More recently, the French have decided that, if one national champion is too few, five are too many; since the Mitterrand government came to power, extensive discussions aimed at consolidation have been underway. Three centers of excellence in microelectronics seem likely to emerge. Both Matra and Saint-Gobain have been nationalized, with Saint-Gobain evidently forced out of elec-

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[50] *Technical Change and Industrial Policy: The Electronic Industry*, op. cit., p. 46. Other estimates have ranged as high as $1 billion. Prior to the merger with Honeywell Bull, CII had been a participant with Philips and Siemens in the European consortium, Unidata. The consortium did not prove workable,

[51] "CII-Honeywell Bull Announces Restructuring in Line With French Plans for Computer Firms," *Wall Street Journal*, Dec. 21, 1982, p, 30. Honeywell's interest has been reduced to about 20 percent.

tronics.[52] Eurotechnique has been sold to Thomson, which purchased the shares of both Saint-Gobain and National Semiconductor, while retaining a technology exchange agreement with the American firm.

The R&D portion of Le Plan des Composants, known as Le Plan Circuits Integres, channeled about $150 million in government funds as direct grants and loans to the five companies. The money supported work on very large-scale ICs, ranging from circuit design to the development of processing equipment. Research centers, including the Electronics and Informatics Technology Laboratory of the French Atomic Energy Commission, were strengthened, while Le Plan Circuits Integres also supports microprocessor applications through a new Information Agency .[53]

It is too early to judge the success of Le Plan des Composants in building a viable commercial industry, but in terms of technology French semiconductor firms have made great progress. Eurotechnique manufactured its first ICs at the end of 1980 and has since expanded output at a high rate. EFCIS's production of advanced devices began about the same time. Despite rapid increases in production, however, the French entrants remain small on a world scale (see ch. 4, table 32), suffering from thin product lines and limited distribution networks. Still, the technical know-how they have acquired from American firms places them in advantageous positions compared to other European semiconductor manufacturers.

In recent years, the French bureaucracy has also given a good deal of attention to minicomputers and peripherals through Le Plan Periinformatique. Moreover, the components program has been linked to a major push into telecommunications—including developments such as videotext—that French planners embarked on in the mid-1970's; the PTT's ambitious projections envision 25 million terminals in French homes by 1990, pointing toward a rapidly growing market for semiconductors. As part of its telecommunications policy, the government has forced the sale of two foreign-owned companies (subsidiaries of ITT and Ericsson) to the Thomson group.

Recent Developments

French industrial policy has been in something of a turmoil since Mitterrand's election. The outlines of the Socialist Government's program remain murky, although the intent is to emphasize electronics. Initiatives in semiconductors, computers, communications, and consumer products are likely to be even more tightly coordinated than in the past, And, while the themes of nationalization and merger policy predate Mitterrand, the Socialists have carried this aspect of French industrial policy still further.

Even before Mitterrand came to power, the Eleventh Five-Year Plan (1981-85) had targeted electronics for special support. The plan singled out six fields for massive government assistance, with electronics—ranking third in French exports of manufactures, after machine tools and chemicals—viewed as a critical sector.[54] Under the plan, total R&D expenditures in France are scheduled to increase to 2.5 percent of GNP by 1985. Currently, France is making a more concerted effort than any other European country to strengthen its technological base and promote high-technology industries, with considerable attention to training greater numbers of engineers and technicians. Le Plan des Composants indicated that the French had learned from the mistakes of Le Plan Calcul—and also from the commercial failings of the Concorde—with French industrial policy as it affects electronics and other high-technology sectors passing into a new stage, one marked by a more sophisticated un-

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[52] See "Possible Strategies for Executing Microelectronics Plan," *West Europe Report, Science and Technology, No.* 112, Joint Publications Research Service JPRS 81340, July 22, 1982, p. 18; D. Marsh, "Thomson Absorbs Eurotechnique," *Financial Times,* Jan. 21, 1983, p. 14.

[53] "190 Million Francs in Next Five Years for VLSI Research," *West Europe Report, Science and Technology, No. 89,* Joint Publications Research Service JPRS 80022, Feb. 3, 1982, p. 7; "Le Developpement des Applications de L'informatique," *Lettre 101,* Oct. 7, 1980.

[54] *Rapport de la Commission Industrie,* Commissariats General du Plan, July 1980, p. 48. According to this report, electronics has received about 10 percent of all direct sector-specific aid to French industry in recent years [p. 113).

derstanding of international competition in commercial products and technical developments. This shift began during the 1978-80 period. Under Prime Minister Barre, the government claimed to be "decontrolling" markets, for instance cutting back on price controls. With a reemphasis on planning and national champions, came more stress—at least in official rhetoric—on market forces. Is Mitterrand likely to reverse this trend?

A fundamental plank in the Socialist platform had been nationalization of companies like CII-HB. As Mitterrand himself explains the Socialist strategy, the object is first to win back the domestic market in key industries such as steel, machine tools, semiconductors, and small computers.[55] In conjunction with further nationalization in the financial sector, the announced philosophy was "flexible" nationalization—with the government providing considerable support while promising to eschew extensive involvement in business affairs or economic planning at the micro-level. In appearance, this is not a sharp turn from the past; despite the lengthy history of planning in France, nationalized firms—so long as they have performed adequately–have operated relatively free of direct intervention by the bureaucracy.

In R&D and technology development the new government has also moved ahead in bold if seemingly disorganized fashion, Research support has been increased under the current 5-year plan, and is to include a new microelectronics project as a follow-on to Le Plan Circuits Integres, plus more money for computers and data processing, The government expects to put up two-thirds of the $500 million it believes must be invested in microelectronics over the 1982-86 period.[56] As in the past, much of the money will come from the Ministry of Defense. And as also in the past, the new microelectronics plan is but one piece of a much larger effort aimed at strengthening the entire French electronics industry.

While the overall outlines remain vague, the government is promising that investments in electronics—from both public and private sources, and including investments by foreign-owned firms (IBM, Texas Instruments, and Motorola are among the American electronics companies with a major presence in France)—will total $20 billion over the 5-year period 1982-86. The Government Program for Development of Electronics—presented in September 1982 after an extensive study by an Electronics Industry Task Force—is to be coordinated by an Interministerial Committee for Electronics, with representatives from the ministries of Industry and Defense, the Plan, and the PTT.

A primary vehicle will be 9 "national projects," chosen from 14 originally recommended by the Task Force. These national projects, which will get extensive government support, are intended to link private and nationalized firms, as well as the labor and user communities. The nine projects have the following titles:[57]

- consumer electronics;
- information displays;
- local networks;
- cable TV networks;
- very large-scale ICs (fabrication as well as design);
- central processing units for small computers;
- computer-assisted education;
- computer-assisted engineering; and
- computer-assisted translation.

The list is noteworthy for emphasizing computer systems from the perspective of user needs—not only the last three projects, but also that on local networks. All are software-inten-

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[55] " Mitterrand: Why Nationalization Will Work, " *Wall Street Journal,* Oct. 7, 1981, p. 27.

[58] "Microelectronics Plan: Win Market, Technology Independence, " *West Europe Report, Science and Technology, No. 113,* Joint Publications Research Service JPRS 81392, July 29, 1982, p. 10.

[57] See R, T. Gallagher, "$20 Billion for French Electronics," *Electronics,* Sept. 8, 1982, p. 104; "Fourteen Projects, "*West Europe Report, Science and Technology, No. 116,* Joint Publications Research Service J PRS 81575, Aug. 18, 1982, p. 14. Among the five that were dropped-not necessarily permanent ly—was a supercomputer effort.

sive, a field in which France is in a relatively good position. The plan does not neglect consumer products. France hopes to increase its presence in consumer electronics markets throughout Europe, with Thomson moving aggressively into new generations of products like VCRs, electronic toys and games, and home information systems.[58]

The Socialist Government faces severe obstacles in implementing such a vast program. In addition to the $20 billion in planned investments, a considerable increment compared to recent expenditures within the industry, France has an inadequate supply of men and women with training and skills in electronics; the shortfall is reckoned at more than a thousand engineers yearly and at least three times as many technicians. The development plan contemplates an extensive training effort, including the establishment of several new schools, Moreover, foreign firms with investments in France may resist some elements of the program. Joint venture participants, for instance, could prove less willing to transfer technology when the partner is a nationalized concern. But in the end, money will probably be the limiting factor; boosting France's R&D expenditures from 2 percent of GDP in 1982 to 2.5 percent by 1985 is extraordinarily ambitious. And, with nearly three-quarters of R&D carried out in government-controlled institutions, France runs a real risk of stifling innovation and new ideas.

Future Prospects

While the hallmarks of French industrial policy remain the same—an elite corps of officials, centralized policymaking, and a preference for sectoral policy along with a tradition of state intervention in the affairs of industry—Mitterrand's philosophy does represent a turn away from the market orientation of Giscard d'Estaing. It is too soon to assess the effectiveness of the new avenue, but past results give some insights. Government efforts under Le Plan Calcul must be termed a failure, although CII-HB's troubles had multiple sources. In semiconductors, Le Plan des Composants seems to have functioned much better. Even so, the largest French producer—Thomson—controls only a quarter of the domestic market, with a market share in all of Europe that is perhaps 7 percent. Most of Thomson's sales are in discrete semiconductors; the company has no more than about 2 percent of the European IC market. Although Thomson appears to have benefited considerably from technology-assistance agreements with Motorola, as have Matra and Eurotechnique through their joint venture with American partners, French electronics firms—along with most European manufacturers—remain heavily dependent on foreign sources of MOS and microprocessor technology.

The history of French electronics policy shows that *strong government direction cannot by itself produce a competitive industry,* At the same time, the French seem to be learning how to make their electronics policy function more effectively.

United Kingdom

In contrast to the French, with their reliance on centralization and government action, Britain's industrial policy has been closer to that of the United States—largely ad hoc, not well coordinated. There is at least one major difference: the United Kingdom during the 1970's began to experiment with a variety of novel measures intended to directly affect the actions of industry. Ranging from programs to encourage applications of microprocessors to government investment in the semiconductor venture Inmos, these initiatives are far different from the arms-length approach to industrial policy of the United States (U.S. policies related to national defense are, as usual, the exception). At the same time, these policies—some of which attracted considerable attention in other parts of the world—were pursued with little sense of direction. Only in its support of International Computers Ltd. (ICL) through procurement practices, R&D funding, and other con-

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5a" First Details Published on Electronics Plan, " West *Europe Report, Science and Technology, No. 120,* Joint Publications Research Service JPRS 81804, Sept. 20, 1982, p. 7.

ventional policy tools has Britain shown much consistency over the longer term in policies toward electronics.

Measures to aid ICL, in several respects similar to the somewhat earlier French effort to build and strengthen CII-HB, date from the late 1960's. In the latter part of the 1970's, the United Kingdom's electronics policies, as in many countries, turned towards semiconductors; a group of programs were developed to promote IC technology and applications, Even so, neither today nor at any point over the past decade does the British example show much evidence of a coherent view of industrial policy.

Early Experiments

Certainly Britain has had ample incentive to try new approaches; since the early 1960's, policymakers in the United Kingdom have sought ways of grappling with the nation's lackluster economic performance—by most measures the poorest among industrialized nations. During the 1950's, macroeconomic policies had been assumed sufficient for revival. But continuing inflation, along with persistent wage disputes, convinced the ruling conservatives to move toward a more active government role. The National Economic Development Council (NEDC) was established in the early 1960's as a forum where business, labor, and government could air their ideas about the future direction of the economy.[59] Inspired by the prestigious French Commissariats du Plan, NEDC was empowered to produce 5-year plans intended to reduce uncertainty about the directions of government economic policy. Planning responsibility fell mainly on a National Economic Development Office attached to the NEDC.

The Labor Government which came to power later in the decade continued this general orientation, and picked up the pace by establishing a number of Economic Development Committees to deal with specific industries. The Electronic Development Committee, set up in 1964, produced a series of reports that identified problems and proposed strategies for overcoming them. But by the end of the decade, the planning experiment had run afoul of persistent conflicts with the macroeconomic policies that Britain's leaders were determined to pursue; economic planning came to be viewed as a failure, and the visibility and influence of the Economic Development Committees waned.[60]

The More Recent Context

Since the beginning of the 1970's, U.K. industrial policy has been a hedge-podge. As in the United States, consistency has been found mostly in the area of national defense. A host of government offices, themselves subject to periodic reorganization and changes in direction, have been involved in policies affecting Britain's electronics industry. The National Research Development Council, set up as early as 1948 to provide financial support for joint research ventures under the Ministry of Technology, is one example. The Ministry of Technology also had jurisdiction over the Industrial Reorganization Corp. (IRC), established in 1966 to aid industrial restructuring. Under the authority of the Industrial Expansion Act, the Ministry of Technology engineered the mergers creating the computer firm ICL, as discussed in more detail below. The IRC likewise provided financial backing and other encouragements for a series of mergers that enlarged GEC, the British General Electric Co. But the interventionist IRC was abolished in 1971, about the time the Ministry of Technology became part of the larger Department of Trade and Industry—which has since again been di-

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[59] For an outline of the origin and role of the NE IX, see T. Smith, "The United Kingdom," *Big* Business *and the State,* op. cit., pp. 88ff. Most of the discussion on the earlier years of Britain's industrial policy is drawn from this source. Also see S. Blank, "Britain: The Politics of Foreign Economic Policy, the Domestic Economy, and the Problem of Pluralistic Stagnation," *Between* Power *and Plenty: Foreign Economic Policies of Advanced Industrial States,* P. J. Katzenstein (cd.) (Madison, Wis.: [University of Wisconsin Press, 1978), pp. 114ff.

[60] They still exist, however. The committee for electronics recently issued a report urging a comprehensive sectoral policy for the industry. See "Prescription for Electronics," *Financial Times,* Apr. 30, 1982, p. 16.

vialed, leaving a Department of Industry and a Department of Trade.

Among other agencies active in industrial policymaking, the National Enterprise Board (NEB) has had considerable leverage because of its ability to provide direct financing to British firms. Established in 1975, NEB has concentrated on startups such as the semiconductor manufacturer Inmos, to which it gave about $90 million in equity capital (ch. 7). In quite different realms, the Science Research Council and the Advisory Council for Applied Research and Development, set up in 1976, are intended to supply policy guidance on such topics as applications of new technologies and the education and training of engineers,

The number of government bodies involved in Britain's industrial policy provides one explanation for the random approach to programs in electronics. In France, relatively clear lines of authority link the various parts of the bureaucracy dealing with electronics; certain agencies have the lead role in certain areas. By comparison, the British approach is uncoordinated. In further contrast to the situation in France, Britain has never been very comfortable with government intervention in the affairs of business–rather surprising considering the size of the public sector. Not only do government plus the nationalized firms employ about a quarter of the British labor force, but publicly owned enterprises account for more than 10 percent of the country's industrial output and in recent years about a quarter of total capital investment.[61] Nationalized firms in industries like steel and automobiles have received more attention from British policymakers than electronics. Still, the United Kingdom's approach to the electronics industry does reflect a belief that government can strengthen existing firms as well as create new ones,

ICL

The formation of ICL was preceded by much less rhetoric concerning the need to create national champions than in France, but the emergence of ICL in 1968 was similar to that of CII-HB. ICL benefited not only from government financing, but from aid for R&D and the promise of public sector purchases of its products, Britain's Government encouraged the series of mergers by which the company was formed, and supplied about $12 million a year until 1976 to stimulate its growth.[62] Despite this, ICL never emerged as a viable competitor in the world computer industry. Although still holding more than a third of the U.K. market—largely the result of government procurements coupled with "Buy British" persuasion aimed at private firms—ICL has had little success outside the United Kingdom. Within Britain, the Central Computer Agency, responsible for government purchases, gave perhaps 90 percent of its orders to ICL during the early 1970's.[63] This is a major reason why the United Kingdom joins Japan as one of only two countries where American computer manufacturers and their subsidiaries do not have at least half the installed base.

ICL is known for its software, but—like most computer manufacturers outside the United States—missed the shift toward small systems. The company has also been handicapped by the lack of a strong local semiconductor industry. Since the latest government initiative—a package of loan guarantees totaling nearly half a billion dollars, and the installation of a new management team headed by a long-time executive of Texas Instruments' U.K. subsidiary—there have been signs of revival. [64]

Not long before jumping back into try to save ICL—in part because mergers or takeovers involving American companies were rumored—

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[61] P. Maunder, "Government Intervention in the Economy of the United Kingdom, " *Government Intervention in the Developed Economy,* op. cit., pp. 131-137,

[62] "Technology and Trade Policy: Issues and an Agenda for Action, " op. cit., p. 58.

[63] G. de Carmoy, "Subsidy Policies in Britain, France, and West Germany: An Overview, " *International Trade and Industrial Policies,* S. J. Warnecke (cd.) (New York: Holmes& Meier, 1978), p. 38.

[64] E. Bailey, "Britain's Role at Ailing ICL, " *New York Times,* May *18, 1981,* p. Dl; S. Love, "New Talent Spurs Britain'sICL, " *Wall Street Journal,* Mar. *1, 1982,* p. 27.

the Thatcher government had sold off the publicly held 25 percent of the company's stock. ICL's checkered past thus illustrates the "stop-go" quality of industrial policy in the United Kingdom. The uneasy relationship between Inmos and the government has followed a similar pattern, one in which Inmos faced considerable uncertainty over whether the Thatcher administration would provide the second installment of capital—another 25 million pounds—that the company was counting on.

Research and Development

Beyond support of ICL, the U.K. computer industry benefited during the late 1960's and early 1970's from R&D funding provided through the Advanced Computer Technology Project, which provided up to half the costs of projects dealing with hardware or software. The British have also attempted to aid their electronics industry through efforts like a preproduction order program, in which the government purchases newly developed products and leases them to users—or "clients. " After a trial period, the client prepares a report on the new product and then must either buy or return it. Other programs have supported software development and marketing, as well as microelectronics. In addition to contracted basic research, paid for by both civilian and defense agencies, commercial product development has been financed through government contracts, particularly to ICL.

Nonetheless, the United Kingdom has been a poor performer in R&D—more precisely, in development, Although British scientists continue to do excellent basic research, industry has been reluctant to invest heavily in R&D directed at commercial products and processes; between 1967 and 1975, real R&D expenditures by industry declined. Furthermore, sectors like electronics have suffered from a lack of capable engineers. While government R&D expenditures have been heavily concentrated on electronics and aerospace—in 1975, 30 percent went to electronics and communications alone —this spending, largely motivated by military needs (table 77, ch. 10), has had little perceptible effect on the competitiveness of British firms. Tellingly, electronics and communications manufacturers have spent less of their own money on R&D than the government has contributed; in 1975, private firms spent 113 million pounds on R&D, publicly held corporations 36 million pounds, and the government 130 million.[65] In the United States, the impacts of military spending on electronics have been far overshadowed by the vigor of the commercial industry; the British case has been vastly different.

Other Policies Toward Electronics

Among the more intriguing programs of the U.K. Government have been those aimed at utilization of microelectronics. In the midst of a lengthy debate on the question of whether the country needed an indigenous capability to design and manufacture advanced ICs, the Microprocessor Applications Project (MAP) was established to encourage companies in any industry that could to incorporate these devices in their products, MAP, which began in 1978 and has been somewhat reluctantly continued by the Thatcher government, funds up to 25 percent of the costs of product development. Increased support is provided for microelectronics-related programs in schools and colleges, principally teacher training. A third element consisted of a consciousness-raising campaign aimed at 50,000 managers in private industry, with MAP funds supporting seminars to educate corporate decisionmakers on the virtues of the new technology. Government spending through MAP totaled nearly $100 million over a 3-year period .88

A related program known as MISP—the Microelectronic Industry Support Programme, also started in 1978—aids firms in developing and manufacturing ICs. MISP was stimulated by a report prepared for the NEDC which stressed the importance of design and processing expertise; a central goal was mass produc-

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[65] K. Schott, *Industrial Innovation in the United Kingdom, Canada and the United States* (London: Contemprint, July 1981), p. 12.

“’’Microelectronics, The New Technology, " Department of Industry, London, 1981, p. 23.

tion capability in standard devices.[67] Among the steps taken were the establishment of a joint venture between the British firm GEC and Fairchild, then still American-owned, to manufacture a broad-based line of ICs. More ambitious was the decision to establish a greenfield firm, Inmos.

NEB's announcement in June 1978 that Inmos would receive equity funding from the government to design and manufacture n-channel MOS circuits, starting with memory chips, generated a good deal of controversy within Great Britain (NEB has considerable independence in making such decisions). The attempt to replicate a merchant semiconductor firm on the American model—complete with executives experienced in U.S. companies and a design center in Colorado Springs—was a move directly into the central arena of worldwide competition, The risks were high. Inmos was to begin production of 64K RAMs in 1981—a target which slipped, but as it turned out, no more than those of a number of well-known American firms.

Inmos is a unique experiment; the government committed 50 million pounds, split into two installments, with the hope not only of creating a first-rank semiconductor company, but also of luring talented British engineers back from employment with foreign firms (one reason for the Colorado Springs location), Stimulating end-users in Britain was another major objective, While there are still many doubters, Inmos appears to have had reasonable success in developing its first products. The company has plans for a new family of microprocessors, as well as a broad line of memory chips. Becoming profitable may be more difficult.

Since the election of the conservative Thatcher government in 1979, efforts such as MAP and MISP have been scaled back. The conservatives' review of the Inmos venture revived public debate over the company's prospects. After a considerable period of uncertainty, during which it appeared that NEB's holdings in the firm might be sold, and following a decision by Inmos executives to locate a production facility in the depressed area of South Wales, funding was continued. In late 1981, NEB reported $22 million in pretax losses, more than half accruing from its holdings in Inmos; losses are to be expected during the early years of such an enterprise, and it is still too early to judge the success of this recent entry into the world semiconductor industry, but the qualms of the conservative government are not surprising.

Has Britain's Approach Worked?

The answer, implicit in much of the discussion above, is that it has not. While some of the initiatives in electronics may eventually have positive results, U.K. industrial policy as a whole has suffered from lack of consistency—even during periods when the same party has been in power–and from a rather odd, if not chaotic, mixture of policy instruments. Even the direct beneficiaries, British electronics companies, have not been very enthusiastic about the government's support efforts, viewing them as favors likely to be withdrawn on short notice.[68] Some executives in British industry could be described as not only skeptical but cynical about their government's policies. Nothing like the symbiotic relationship between business and government in Japan, or even France, has emerged in the United Kingdom.

The grab-bag character of U.K. policies toward electronics has stemmed in part from the inconclusive nature of debate over the need for a continuing British presence in semiconductor *manufacturing*. Many took the position that, so long as British industry *applied* ICs in its products, there was no need to have home-grown design and production capability. Others held that, lacking an IC design and production base, applications would always lag those in other countries, Rather than coming

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[67] See *Microelectronics Into the 1980's* (Luton, England: Mackintosh Publications Limited, 1979], p. 27, for a summary of the Sector Working Party report to NE DC.

[68] See D. Imberg and J. Northcott, *Industrial Policy and Investment Decisions* (London: Policy Studies Insitute, 1981), pp. 72-73. Also J. Northcott and P. Rogers, *Microelectronics In Industry: What's* Happening in Britain, No. 603 (London: Policy Studies Institute, March 1982], especially ch. 8.

to a decision, the British have tried to have it both ways—supporting Inmos, though never whole-heartedly, while also pursuing applications and technology diffusion through MAP and MISP. Similar patterns, over a longer time period, have characterized the government's dealings with ICL; after many years of public support, the Thatcher government withdrew, only to find itself forced to the rescue of the faltering computer manufacturer. Industries like steel and automobiles show similar oscillations in government attitude.

The fact is that foreign firms have already captured major shares of most British electronics markets, except where the government itself is the customer—e.g., the defense sector. Outside the government market, ICL presents little challenge to its American and Japanese competitors, just as British firms now hold only a small share of U.K. semiconductor sales. Thus, ICL's agreement with Fujitsu, entailing marketing of Japanese-built mainframes in England, also involves purchases of Fujitsu semiconductors. While ICL has also negotiated for rights to U.S. and Canadian technology, Britain does not seem as well-placed as France to make use of foreign know-how, and may find that it is already too late for technological independence.

In sum, many of Britain's industrial policy efforts in electronics seem to have been too little and too late. The formation of Inmos and the creation of MAP and MISP came at the close of the 1970's, by which time American and Japanese suppliers were firmly established in the U.K. market.

Industrial policy has been doubly difficult because of the stagnant British economy. As economic troubles continued, the government cut back its R&D support, making progress in industries like electronics still less likely. Recently, the Thatcher administration has tried to streamline industrial policymaking by merging the National Research Development Corp. and the NEB into a "British Technology Group. " One goal has been to temper the activist policies of the NEB, which enjoyed considerable autonomy in the past. There is no indication yet that this will produce positive results. To be fair, industrial policies—of whatever stripe—are a limited tool when the overall economic situation has been as grim as Britain 's. While U.K. industrial policies may seem neither efficient nor effective, they have perhaps been asked to do the impossible.

West Germany

Industrial policy in the Federal Republic of Germany (FRG) has been distinguished by reliance on the market. Objectives have been allowed to remain vague beyond the level of macroeconomic policy, where stability has been paramount. But if private sector actions have been central, this does not mean the role of the public sector has been negligible, Following a "social market philosophy, " the West German Government has helped reconcile national, regional, and interest group concerns. The Act for the Promotion of Stability and Economic Growth (Gesetz zur Forderung der Stabilitat und des Wachstums der Wirtschaft) provides a set of tools to coordinate economic policymaking among government, management, and labor aimed at ''macroeconomic equilibrium." While avoiding extensive planning, policymakers have paid consistent attention to structural adjustment; since the mid-1960's and the tenure of economics minister Karl Schiller, it has been widely accepted that policy instruments could be deployed to "rationalize" markets and ease structural change. Especially since the mid-1970's, the FRG has also provided considerable support for R&D. Although proponents of an avowedly sectoral approach to industrial policy have become more vocal, it is still true that industrial policies are market-oriented, with limited reliance on public ownership compared to a number of other Western European nations, and a strong commitment to open international trade. Nevertheless, the German Government has sometimes taken strong and direct action on the sectoral level when economic problems have arisen.

The Institutional Setting

Economic and industrial policymaking in the FRG combines elements of decentralized decisionmaking with representation by major interest groups, including labor. The ministries of Finance, Economics, Labor and Social Affairs, and Research and Technology are among the more influential in terms of policies affecting industry. Macroeconomic policies are developed and implemented by a number of agencies. The Ministry of Finance submits 5-year plans. Since the early 1960's, a five-person Council of Economic Advisers–comprised of academics not otherwise attached to the government—has been responsible for macroeconomic forecasting. The Council also prepares annual reports on the health of the West German economy. Money supply is the responsibility of the Deutsche Bundesbank—legally independent of the government, though closely tied to it. Policies and analysis related to economic and industrial development are centered in the Ministry of Economics. The Lander (state) governments help formulate economic as well as regional development policies. A joint Federal-Lander planning committee, for instance, draws up regional action programs identifying growth points (schwerpunktorte) to be promoted via investment grants, West Germany has emphasized regional development perhaps more heavily than any other Western industrial nation, with the Lander Governments central to these efforts.[69]

As chapter 7 pointed out, financial institutions have a special place in the West German policymaking structure—as they do in France and Japan. Executives of the central Bundesbank keep in close contact with public officials, and normally act in support of the government's economic policy, The Bundesbank's control of the money supply gives it direct influence over the value of the deutsche mark, During the years of rapid economic expansion, particularly the early 1960's, the bank helped maintain an undervalued currency—a strategy that strengthened the export competitiveness of German goods but earned a good deal of criticism from the country's trading partners.

The Federal Government also holds majority shares in five banks, while cities and states have their own financial institutions. One of the nationalized banks, the Kreditanstalt fur Wiederaufbau, is a development bank that provides funds to commercial lenders. [70] While the financial communities are major seats of influence over industrial policy in both West Germany and France, they function quite differently in the two countries: rather than selective credit for favored firms and industries as in France, German banks have supported fiscal and monetary policies oriented toward aggregate growth.

If economic and industrial policymaking in West Germany is less centralized than in France, the lines of responsibility are more clearly drawn than in Great Britain. While the Research and Technology Ministry (BMFT), say, tends to approach industrial policy with a perspective quite different from that of the Economics Ministry, the division of authority is more or less predictable and consistent. Germany's parliamentary system has seen few changes in government since 1949; when a different party has come to power, overall objectives such as maintaining the country's export strength while controlling inflation have been retained.

Policymaking Processes

A distinctive feature of the German system is the broad representation of interests, the effort made to integrate diverse points of view. The Stability and Growth Act empowers the Federal Government to provide "orientation data" for policy measures to be "simultaneously and mutually agreed upon" by Lander and local governments, labor unions, and employers' associations, In the late 1960's, "concerted action" incomes policies were developed, aimed at consistency in approach among government bodies and socioeconomic groups on budgetary matters as well as wages and prices. Concerted action was not an attempt to sup-

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[69] G. de Carmoy, "Subsidy Policies in Britain, France and West Germany: An Overview, " *International Trade and Industrial Policies, S.* J. Warnecke (cd.) (New York: Holmes & Meier, *1978), p. 52.*

[70] E.Owen-Smith, "Government Intervention in the Economy of the Federal Republic of Germany, " *Government Intervention in the Developed Economy,* op. cit., p. 176.

plant the monetary and fiscal policies of the Federal Government, but was intended as an adjunct and complement to these, the basic objective again being the creation of an environment conducive to economic growth. Like codetermination—which ensures labor a voice in plant operations—concerted action sought to integrate labor and other interest groups into the mainstream of policy formulation. Today, concerted action has fallen into disuse, but speculation on its revival regularly surfaces; if nothing else, this indicates the persistence of the view in Germany that sound economic and industrial policies depend on broadly based consensus-building.

Indeed, institutionalized participation by major social groups appears to offset much of the fragmentation that otherwise might seem to characterize industrial policymaking in the FRG. As in a number of other Western European countries, notably the Scandinavian nations, Germany's industrial policy is marked by concern with labor issues. In 1974, the BMFT and the Ministry of Labor and Social Affairs set up a joint research program on "humanization of the workplace. " Directed not only at health and safety issues, the program aims as well to identify and encourage organizational changes that would increase job satisfaction (ch. 8). A number of studies sponsored by the program, which is oriented strongly toward field experiments and employee participation, have explored impacts of automation and computer technologies. [71]

The systematized participation of labor in West Germany is especially noteworthy in contrast to Japan or France, In Japan, organized labor is in fact—if not always in appearance—relatively powerless; the consensus so clearly visible in Japan comes, not from full participation, but from a rather passive acceptance by other groups of policies that business and government have agreed on. In France, organized labor is vocal—with a marked radical cast—but labor participation in setting policy has not been internalized as in Germany. French unions traditionally exert pressure on the government through political activism, often confrontational. Even with Mitterrand and the Socialists in power, this is not likely to change much,

Policies Toward Electronics

Despite its stress on macroeconomic tools, West Germany has, over the years, instituted a considerable number of policies directed at specific industrial sectors, Some have been in portions of the economy where government ownership has been widespread—e.g., energy and banking, In contrast, sectoral involvement in electronics has been mostly restricted to R&D; compared to both France and the United Kingdom, military involvement has not been prominent. Moreover, in further contrast with these two countries, when FRG officials attempted to encourage a "rapprochement" among Siemens and several other computer manufacturers, the large and powerful Siemens concern resisted quite successfully.[72] When AEG-Telefunken—after Siemens the country's largest electrical and electronics producer–fell on hard times, the private sector at first dealt with the crisis on its own. A consortium of 24 commercial banks engineered a massive rescue effort, with financing totaling more than half a billion dollars.[73] Only when the bankers' efforts proved insufficient did the government step in with a package involving further loan guarantees and export credits. 'A As this implies, and as chapter 7 described in more detail, cooperation among industry and financial institutions in the Federal Republic has been common—and an increasing subject of parliamentary scrutiny and public criticism, on grounds that the power of the banks is too great.

Despite efforts such as the aborted Telefunken rescue, government influence has not been exercised as directly in electronics as in

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[71] "Research on the Humanization of Work, " Ministry for Research and Technology and Ministry of Labor and Social Affairs, document No. 2181/74e,

[72] Jequier, op. Cit., p. *217,*

[73] K. Done, "The Last Chance Rescue, " *Financial Times, June 14, 1982,* Under *West German* law, banks can own equity in private firms and act as brokerage houses (ch. 7). German banks held about *40* percent of Telefunken's stock.

[74] See "Germany's Telefunken Insolvent, " New *York Times,* Aug. 10, 1982, p. D1. Nonetheless, the firm entered bankruptcy in mid-1982.

sectors such as energy (where subsidies have contributed to high domestic coal prices), steel (where firms such as Salzgitter are publicly owned), or shipbuilding (where a range of policy initiatives have been marshaled to shelter the industry from decline) .[75] Still, since the late 1960's the West German Government has sought ways of strengthening the nation's computer industry. While on the whole the German electronics sector has been the strongest of any in Europe, it has shared the common weakness in computers. Part of the reason appears to have been that the bigger electronics firms—Siemens, AEG-Telefunken, SEL–were already heavily committed to other lines of business—consumer products, telecommunications, electrical machinery. Much like such American companies as RCA or General Electric, these large and diversified enterprises never developed much strength as computer manufacturers. From the standpoint of the German Government, there really was no computer industry as such to support. As a result, it proved difficult to devise effective policies for encouraging either the technology of computing or commercial production. As in many other countries, government procurements have been channeled to local firms. Nevertheless, in contrast to Japan and France, the FRG has largely avoided attempts to shield the industry from foreign competition, relying instead on domestic supports and subsidies. * A major thrust of German efforts has been to stimulate utilization of computers through training programs and applications support.

Although benefiting from government funding amounting to more than 100 million deutsche marks (something over $50 million—in fact a relatively small fraction of West Germany's total subsidies during the 1970's for computers and information processing), Telefunken never achieved much success in computer systems. Siemens remains the largest German-owned computer manufacturer, somewhat ahead of Nixdorf in sales (ch. 4, table 42). But Siemens' production is far less than that of IBM's German subsidiary; Siemens has never appeared to view computers as a major piece in its corporate strategy. The company has only about 20 percent of the German computer market, and less than 10 percent for Europe as a whole. Nonetheless, Siemens continues to receive by far the largest share of government funds for R&D in computer technology. [75] The contrast with Nixdorf—a manufacturer of business-oriented minicomputers—is striking. Nixdorf is an aggressive worldwide competitor in its chosen markets, much in the American mold; the company has accomplished this with little government assistance,

Again in common with other European electronics firms, a number of German manufacturers have pursued ties with American and Japanese enterprises, one aim being technology acquisition. In 1978 Siemens purchased 20 percent of Advanced Micro Devices. More recently, the company negotiated an agreement with Japan's leading producer of computers, Fujitsu; Siemens now markets several of Fujitsu's IBM-compatible mainframes in Europe. Such arrangements have brought criticism of government support for Siemens as failing to promote an indigenous computer industry.

Research and Development Support

Financial subsidies for Siemens' computer efforts have been part of a considerably larger program of technology development in the FRG. Total R&D expenditures grew more than 60 percent in real terms between 1969 and 1980, increasing from 2.1 percent of GNP to 2.3 percent; the West German Government has

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[75] See Owen-Smith, op. cit.: p. 174 on coal prices; P. 184 on Salzgitter; p. 173 on shipbuilding.

*Even so, a recent trade dispute shows that—in Germany as elsewhere—foreign firms are often discriminated against. In a case similar to AT&T's choice of Western Electric over Fujitsu in fiber-optics, Bremen University was forced to reverse a decision to purchase a computer system from Burroughs. The contract went to Siemens at a price considerably above the American bid. See "Technology and Trade Policy: Issues and An Agenda for Action, " op. cit., p. 49.

[76] By 1978, the West German Government had supplied Siemens with a cumulative total of 351 million deutsche marks (nearly $200 million) for the development of large- and medium-sized computers. See "Sixth Report of the Federal Government on Research, ' Federal Minister for Research and Technology, Bonn, 1980, p. 82. The computer support programs of the BMFT now seem widely viewed as failures; they have been drastically scaled back.

strongly supported R&D, which has accounted for 3 to 4 percent of the Federal budget during the past decade.[77] Since the initiation of the second data processing program in 1969, the electronics industry, and particularly the components sector, has received a substantial fraction of this spending; 30 percent of German R&D funds have gone to electronics (and electrical equipment)—a greater fraction than in any of the other countries listed in table 77, But while government support for electronics as a whole increased steadily during the latter part of the 1970's, it appears to have peaked at the end of the decade, with the more recent contraction stemming from disappointing results in computer technology.[78]

Disillusionment with support for computer systems has led industrial policy makers in the Federal Republic to reorient their programs toward microelectronics. Here funds have gone toward device physics and processing technologies, as well as IC design and development. Between 1974 and 1978 relatively modest sums were spent by the government on microelectronics R&D—about $30 million annually. A somewhat more ambitious effort began in 1979. Like the computer R&D which it supplanted, VLSI support at first centered on the large electronics manufacturers. In its first program, the government contributed about $300 million over the period 1976-82, with industry participants putting up matching funds and competing on a proposal basis.[79] The German VLSI program has been much less centralized than Japan's; participants work independently, with the responsibilities of government officials limited mostly to coordination and avoiding duplication. Siemens has received 25 to 30 percent of the money, with Telefunken and Valvo each getting 10 percent or more. Industry seems to have regarded the program as useful but not of great impact; the major German electronics firms have traditionally had strong commitments to R&D—including basic research—and government money appears to have gone mostly to efforts that the private sector has judged marginal. Indeed, a principal rationale has been to finance projects with time horizons too long for industry to justify.

While most of the money in this first major VLSI program went to big companies, the FRG has also paid a good deal of attention to smaller firms—of which there are more than a thousand in electronics.[80] In contrast to the market orientation of other German industrial policy initiatives, the BMFT—a relatively new agency—has designed an array of sector-specific programs aimed at small enterprises and growth industries like electronics and biotechnology. Small technology-based firms in the Federal Republic often face difficulty in raising capital. As in most countries other than the United States, venture capital markets are miniscule. Viewing this as an obstacle to innovation, and with motives much like those leading to the creation of the National Enterprise Board in Great Britain, the FRG Government set up a venture financing company (Deutsche Wagnisfinanzierungsgesellschaft) in 1975. This organization purchases minority interests in German firms —with the intent of backing innovative developments—while giving the proprietors preferential rights to buy back the equity if their business succeeds.

The turn toward support for smaller companies has also been reflected in the BMFT's latest

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[77] "Sixth Report of the Federal Government on Research," op. cit., p. 75; "FRG's Position in World R&D Community Assessed," *West Europe Report, Science and Technology, No. 72,* Joint Publications Research Service JPRS *78876,* Sept. 1, 1981, p. 40.

[78] "Sixth Report of the Federal Government on Research," op. cit., p. 53. While the budget for government expenditures on electronics R&D was scheduled to increase from about 350 million deutsche marks in 1975 and 1976 to more than 600 million in 1980 and 1981, expenditures in these later years were cut back considerably from the amounts originally planned.

[79] M. Gold, "West Germany Reported About To Launch $300 Million VLSI R and D Plan," *Electronic News,* Apr. 30, 1979, p. 1; "European Semiconductor Industry Markets, Government Programs," *West Europe Report, Science and Technology, No. 134,* Joint Publications Research Service JPRS 82 686, Jan. 20, 1983, p. 32.

[80] "General Scheme of the Federal Government's Research and Technology Policy for Small and Medium-Sized Undertakings," Ministry for Research and Technology and Ministry of Economics, 1979 updating. Also see *Innovation in Small and Medium Firms* (Paris: Organization for Economic Cooperation and Development, 1982), pp. 133-139; and G. Kayser, "Small Business Policy in the Federal Republic of Germany," *European Small Business Journal,* vol. 1, winter 1983, p. 39.

semiconductor program. The 3-year effort, beginning in 1982 and funded at about $45 million per year is—like a number of Britain's more recent initiatives—directed primarily at applications.[81] This new program comes on top of a 40-percent increase in microelectronics R&D support that had already been scheduled. Most of the applications money will be channeled to small firms, with one of the objectives being job creation; of 1,000 grant applications received during the first 6 months, two-thirds were from companies with fewer than 200 employees, Administration is the responsibility of the VDI Technology Center, established by the BMFT in 1976 specifically to help small- and medium-sized firms develop and apply microprocessor technology.

The Fraunhofer Gesellschaft[82]

West Germany's attentiveness to smaller enterprises does not stop with microelectronics. The Ministry of Economics supports more than 80 industrial research associations, while the Fraunhofer Gesellschaft (Association of Institutes of Applied Research, FhG)—comprised of some 25 institutes which function as R&D laboratories—has as one of its major responsibilities the diffusion of technology to industry, especially small companies.

Strengthening the FhG, which was founded in 1949 to perform applied research and engineering development on a contract basis, has been one of the more intriguing BMFT initiatives. The FhG remained small until a government decision in 1969 made it the chief vehicle for support of applied research. At this point funding began to increase rapidly. A reexamination of FhG goals in 1973-74 led to a strengthening of its mandate for transferring technologies to the private sector, as well as developing them.

Joint government-industry financing on a project basis is the rule. FhG institutes—which together employ more than 2,500 people—provide technical advice to smaller firms, cooperate with universities, and function as technology conduits. Institutes are organized around technical disciplines; one concentrates on semiconductor devices and processing technology (the Institute for Solid State Technology in Munich), another on computer systems (the Institute for Information and Data Processing, Karlsruhe). Several others work in areas less directly related to electronics.

The Institute for Solid State Technology, one of the more successful of the Fraunhofer laboratories, can serve to illustrate the FhG model. Loosely associated with the Technical University of Munich—the Institute's director holds a chair there, and perhaps 20 students work at the laboratory—the Institute employs nearly 100 people, about half of them engineers or scientists. This makes it the largest organization of its type in West Germany, and perhaps in Europe. Founded in 1974, housed in its own building away from the university, and growing largely through the initiatives of its director, internationally known for his research in semiconductor technology, the laboratory gets 70 percent of its annual funding—about $5 million—via separately budgeted R&D projects. The BMFT typically provides a major share of project budgets, the remainder coming from one or more industrial sponsors. In essence, the government shares risks with industry, Two of the Institute's staff members are paid directly by the BMFT to advise and consult with small- and medium-sized companies. Much of the laboratory's work is concerned with processing technology; prototype circuits can be fabricated, along with small lots of specialized devices such as sensors and ICs for medical applications. The Institute also operates an X-ray lithography facility at West Germany's synchrotrons storage ring in Hamburg.

Perhaps the most noteworthy aspect of the FhG and its mandate from the BMFT is the ori-

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[81] See "Increased Government Funding for Microelectronics," *West Europe Report, Science and Technology, No.* 92, Joint Publications Research Service JPRS 80133, Feb. 18, 1982, p. 5; "Special Microelectronics Program, " West *Europe Report, Science and Technology, No. 113,* Joint Publications Research Service JPRS 81392, July 29, 1982, p. 13.

[82] Much of the information in this section is based on interviews. See also H. Keller, "30 Jahre Fraunhofer-Gesellschaft: Rück-und Ausblick, " *FhG Berichte 3-79* (Munich: Fraunhofer-Gesellschaft, 1979), p. 3, and *Vertragsforschung für Wirtschaft und Staat* [Munich: Fraunhofer-Gesellschaft, 1981).

entation toward *commercial* technologies. The institutes are not basic research organizations —that function remains with the Max Planck Gesellschaft. Nor do they function as government laboratories, although the relationships between individual FhG institutes and government agencies vary considerably; the ties are closest among the six that carry out R&D financed by the Federal Ministry of Defense. The institutes are a conscious attempt to speed commercialization of new technologies and diffuse R&D results through industry. One way in which the FhG does this is simply to provide a venue for bringing representatives of Federal, Lander, and local governments together with industry and the universities, The Fraunhofer experiment is an attempt to compensate or the weak links that exist in Germany-as in most countries—among these groups, especially where commercial technologies rather than basic research are involved. Likewise, the decision to accept defense-related projects in 1955 was based on the belief that it was better not to isolate defense R&D, but to combine it with civilian work in hopes that each would benefit. (Defense-related projects now account for 20 to 25 percent of the FhG's effort.)

Within Germany, the Fraunhofer Gesellschaft has won high marks for facilitating technology transfer while avoiding direct government involvement in decisions on directions and priorities, but its comparatively small budget—about 230 million deutsche marks in 1981, something over $100 million—limits the assistance that flows to any one industry,[83]

The Future

If a joint strategy for the European Community in electronics comes to pass—a prospect that seems slight, as discussed in the next section, but not so improbable as a few years ago—West Germany's industry would probably be the best placed of any in Europe. But in the more likely event, progress in electronics in the Federal Republic will depend—as it has in the past—on domestic actions, public and private.

Past government policies, when directed at electronics, have not been notably successful. Nonetheless, German industry has a sound base to work from. Siemens, if not a leader in computers, probably has the best semiconductor technology of any company in Europe. (Philips is strong in linear circuits because of its emphasis on consumer electronics, but Siemens was virtually the only European manufacturer that recognized the importance of MOS ICs at an early date.) Germany's domestic production of ICs has grown as a percentage of consumption in recent years, a sign of Siemens' continued technical strength and perhaps of positive results from government R&D programs.[84] But the entire consumer electronics sector in West Germany, not just AEG-Telefunken, has faltered under the pressure of Japanese competition. ZVEI, the Central Association for the Electrotechnical Industry, has claimed that increased sales of imported home entertainment products have been a direct cause of shrinkage by such firms as Grundig AG, and consequent losses of jobs; at the end of 1982, Grundig and Philips filed an antidumping complaint against Japanese producers of VCRs.[85] In computers, West German firms have less than 5 percent of world sales. Nixdorf has chalked up respectable profits and exports by concentrating on smaller business-oriented systems; the company has done this on its own, without significant government aid. *As the example of Nixdorf shows--a lesson repeated in other countries-industrial policy is no substitute for well-managed private firms,*

West Germany has thus maintained its position in the second tier of the world electronics industry. Can it compete in the years ahead when faced with *both* American and Japanese

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[83] *Vertragsforschung für Wirtschaft und Staat,* op. cit. In 1978, 35.7 million deutsche marks ($18.7 million) went to the four Fraunhofer institutes involved in work related to microelectronics and information processing; see "Cooperative R and D Programs To Stimulate Industrial Innovation in Selected Countries—West Germany," Department of Commerce, National Bureau of Standards, Office of Cooperative Technology, November 1979, p. 69.

[84] G. Dosi, *Technical Change and Survival: The European Semiconductor Industry* (Brighton, U. K.: Sussex European Research Centre, Sussex European Papers, May 1981.)

[85] J. Gosch, "German Consumer Firms Face Bad Times, " *Electronics,* Sept. 11, 1980, p. 97; "Japanese VTRs Are Target of EC Antidumping Case," *Wall Street Journal,* Dec. 24, 1982, p. 9.

firms? At present, many of the industry's problems stem from the broader dilemmas of the FRG economy; high interest rates and low profit margins have made it difficult for German companies, which have traditionally borne the bulk of such expenses themselves, to maintain high levels of spending for R&D and new capital investment. In recent years, Siemens has accounted for as much as 12 percent of all West German industrial R&D—for many observers this alone signifies imbalance.[86]

West German firms also face a critical deficit in technical manpower, despite mounting unemployment in the nation as a whole. According to the Association of German Engineers, 16,000 jobs have been vacant for lack of people —particularly in electrical, mechanical, and civil engineering; in 1980 only 3,600 students were enrolled in technical universities able to accommodate 4,700.[87] Such problems are in no sense unique to West Germany—the question is whether government policies will help to resolve them.

How Effective Are West German Industrial Policies?

Industrial policy has a less distinct identity in the FRG than in many other countries—at least it is harder to summarize. On the one hand, the approach has been more market oriented than in France; certainly planning and coordination on the French model are absent. On the other hand, the West German Government has consistently supported industrial development through macroeconomic measures and by integrating a broad range of perspectives and interests into the policymaking process (critics in some countries might regard this as a weakness). The role of the government, then, is far from laissez-faire. In contrast to the British case, sectoral initiatives have been pursued with a good deal of consistency over time, although such policies have not necessarily entailed extensive involvement by government officials. *The West German case does underscore the critical importance of aggregate policies as necessary (if perhaps not sufficient) to sectoral development.*

Industrial policy in Germany has benefited from a better sense of timing than in the United Kingdom. Government support for R&D in electronics began to pick up in the late 1960's, and has continued to grow—this despite an ongoing debate between the BMFT, which favors expanded sectoral thrusts, and the Economics Ministry, which continues to stress aggregate measures. While R&D programs—including funding for VLSI research and the efforts of the FhG—have not advanced the competitive position of the German electronics industry in any very obvious or dramatic sense, they appear to have nurtured it in a variety of less direct and visible ways. Unlike electronics policies in nations which have tried to leapfrog the competition, the German approach has been one of broad support for more basic kinds of research, in the hope of returns over the longer run.

As the Federal Republic struggles with rising unemployment and continuing economic stagnation, such policies will be severely tested. Formulated in a time of overall growth, there is no guarantee that the FRG view of industrial policy will prove adequate to deal with the adverse conditions promised by the rest of the 1980's. Germany's problem is much the same as that faced by the United States.

The European Community

In West Germany and elsewhere in Europe, concern over technology gaps vis a vis American and Japanese competitors has led to periodic proposals that the European Community (EC) develop a joint policy toward electronics. Rapid increases in consumer electronics shipments from Japan have stimulated talk of import restraints, but a common effort in R&D has been the most frequent suggestion. A 1980

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[86] According to Siemens' annual report for 1980, the company spent over 3 billion deutsche marks (about $1.6 billion), more than 9 percent of worldwide sales, on R&D. Over 90 percent of the money came from Siemens' own funds, the rest from government contracts and grants. For comparison, U.S. firms during the same year spent the following amounts as a percentage of sales: Amdahl, 15.8 percent; IBM, 5.8 percent; Data General, *10.0* percent. See '*Spending for Research Still Outposes Inflation, " *Business* Week+ July 6, 1981, p. 60. Siemens is clearly committed to keeping up in technology

[87] J. Tagliabue, "Germany's Economy Stumbles, ' *New York Times*, Apr. 13, 1981, p. D1.

study by Siemens, for instance, held out little hope for indigenous semiconductor industries; the conclusion was that continued growth in European sales would probably benefit Japanese firms the most, with the U.S. market share dropping from three-quarters to less than two-thirds by 1985.[88]

Although much of Europe has suffered similar problems—the twin maladies of recession and inflation, a perceived slowdown in technological advance, rising labor costs, unemployment, low rates of capital investment, slipping competitiveness—joint responses have been slow to appear. In 1980, the EC's industry commission proposed a European strategy in electronics that would have included government-funded programs to develop semiconductor processing equipment, as well as an advanced communications network linking the members of the Community. *g The proposal, which would have required modifications to national procurement policies, stalled when the French dismissed it as insufficient while the British dithered over the implications of exposing ICL to open procurements. So, while the EC countries have recognized the need for a more unified approach, national concerns have thus far remained paramount.

The latest attempt—which bears the name Esprit (European Strategic Programme of Research in Information Technology)—got underway in mid-1982. At first directed chiefly at semiconductor processing, in part because Europe has been heavily dependent on imported processing equipment, Esprit will also support work on chip architectures for VLSI, device modeling, and computer-aided circuit design and testing.[90] The program has been carefully designed to avoid areas where countries and companies compete directly. Funding, planned to be about $45 million over 3 years, will be contingent on substantial contributions from the industrial participants, which number a dozen of Europe's largest electronics firms (ICL, Siemens, Nixdorf, CII-HB, Philips, Olivetti—the planning effort began with company managements rather than government officials). EC planners hope the effort will expand within a few years to encompass more ambitious targets—e.g., projects analogous to Japan's government-sponsored R&D ventures in supercomputers and fifth-generation systems. It remains to be seen, however, whether the Europeans will manage to cooperate effectively—and, if they do, whether cooperation in basic research will make much difference, given that many of the large European electronics companies have always performed high-quality research but have had difficulty translating the results into commercial products.

Japan

Japan is the exception to many rules in the international electronics industry. Government policies evolved along with the industry; they have consistently supported private firms, directly and indirectly. Subsidies have been substantial, though not inordinately large compared with other countries. Both financial support and indirect measures have been carefully targeted—benefiting some parts of Japan's electronics industry much more than others—a feature that has attracted much attention in the United States. Consumer electronics, for example, has not been a major focus of government policy compared to microelectronics and computers; nevertheless, during the period of consolidation and concentration that extended through the 1960's, the government maintained a series of barriers to imports and foreign investment that effectively limited competition in consumer electronics to local firms.[91] Lib-

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[88] ''Growth of Electronics Market in Europe Seen Benefiting Japan, " *New York Times, Nov. 28, 1980,* p. D3.

[89] ''Europe's Electronic Strategy is Modest, But It Still Isn't Easy,'' *The Economist,* July 26, 1980, p. 63. Over the years, the EC Commission has produced a variety of elaborate proposals and studies, to little evident effect. See, for example: "New Information Technologies, " Sept. 1, 1980; "Proposal for Council Regulation Concerning Community Actions in the Field of Microelectronic Technology, " Sept. 1, 1980; "The Competitiveness of European Community Industry, ' Mar. 5, 1982; all Commission of the European Communities, Brussels.

MID. Fish look, ''Why Europe Wants Esprit, " *Financial Times,* Aug. 3, 1982, p. 13; J. Smith, "Can Europe Cooperate on Research?" *Electronics,* Aug. 25, 1982, p. 85.

[91] '' Sources of Japan's International Competitiveness in the Consumer Electronics Industry: An Examination of Selected Issues, " prepared for OTA by Developing World Industry and Technology, Inc. under contract No. 033-1010.0, pp. 31-46; see also *The U.S. Consumer Electronics Industry* (Washington, D.C.: Depart-

eralization began only in the late 1960's, as the government's attention turned elsewhere; by this time Japan's consumer electronics industry had become well established. Foreign investment controls on monochrome TV production facilities were relaxed in 1967, on color production 2 years later (in some contrast with European governments, Japan limited inflows of foreign capital as well as products). Likewise, the tariff on color TV imports—formerly 30 percent—dropped to 7½ percent in 1971. Similar measures were adopted to protect the fledgling computer and microelectronics industries.

TV manufacturers clearly benefited from government support of broadcasting, from the array of direct and indirect trade barriers that Japan erected during the postwar years, and from policies that encouraged exporting. Still, direct and positive support–e.g., for R&D and product development—was modest compared to the attention lavished on information processing. Beginning in the 1960's, computers and semiconductors have been at the center of policies toward electronics and "the information industry. " As these sectors grew, Japanese policymakers shifted direction—away from the complex of measures for protecting domestic industries that had been the hallmark of the government's approach during the 1950's and 1960's, toward more positive measures. Rather than simply sheltering local companies, the government sought to actively strengthen Japan's capability in data processing, with the aim of moving into world markets. Financial subsidies, primarily for R&D, were a major vehicle, along with other, less direct supports for research, as well as measures to encourage and facilitate applications of new technologies. An example of the latter is the Japan Electronic Computer Co., which buys data processing equipment from computer manufacturers and leases to users (ch. 4).

Today the information industries are viewed as the flagship of the knowledge-intensive sectors at the core of Japan's emerging industrial structure, the structure that will keep the country's economy growing and competitive into the next century. A unique feature of electronics policy in Japan—since copied by other nations—is official sanction and promotion, not only of the industry as such, but of electronics as the epitome of a broad array of emerging technologies (including CAD/CAM, robotics, composite and ceramic materials, and biotechnology); the policies *of Japan's Government toward electronics are in fact aimed at goals transcending conventional sectoral boundaries.* These policies, for years, have also been consciously directed at leapfrogging other nation's technologies—another aspect of the Japanese strategy that governments elsewhere, particularly in Asia, have tried to emulate. In several respects then, Japan's use of the tools of industrial policy has been innovative; Japanese policy makers have been both more ambitious and more experimental than, for in-

Photo credit Be// Laboratories

Light emerging from glass filaments used in fiber-optic communications

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ment of Commerce, September 1975), pp. 12- I 3, and *United States—Japan Trade: Issues and Problems* [Washington, D. C.: General Accounting Office, ID-79-53, Sept. 21, 1979), ch. 5.

stance, their counterparts in France or the United Kingdom.

The efforts of people like Yoneji Masuda have fed the broad consensus which evolved among leaders in Japanese business and government concerning the critical importance of electronics, and particularly computers. Active since the mid-1960's on advisory councils to the government, Masuda was responsible—as Executive Director of the Japan Computer UJsage Development Institute—for the 1972 report, "The Plan for an Information Society: Japan's National Goal Toward the Year 2000." Respected academic and author of more than 20 books, as a government advisor Masuda advocated a comprehensive national plan for ''computerization" in Japan, including government investment in future-oriented projects such as a ''computopolis, or computerized city, and a computer peace corps. Masuda's ideas--which are well within the mainstream of this brand of futurism, based on the assumption that the production of information will gradually overshadow the production of material goods, eventually comprising the next stage in economic development-heavily influenced MITI's (the Ministry of International Trade and Industry) vision of a future information society.[92] Most Japanese policy makers take a more pragmatic view, but the visionary outlook of Masuda and others like him helped crystallize a broadly based consensus on the importance of computer technology.

The Institutional Setting

In contrast to the United States or the United Kingdom, a well-defined group of government agencies in Japan bears the responsibility for official policies toward the electronics industry. Both policy development and implementation are centralized in MITI, specifically its Information Machine Industries Bureau. Satellites attached to MITI include the Agency for Industrial Technology, with functions in R&D, and the Information Processing Industries Advisory Council, a prestigious group with membership drawn from the private sector.

The only other public agency with significant ongoing jurisdiction related to electronics is the Science and Technology Agency (STA), under the Prime Minister's Office. In size and resources, STA cannot rival MITI. It does, however, coordinate the government budgetary outlays for R&D and related expenditures, preparing, for example, an annual "Science and Technology White Paper. " STA also funds research projects, including contract research by private firms, through its New Technology Development Corp. [93] STA influence over nuclear, ocean, and space technologies has been more extensive than in electronics.

This is not to say that other government agencies do not develop policies that affect the Japanese electronics industry. They do, but on a less regular basis than MITI and STA; moreover, the influence of other agencies tends to be less direct, The Ministry of Finance (MOF) has jurisdiction over macroeconomic matters-e.g., fiscal and monetary policy. In recent years, growing budget deficits have forced the MOF to weigh proposals for sectoral assistance more carefully; competition for funds among electronics and other industries-as well as with government objectives other than industrial—development-has become stiffer. The MOF also exercises a good deal of' influence over the Bank of Japan, while public corporations such as the Japan Development Bank can channel funds to favored companies through loans and grants (ch. 7). Long-term projections by the Economic Planning Agency include forecasts of output by sector of the economy that are widely regarded as reliable guideposts to future business prospects. While neither public nor private banks need subscribe to the government's investment priorities, they often put money into sectors targeted by such plans.

An independent body, the Fair Trade Commission (FTC)—though peripheral in industrial policy compared to MITI or the MOF--has

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[92] Y. Masuda, *The Information Society as Post-Industrial Society* (Tokyo: Institute for Information Society, 1981), p. 29.

[93] *Kagaku Gijutsu-cho/Kankyo-cho* (Science and Technology Agency/Environment Agency) (Tokyo: Kyoikusha, 1979), pp. 48, 77.

often resisted policies formulated by those agencies. Examples include legislation exempting sectors like electronics from provisions of Japanese antitrust law to facilitate "collaboration" among firms for "rationalizing" the industry.[94] The FTC has repeatedly, though seldom successfully, opposed MITI recommendations for antitrust exemptions—but in contrast to the Japanese petroleum industry, where the FTC has frequently investigated particular companies, electronics firms have seldom been scrutinized apart from matters of rebates and resale price maintenance. Even the public outcry over price-fixing among color TV manufacturers fueled by media reports of dumping charges against Japanese firms in the United States—was assuaged informally rather than by FTC decision; MITI persuaded the companies involved to lower domestic prices by 15 percent. Legal challenges to the business activities of Japanese electronics firms have come primarily from abroad: in the United States alone, Japanese electronics companies have been involved in more than 30 lawsuits, the majority over dumping.[95]

In addition to these traditional actors, other agencies and organizations have recently found more prominent roles, The interministerial Council for Science and Technology has been active in developing and coordinating large-scale R&D programs, The Ministry of Education has launched its own 3-year VLSI project, Diet (parliamentary) committees dealing with science and technology have become more visible. Local governments have started to court new technology-based industries; Kawasaki has put together a plan calling for transformation into a "microcomputer city, " while Hiroshima has organized a council to study the impacts of high technology on its established industrial base, Given this proliferation, science and technology policy in Japan may become more politicized in the years ahead (in some energy research areas, such as nuclear power, this has already occurred).

Policymaking in Japan

Japanese industrial policy is built on close consultation among business leaders and government officials. Corporate executives routinely participate in both formal and informal discussions concerning policies toward electronics. It is an overstatement to claim, as some observers have, that in Japan industry tells government what to do, while in France government tells industry—but this does convey a sense of the difference. The Information Processing Promotion Advisory Council, for instance, brings together representatives of Japan's leading electronics firms to discuss MITI proposals. While such advisory councils meet relatively infrequently, and rarely have a determining voice in policy development, they serve to mobilize business interests and help form a consensus in support of the eventual outcome, Advisory councils are only one such forum. Representatives of the many electronics industry associations in Japan interact with officials from MITI and other agencies through a wide network of public and semipublic institutions. Several organizations bring together government, industry, and university leaders to stimulate work on computer software; the Information Technology Promotion Association (IPA), for one, had a 2.78 billion yen budget (about $13 million) in 1980, raised from both public and private sources. Established in 1970, IPA organizes programs through which private corporations and IPA staff conduct joint research on problems such as computer-aided design or software packages for small businesses.[96]

Similarly, the Japan Information Processing Development Center (JIPDEC)—a semipublic organization with a staff of 150, the bulk of whom are engineers—was established in 1967 with the support of MITI and the Ministry of Posts and Telecommunications. JIPDEC's pri-

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[94] *Kijoho no Kaisetsu* (An Explication of the Law for Special Measures for Specified and Information Industries) (Tokyo: Ministry of International Trade and Industry, 1979).

[95] *Denshi Kogyo Nenkan, 1979* (Electronics Industry Annual, 1979, Ministry of International Trade and Industry) [Tokyo: Denpa Shuppansha, 1979), p. 303.

[96] *Konputa Hakjusho- 1979* (Computer White Paper-1979), Nihon Joho Shori Kaihatsu Kyodai (Japan Information Processing Development Association) (Tokyo: Konputa Ejisha, 1979), p. 94,

mary mission is the marketing of software. Loans and grants for some of its programs have been provided by IPA. Operating with a $10 million budget, JIPDEC carries out surveys on information processing, conducts R&D, supports technical training and education, and encourages information exchange through seminars and publications. Examples of JIPDEC projects include a microcomputer promotion center and an Institute of Information Technology for retraining technical specialists, JIPDEC activities also led to the fifth-generation computer project,

Government-Sponsored Research and Development Projects

The fifth-generation computer effort typifies Japan's approach to R&D–bringing together private sector firms, along with selected public institutions. With funding from MITI and the bicycle racing association, the fifth-generation project—which has attracted worldwide publicity—is overseen by a 22-member panel including representatives from Tokyo University, companies such as Fujitsu, and MITI.[97] About half the roughly $500 million budgeted for the lo-year effort is to be provided by the government. A research association (kenkyu kumiai) was setup in 1979 to mobilize nine Japanese companies for R&D on microelectronics devices and peripheral and terminal equipment, as well as software—all aimed at major strides in computing technology. JIPDEC's role has been largely facilitative; the research association now carries the primary responsibility. The association's administrative staff has been drawn from employees of the participating companies, who are dividing the R&D effort.

As discussed in more detail in chapter 5, the fifth-generation computer project is far from an independent *or* all-inclusive effort; its work is proceeding in a context of government-subsidized R&D—as well as company-funded research—aimed at related aspects of information processing. Likewise, the project is only one of a number of follow-ons to earlier MITI-sponsored activities such as the VLSI R&D program (discussed in ch. 5, as well as below) and the Pattern Information Processing System Project (PIPS).[98] Such R&D efforts complement one another; they involve shifting groups of public and private sector participants drawn from a wide range of institutions. In parallel with the fifth-generation computer project, MITI is sponsoring the supercomputer effort mentioned earlier, along with a 10-year program on advanced microelectronic devices and work on optical measurement and control. Despite the funding that MITI provides, the Ministry's officials seldom attempt to guide or direct research, but confine their participation to helping shape objectives and to administrative functions,

Compared with other countries, Japan's approach to aid for electronics is unique in at least three ways: 1) government-supported programs are multiple but carefully coordinated with one another; 2) they are oriented toward facilitating the activities of industry, rather than telling industry what to do; and 3) the time horizons are unusually long. The last point is critical: *the 8- or 10-year planning horizons for many current Japanese R&D projects—with every indication that, while projects will be adapted to evolving circumstances, continuity will be preserved—point to the depth of the government's commitment,* Certainly there are few analogs in the United States, even in defense research–where the 6-year VHSIC program is the exception, not the rule.

Cooperation in Research and Development

Observers in the West often misconstrue the nature of Japan's "cooperative" R&D efforts. While corporate leaders and government officials do in some cases work closely with one

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[97] "Fifth Generation Computers," *JIPDEC Report*, Japan Information Processing Development Center, summer 1980. The discussion following also draws on interviews with MITI officials in the Information Machine Industries Bureau.

[98] PIPS has been much less visible in the United States than several of Japan's other R&El efforts, but it played a *major role* in laying groundwork for the fifth-generation computer project. See H. Nishino, "PIPS (Pattern Information Processing System] Project—Background and Outline," *Proceedings Of the 4th International Joint Conference on Pattern Recognition,* Kyoto, Nov., 7-10, 1978, International Association for Pattern Recognition, p. 1152,

another during ongoing projects, the more usual pattern has been a carefully planned division of labor. MITI bureaucrats help initiate new projects—after lengthy preliminary discussions with industry advisory committees—by winning budgetary approval, They also monitor ongoing programs, evaluating progress and judging success, Government officials are often detailed to organizations like JIPDEC. Program administration is normally delegated to representatives of participating firms, with the research itself divided among these firms. People from different companies seldom work side by side.

The two government-supported VLSI projects—paralleling one another in time—illustrate these patterns. The first, oriented toward communications, was carried out by the public corporation Nippon Telegraph & Telephone (NTT) under the aegis of the Ministry of Posts and Telecommunications. The second, directed at applications of ICs to computers and much better known outside Japan, was sponsored by MITI; with 40 percent government and 60 percent private funding, the $300 million, 4-year effort took the form of a research association linking five participating firms, Three laboratories divided the work: a shared facility managed by the VLSI Technology Research Association; the Computer Development Laboratory jointly run by Hitachi, Fujitsu, and Mitsubishi; and the NEC-Toshiba Information Systems Laboratory. Staffs of the latter two laboratories came, not from the larger group of participants, but from the companies operating them; the joint facility drew engineers and scientists from all five, as well as MITI employees from the AIST. MITI was deeply involved in planning and organization during the preliminary stages. Later, the teams from the participating companies independently carried out their assigned research tasks. Only in the association's joint laboratory was a real effort at cooperation—with technical people from different companies working together—undertaken; this was a minor portion of the overall program, restricted to more fundamental research.[99] Individual firms did not cooperate on either product designs or processing technology. Thus, while the MITI-sponsored VLSI project has become known abroad as a "cooperative" effort, the actual extent of interaction among participating firms was limited; spokesmen for the Japanese electronics industry say that dividing the research enhanced the overall success of the project. It appears that the organizational form involved a compromise between attempts to encourage individual interactions—with objectives such as stimulating personnel development—and the more concrete technical goals. Certainly as the work undertaken by joint R&D projects in Japan moves toward development, interfirm cooperation declines; a MITI-orchestrated follow-on to this VLSI project, which began in 1980 and emphasizes chip designs and applications, takes the form of totally independent efforts by each participant.

The work of the "Research Association for R&D on New Function Elements, " also beginning in 1980, can be viewed as another follow-on to the VLSI project; it illustrates the way in which MITI-sponsored research efforts complement one another. This association's laboratory draws on a larger group of companies. Matsushita, Sanyo, Sharp, Oki, and Sumitomo Electric—none as strong in their technology as the five companies that had participated in the VLSI project—will all be involved in one or more of three major microelectronics development efforts.[100] These are:

- Three-dimensional circuit elements—which can be visualized as more or less conventional ICs stacked atop one another, increasing the density,
- High electron mobility transistors (HEMTs), one variety of which consists of extremely thin layers of semiconducting

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[99] Interview with Mr. Nebashi, I B M-Japan and formerly at the VLSI Cooperative Laboratory, *Nihon Keizai Shimbun,* Jan, 19, 1981, p. 1.

[100] "FY82 Government Projects in Electronics Listed, " *Japan Report,* Joint Publications Research Service JPRS 1,/10676, July 22, 1982, p. 55,

materials such as gallium arsenide or gallium aluminum arsenide; these structures carry the potential for higher switching speeds, hence faster computers,

- Radiation-hardened devices suitable for use in extreme environments such as nuclear powerplants or outer space (resistance to heat and vibration is a related objective).

The first two especially will support both the supercomputer and fifth-generation projects.

The Role of Universities

University-industry interactions in R&D are no closer in Japan than in other countries—again perhaps in some contrast to the common perception. Close collaboration is rare, even though the rules prohibiting professors in the national universities from working for private companies can be circumvented. Contract research and consulting by university faculty are more limited than in the United States,

Japanese policy makers universally express the wish that university-industry relations be improved, and that sufficient numbers of well-trained professionals be available to meet the economy's needs. To date, however, little progress seems to have been made—nor, in fact, have new policy initiatives directed at such concerns emerged. As discussed in chapter 8, Japan's colleges and universities have for some years been turning out more engineering graduates than in the United States. Nonetheless, as in other industrialized countries, there has been concern over future shortfalls in the supply of engineers and scientists; a recent survey covering the hiring plans of more than 1,600 Japanese firms points to stiff competition during the 1980's for university graduates trained in technical fields.[101]

How Significant Are Supports and Subsidies in Japan?

As for any country, it is impossible to place a monetary value on the policy measures that benefit Japanese electronics companies. Nor would an attempt at such an accounting be very meaningful. Indirect benefits—e.g., temporary exemptions from antitrust provisions—escape quantification. Even when government funds flow directly to industry—as in the cost-sharing typical of joint R&D projects in Japan, or the subsidies for the West German computer industry during the 1970's—the real questions concern the effectiveness with which the money is spent,

Nevertheless, subsidies deserve special attention in the case of Japan because the (J. S. electronics industry has argued that they have been a key to the competitive success of Japanese firms. Research funding is only part of the total picture of industry-specific support, but as table 77 indicates—and in common with other industrialized countries—more than a quarter of all Japanese R&D expenditures, both government-funded and industry-sponsored, have gone to the electronics/electrical machinery sector. At the same time, *government* expenditures on research are not high compared to other countries; considering *only* R&D, and counting only expenditures *directly* related to electronics, public funding is quite small—about 1 percent of the total for 1978, according to the Japanese Government.[102] This is hardly the whole story; it does make the point that R&D in Japan is primarily the responsibility of private industry, Japanese R&D is heavily concentrated on commercial applications; neither military technologies nor basic research get the attention they do in other countries. Looking at all R&D spending, the private sector in Japan provides over 70 percent of total funding—more than in the United States, where industry spending accounts for 50 to 60 percent (table 77).

MITI's annual compilation of government supports and subsidies for the "information industry" is the most comprehensive listing of

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[101] "Daisotsu Danshi Nohi Niketa" [Number of Male Graduates Declines), *Nihon Keizai Shimbun*, Aug. 27, 1981, p. 1.

[102] In 1978, government bodies in Japan, including state and local, reportedly contributed 6.8 billion yen (about $34 million) to the total of 580 billion yen (about $3 billion) spent for R&D on "electrical machinery. " This includes household electric equipment, as well as communications and electronics. Most of the R&D work is for development, See *Kagaku Gijutsu Kenkyu Chosa* (Report on the Survey of Research and Development, Prime Minister's Office, Statistical Bureau) (Tokyo: Nihon Tokei Kyokai, 1979), pp. 39-40, 94.

programs related to electronics. (For the United States, no comparable data exist—in part because no one agency has responsibility for such programs). For 1980, the Japanese Government budgeted about $1.3 billion toward the development of the information industry—expenditures encompassing much more than just the R&D programs highlighted above; a large fraction of the total consists of loans and loan guarantees rather than direct grants.[103] Included in the total, for instance, is the more than $200 million that the Japan Development Bank loaned to the Japan Electronic Computer Corp. for lease financing; this aids Japanese computer manufacturers by reducing the funds they would otherwise have to commit to rental and lease arrangements with their customers, as well as absorbing risks associated with repurchasing.

The computer industry has received a substantial share of direct subsidies. Budgeted MITI expenditures for major projects closely related to data processing—including several of those outlined above—are listed in table 80. The table is not inclusive, and is intended only to give an idea of the magnitudes of typical government expenditures, These sums are not large compared to R&D spending by industry itself in either Japan or the United States, or in comparison with government funding in other countries. Portions of such subsidies have funded large-scale, long-term programs aimed at social applications of electronics technologies—e.g., health care, regional energy saving, computerized traffic control systems. The figures in the table also include money for conducting surveys on computer usage, administering qualifying examinations taken by computer technicians, and the costs to the government of special tax deductions extended to companies that train information processing specialists.

Taken together, it is the comprehensive nature of such programs—not their spending levels—that distinguishes Japan's policies toward electronics and other targeted industries.[104] The very fact that the government publishes an information industries budget indicates the care with which the bureaucracy monitors developments in electronics and disseminates information among government, business, and financial circles. It is this attentiveness on the part of government, and the fact that most programs are coordinated by MITI, that sets Japanese industrial policies apart. Over the years, funding by the Japanese Government has grown, but the significance of MITI's initiatives goes well beyond financial support; indeed, to look only at the money spent is to un-

Table 80.—Japanese Government Expenditures on Selected Projects Related to Computer Technology

Project	Budgeted expenditure (millions of dollars)[a] 1981	1982
Basic technology for next-generation computers	$28	$22
Basic software technology	24	20
Microelectronics ("new function elements")	3.1	4.5
Supercomputer R&D	0.14	3.3
Peripherals	4.8	2.6
Fifth-generation computer R&D	0.07	1.7
	$60.1	$54.1

[a] Fiscal year basis, converted from yen at 220 to the dollar for 1981, 249 for 19132

SOURCE "FY82 Government Projects in Electronics Listed," *Japan Report,* Joint Publications Research Service JPRS U10676, July 22, 1982, p 59

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[103] *Denshi Kogyo Nenkan 1979,* op. Cit., p. 340.

[104] The " Research and Development Project of Basic Technologies for New Industries, " established in late 1981, is another example. The original plan called for total spending of about $460 million over 10 years; however, the first year's expenditures have been scaled down by the finance-conscious MOF. Private corporations are being funded to participate in one of 12 R&D "themes," such as biotechnology and advanced materials. The "New Function Elements" microelectronics projects mentioned earlier are also part of this umbrella program, See "AIST *1982,* " Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Tokyo, pp. 6 and 7.

derestimate the impacts of such programs, They have considerable symbolic and psychological value in galvanizing the efforts of many participants behind a set of goals shared by government and industry. Programs in electronics have typically been aimed at breaking bottlenecks viewed as critical to continued progress. Both the VLSI project—which, as outlined in chapter 5, was intended to help Japan catch up to the United States in digital MOS ICs—and the fifth-generation computer project, with its software push, have been designed to serve such purposes. The supercomputer project is quite different; not particularly important in any commercial sense, it is first and foremost intended as a highly visible symbol of Japan's ability to compete technologically with the United States—from the Japanese perspective, supercomputers are one of the critical propaganda battlefields of the "computer war. "

Comparing Japan's industrial policy with efforts in Britain or France points to a major difference: government policies in Japan are directed at further strengthening a private sector that is vital and still expanding rapidly, not at revivifying a stagnant industry. Government programs in Japan complement the dynamism and international orientation of the country's electronics firms; they have contributed to, but not created, their competitive ability.

Recent Trends

Major thrusts of Japan's industrial policy have been aid and encouragement for exports of electronics and, to a lesser extent, overseas investment, The international activities of Japanese electronics firms are especially visible in Asian markets, where interdependence is growing (ch. 4). A study by the Electronic Industries Association of Japan forecasts strong expansion elsewhere in the Far East, and urges Japanese firms to develop strategies of "accommodation''—promoting Japanese investment and technology transfer, while importing low-technology, labor-intensive electronics products from other Asian nations.[105] These international moves by Japanese electronics manufacturers have for many years had the active support of Japan's Government.

In the United States, many signs indicate that Japanese manufacturers are now often recognized as peers. Technical exchange agreements between American and Japanese electronics companies—rather than outright purchases by Japan–are on the upswing. Mitsubishi and Westinghouse have arranged a joint venture to design and manufacture ICs. Hewlett-Packard is getting RAM technology from Hitachi. The U.S. Department of Defense has persuaded Japan to transfer defense-related electronics technologies to this country (although what these technologies will consist of is far from clear). American semiconductor firms are setting up design centers in Japan, as well as production facilities—while Japanese firms do likewise in the United States, each seeking to draw on the other's technical talent.

Movement toward cooperation amidst ongoing commercial rivalries has not been confined to the initiatives of private companies, In response to criticism from the United States and elsewhere that MITI-sponsored electronics R&D constitutes an unfair subsidy, Japan has suggested steps in the direction of international cooperation. For example, foreign firms have been invited to participate in discussions aimed at an enlarged fifth-generation computer project having the form of an international joint venture.[106] Such proposals—even if carried through—would not by themselves stem the rising tide of criticism aimed at Japan's industrial policies, as well as the country's indirect and nontariff barriers to trade. Still, if nothing else, they are a sign of the confidence the Japanese now have in their own abilities—while also being a well-calculated public relations ploy.

There are two fundamental perspectives in the United States on questions of Japan's subsidies and indirect trade barriers. On the one hand, those who believe free flows of technology to be a prerequisite for economic growth

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[105] *Denshi Sangyo no Kokusaika no Hoko to sono Eikyo ni Kansuru Chosa Hokoku* (Survey Report on Trends in the Internationalization of the Electronics Industry and Their Influence, Part II on East and Southeast Asia], op. cit., pp 271-291,

[106] "Dai GoSekai no Conputa: NichiBeiOo no Kyodo Kaihatsu Shido'' (Fifth-Generation Computer: Beginning of Joint U.S.-Japan-West European Joint Development], *Nihon Keizai Shimbun*, Aug. 30, 1981.

and technical innovation call for equal access by U.S. firms to programs sponsored by the Japanese Government. The other view is held by those who would prefer restrictions on outward flows of U.S. technology in an effort to preserve "technological security. " As debates in this country continue, the procurement, R&D, and customs and standards activities of Japan's Government will be scrutinized by partisans of both viewpoints.

How Effective is Japanese Industrial Policy?

Any judgment of the contribution of Japan's industrial policies—or government policies anywhere-to international competitiveness in electronics rests in part on intangibles. Precise evaluations are impossible. What is the "worth" of the networks for information transmittal and consensus-building woven by MITI? What are the costs and benefits of the ambiguities and uncertainties surrounding antitrust enforcement in the United States?

In judging the effectiveness of Japanese industrial policy, the starting point is its basic thrust—to cultivate rather than confine the nation's electronics companies. The institutional apparatus that has evolved over the years has contributed far more than absolute levels of financial assistance might indicate. The end result has been effective mobilization of institutional and human resources, comprehensiveness in government efforts, a substantial degree of policy integration without rigidity. The focus of Western observers on cooperation between government and business only hints at how the system works.

With few exceptions, Japan's Government has used the same policy tools to promote electronics as other nations: in the early years, tariff barriers combined with controls on foreign technology and capital flows; today, supports and subsidies for R&D and commercialization. While the highly publicized VLSI R&D project has been held out as a unique instance of cooperation—one that would violate antitrust laws in the United States—under closer examination much of the appearance of interfirm cooperation vanishes. The program was effective because it was carefully crafted to help Japanese firms overcome specific weaknesses that MITI and industry leaders had identified: emphasis on linear devices, a legacy of production for consumer products; lagging capability in the processing of large-scale ICs, because Japanese firms were dependent on semiconductor manufacturing equipment from the United States; lack of experience in digital circuitry among engineers and technicians, In contrast to government-supported R&D projects in West Germany or the United Kingdom, the Japanese were able to define their needs and agree on a program that would help them catch up to the United States. It is the *consistent and coordinated attentiveness to the problems and potentials of electronics (and other industries) that distinguishes the policies of MITI and the rest of Japan Government more than the character of individual programs or policy instruments.*

At a more general level, the *long-term orientation* of policies toward electronics—typified by the fifth-generation computer project—also distinguishes Japan from other countries. Further, development of the electronics industry —while a goal in itself—has been pursued for larger reasons: electronics is viewed as the key to Japan's overall industrial development, the first ingredient in the knowledge-intensive, energy-efficient economy that the country's technocrats are striving toward,

Japanese industrial policies have certainly not been universal triumphs—efforts to prop up declining sectors (steel) or to counter international market trends (petroleum) have not been particularly successful. But policies toward electronics have complemented the dynamism of private companies already well positioned both domestically and internationally. It is the congruence of public policy and evolving shifts in industrial structure that, in the end, is the hallmark of present-day Japanese policies toward the information industry.

Summary and Conclusions

Among nations that have set out to promote their electronics industries, the policy tools come from a common list: R&D funding, investment grants and subsidies, procurement, merger and trade policies. No avenue emerges that can guarantee success in strengthening the competitive ability of a country's electronics firms. Under closer scrutiny, many of the policies adopted by nations like Japan—sometimes thought to be unfair or unique—are not so dissimilar from those used in other advanced industrial economies, even the United States. Matters of timing, comprehensiveness, consistency—rather than the types of policies adopted-differentiate the industrial policies of various countries,

As competition in the international electronics industry has intensified, governments have stepped in to help their own entrants. In the early 1960's, European and Japanese fears over the "American challenge" sparked systematic attempts to protect and strengthen domestic computer manufacturers. At that time, the preferred policy approach began with trade protection-tariffs, controls on flows of foreign investment and technology, discriminatory procurements. Several countries encouraged mergers among computer firms. In the 1970's, as trade liberalization under the General Agreement on Tariffs and Trade continued, industrial policies shifted away from overtly protectionist and defensive approaches. Today, sup*ports for R&D, indirect subsidies such as tax incentives, and other less direct measures comprise the foundations of public policies toward electronics in virtually all countries*. Except in threatened sectors like consumer products, trade liberalization has been accompanied by a parallel movement toward policies with secondary rather than primary effects on international flows of electronics goods. If there is an exception, it is the United States—where, leaving aside defense-related policies, the most prominent measures have continued to be regulatory.

Can, then, industrial policies create comparative advantage? The answer is clearly no. Competitive success in electronics, here and abroad, depends on many factors, of which government actions are only one. Taken alone, public policies are seldom as important as the capabilities of a nation's private companies: human resources and their utilization, including the quality of management; costs and availability of capital; technological ability in electronics and the complementary infrastructure; overall market conditions—these are more central to international competition. Public policies can add or subtract from them, but the ability of governments to compensate for weaknesses—or to reverse declines in competitiveness—is circumscribed. Although they can either help or hinder industrial development, *public policies alone do not determine—directly or indirectly–the competitive standing of electronics industries in any nation.*

Today, policy makers in the U.S. Government must decide whether to continue the ad hoc approach of years past or move toward measures aimed more consciously at preserving and strengthening the advantages that the American electronics industry draws from its setting and structure. If the choice is to develop a more comprehensive industrial policy, much can be learned from studying foreign experience—West Germany's Fraunhofer Gesellschaft, Japan's VLSI project, Britain's schemes to promote commercial applications. But no recipe for success emerges from the countries that have experimented with industrial policy, It is one thing to say that policies toward electronics should be in tune with overall changes in industrial structure and international markets; it is quite another to actually design and implement an effective industrial policy amidst the ongoing uncertainties and ambiguities that characterize the political and economic context,

Government policies, then–as illustrated by the countries examined in this chapter—are generally tailored to the level of technological and commercial development of firms in the local industry. It is no coincidence that the nation which led initially in semiconductors, in color TV, in computers—the United States—made no attempt to devise a systematic policy orientation toward electronics. Where was the need? Nor is it surprising that the countries with more comprehensive policies have generally been those that have perceived themselves at a disadvantage. But why have some countries been more successful in mobilizing institutional resources to create sustained and coordinated industrial policies than others?

A variety of forces work to enhance the ability of government officials to design and implement coordinated, timely, and comprehensive policies toward industries like electronics. A relatively centralized policymaking apparatus, where a single agency or a select few have well-defined responsibilities, is one. The grab-bag nature of British policies mirrors the agencies charged, at one time or another, with policy development. In countries where government officials belong to a respected civil service they are more likely to have the resources to analyze and initiate actions with positive effects on industry. The dominance of political appointees in the United States, and their rapid turnover, works against the kind of consistency seen in nations like Japan. So too does the lack of understanding of technology characteristic of both bureaucrats and politicians in this country. An elite civil service does not ensure success, as the mixed record of French industrial policy shows. But especially in Japan—where consultation and cooperation between industry and government have been closer than in many other countries, if not so close as sometimes pictured in the West—consensus is easier to achieve than in nations where adversarial relations are the norm. Easier too is carrying through the actions that have been agreed on. Such factors have enhanced the effectiveness of industrial policy in Japan, the one nation that has so far managed to catch up—in at least some respects—with the United States. Of course, Japanese electronics firms have been favored by other circumstances as well–skilled labor supplied by a long-established educational system is only one example. Structural features of the political and economic system in Japan-–natural resource endowments, existing capital markets, political stability, established mechanisms for policymaking, characteristic systems of labor-management relations—have tended to shape and limit industrial policy decisions, rather than the other way around.

As Japan and other countries seem likely to discover, it may be easier to develop policies aimed at catching up than to devise strategies for keeping up or jumping ahead. For one thing, as internationalization of industrial and market structures proceeds, the influence of national governments will diminish. But the fundamental point is that in any industry or technology, creating a new model is harder than following a recognized leader. Government aid has helped electronics firms in other countries improve relative to American competitors; the situation for the United States has been—and remains—different. The *leaders, be they American or Japanese, have to break new ground—a commitment that industrial policymakers in Japan have long since made.* Japan's publicly voiced determination to improve the technological base for the country's electronics industry stems from a recognition that past successes have been built on the adaptation and commercialization of technologies originating elsewhere, mostly within American firms. Now, Japan is a leader along with the United States. The public as well as the private sectors in each country face the need to develop appropriate strategies for the years ahead.

Industrial policies for the 1980's *and beyond will be most successful where policymakers grasp the dynamics of ongoing shifts in domestic and international markets and industries.* To the degree that public policies ignore or attempt to counteract such forces, they will be less likely to reach their objectives. Policies designed to complement and reinforce ongoing trends will be more likely to have positive effects. This is not to say that public policies cannot help shape these trends. If it is true that the industries which fueled postwar economic growth—steel, petrochemicals, automobiles—have attained a stage of relative maturity, then emerging technologies are indeed an appropriate focus of government policy. Technologies based on genetic engineering, advanced materials, computer-integrated manufacturing—as well as electronics and information processing—will contribute to growth in existing as well as new industries. It follows that the appropriate emphasis of public policy may not be electronics alone, but economic adjustment and technological development more broadly.

CHAPTER 11

U.S. Trade Policies and Their Effects

Contents

Table

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U.S. Trade Policies and Their Effects

Overview

All trading nations develop policies dealing with imports and exports. On the import side, such policies are usually intended to control flows of incoming goods judged harmful to the domestic economy. Formalized export policies, as a general rule, are less numerous and typically intended to encourage overseas sales. To the extent that international commerce is restricted to trade and its financing, countries must export to be able to import, and vice versa. Over time, exports will therefore approximately equal imports. For such reasons, trade policies seldom have first-order effects in determining *overall* levels of imports and exports, but tend to guide and regulate trade—influencing, for example, the composition of a nation's imports. Policies can also be adopted to encourage exports so that needed imports—e.g., oil—can be paid for. Most common remain import controls serving to limit threats faced by domestic industries.

In recent years, the governments of industrialized nations have, as matters of official policy, generally taken the position that unrestricted trade—or at least trade with minimum impediments in the form of tariffs or similar restrictions—benefits all countries. Although a principle often honored in the breach, nations usually assume that relatively open trade is in their self-interest. Countries import goods which they themselves cannot produce as efficiently, and export products in which they have a comparative advantage (ch. 5). In theory, everyone is better off.

But while the benefits of open international trade are spread widely across society, the costs against which they are arrayed tend to be concentrated. Individual companies, their employees, the cities and regions in which they are located, bear the brunt of shifting patterns of trade and competition. When imports rise, the injured parties are more vocal than the beneficiaries—many of whom do not realize they are paying less for some of the goods and services they purchase. Because of this imbalance, governments often raise barriers for political reasons, sometimes creating serious disruptions. The familiar example is the Smoot-Hawley Trade Bill, adopted by the United States in 1930, which raised the average U.S. tariff to more than 50 percent and was one cause of a steep decline in world trade. More recently, Japan has utilized a wide variety of tariff and nontariff barriers to protect developing industries, including electronics.

Near the end of World War II and afterwards, the United States took the lead in efforts to establish a liberal world trade order. This commitment has continued uninterrupted to the present day. American leadership has been a major force in negotiations among trading nations aimed at moderating tariff and, more recently, nontariff barriers to trade. These efforts have taken place largely within the structure of the General Agreement on Tariffs and Trade (GATT], an organization now comprising some **80** nations. GATT provides a forum for negotiations together with mechanisms for resolving conflicts.

While trade negotiators have made considerable progress in reducing tariffs, nontariff measures are proving less tractable—within GATT or on a bilateral basis. As more nations develop industrial policies nominally for domestic reasons, the trade arena has taken on a new complexion: indirect and nontariff barriers have risen as tariff walls have declined. The result has sometimes been termed "the new protectionism. " In essence, negotiators are struggling to fit the policy framework from an earlier era—GATT mechanisms have roots in the 1940's—to a radically different setting. International corporations now compete in some parts of the world, cooperate in others, ship goods between subsidiaries located in dozens of countries, and take advantage of national industrial policies where they can. Governments design policies to attract foreign investment and technology under some circumstances, to keep it out under others. Trade-related complaints by U.S. firms embrace not only the old-style unfair practices—dumping or export subsidization to boost trade balances, predatory practices aimed at building monopolies or cartels—but asymmetries in the "rules of the game. " The claim is that the industrial and trade policies of other nations tilt the rules in their favor. Trade negotiators will be faced, for years to come, with adapting rulemaking and adjudicating procedures to these new realities,

This chapter briefly reviews the environment for international trade in electronics under GATT, then discusses the trade policies of the United States, particularly as these relate to the electronics industry. Only limited attention goes to other countries, The chapter illustrates impacts of trade policies and discusses policy directions that may be important in the future.

On the whole, the U.S. electronics industry has been helped by the Federal Government's trade initiatives during the postwar period. Semiconductor and computer firms, in particular, have benefited from the opening of international markets. Much of their success has been due to a global perspective and worldwide operations—neither of which would have been possible without the open environment for trade and investment created since World War II. To be sure, foreign countries have often adopted policies intended to restrict inflows of American-made electronics products. But in most though not all cases, such restrictions have had effects that were marginal or indirect or both. While trade barriers have sometimes encouraged U.S. firms to establish overseas manufacturing facilities, for many years American electronics companies had such advantages in technology and cost that they would have been potent competitors virtually regardless of the trade policies adopted by other nations (the principal exception has been Japan). Still, these advantages have gradually diminished over time.

Where technological change is less rapid and labor costs more significant, trade policies carry more weight. In such products as television receivers, CB radios, and passive components, U.S. firms have not been able to maintain advantages in technology or manufacturing cost. Here, liberal U.S. trade policies have made it more difficult for American firms to compete effectively—most notably in the domestic consumer electronics market.

Tariffs; the Multilateral Trade Negotiations

The General Agreement on Tariffs and Trade provides the basic context for negotiations among nations concerning trade, and, where needed, for adjudicating disputes. Other bodies, including the Organization for Economic Cooperation and Development (OECD) and the United Nations, play more limited roles —e.g., collecting statistics. GATT is the primary vehicle for multilateral trade negotiations (MTNs), the latest of which–the so-called Tokyo Round, concluded in 1979—resulted in an agreement which will be the principal framework for international trade over at least the rest of the decade (another round of multilateral trade negotiations before the end of the 1980's is unlikely). This Multilateral Trade Agreement was implemented in the United States by the Trade Agreements Act of 1979.[1]

Earlier negotiations under GATT had focused on tariffs; although the Tokyo Round MTN resulted in further cuts, negotiators concentrated on such matters as quotas, customs procedures, product standards, and public sector procurement practices. Examples of Tokyo

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[1] Public Law 96-39, July 26, 1979.

Round topics of special relevance for trade in electronics include:

- A revised subsidies code, intended to provide a framework for dealing with national industrial policies having the indirect effect of subsidizing exports or otherwise affecting trade flows (as by giving domestic products advantages over imports).
- Staging of tariff reductions for semiconductors, accelerated by Japan in 1981 after extensive bilateral negotiations with the United States, a similar acceleration of Japanese tariff reductions on computers following *a* year later.
- An agreement on government procurement, where again negotiations between the United States and Japan concluded, at the end of 1980, in a bilateral accord more liberal than that arrived at under the MTN framework,

In the United States, passage of the Trade Agreements Act of 1979 was accompanied by a reorganization of trade-related activities carried out by executive order, As discussed below, responsibility for dumping and countervailing duty investigations moved from the Department of Treasury to Commerce, while a new Foreign Commercial Service was established in the Department of Commerce in place of the commercial officers attached to the Department of State, At the same time, the Office of the U.S. Trade Representative was given the job of coordinating international trade negotiations on a continuing basis. This reorganization followed mounting criticism of the fragmentation and diffusion of responsibility for trade matters within the executive branch.

Tariff Effects

As taxes on imported goods, tariffs directly affect price competitiveness. From the viewpoint of the country imposing them, tariffs can serve multiple purposes. One effect is normally to raise domestic prices; tariffs permit local firms to manufacture at higher costs while remaining competitive in the marketplace, protecting domestic industries from foreign rivals. Alternatively, governments impose tariffs to counter unfair trade practices such as dumping or export subsidies, or to retaliate against restrictions by other nations.

The impacts of tariffs on trade patterns are not always so straightforward as the nominal percentage rate would indicate; "real" rates of protection may exceed nominal rates by significant amounts. Table 81 gives a hypothetical but not unrealistic example—a product (which might be something like a computer terminal) with a nominal production cost of $1,000, purchased components constituting 80 percent of this, final assembly the remainder. The table compares two cases: 1) final assembly overseas, with the complete system imported and subject to a tariff of 10 percent; and, 2) final assembly in the United States, with components imported at a tariff rate of 5 percent. In both cases, the components are assumed to be purchased abroad at the same cost. (Transportation costs are ignored.) As shown, assembly in the United States gives a cost advantage of $60. The real protective effect with respect to the operations carried out domestically—the "effective rate''—would then be $60/$200, or 30 percent. This percentage can be interpreted as the amount by which domestic costs of as-

Table 81.—Hypothetical Example Illustrating Tariff Effects on a Product With Nominal Manufacturing Costs of $1,000

	Foreign assembly	U.S. assembly
Cost of components	$ 800	$ 800
Tariff on imported components (5°/0)	—	40
Cost of assembly	200	200
	$1,000	$1,040
Tariff on imported system (10° / 0)	100	—
Total cost in the United States .,	$1,100	$1,040

SOURCE Office of Technology Assessment

sembly could exceed foreign costs before American firms would begin to lose competitiveness. As a result, even where nominal tariff rates are identical, protective effects can differ; each case must be considered individually, The example in table 81 is not atypical in that tariffs on parts and components are generally lower than tariffs on final products; where this is the case, effective tariffs are always higher than nominal tariffs.

Tariff Changes in the Tokyo Round MTN and After

Nominal tariff levels on electronics products vary a good deal, with the Tokyo Round resulting in significant changes for microelectronic devices and computers. As mentioned above, tariffs on both semiconductors and computers were the subject of bilateral negotiations between the United States and Japan subsequent to the multilateral agreement itself, In 1981, Japan agreed to reduce its tariffs on integrated circuits (ICs) to 4.2 percent as of the beginning of 1983. Originally, they were to have dropped in stages, reaching the 4.2 percent level only in 1987. U.S. tariffs on ICs went from 6 to 4.2 percent in 1982. Somewhat later, as part of a larger package of trade concessions, the Japanese Government announced a parallel reduction in tariffs on computers. The cuts, from 7 to 4.9 percent—the U.S. level—went into effect at the beginning of 1983, rather than in 1987 as again originally scheduled.[2]

As part of the Tokyo Round, the United States granted a variety of tariff concessions on imports of electronic products, but these cuts will not have much impact because most U.S. tariffs were already low. The reductions—seldom amounting to more than a few percentage points—will make little difference in landed costs of imports. For example, the average level of tariffs on components (including passive devices such as resistors and capacitors, as well as semiconductors) and telecommunications equipment will decline from 6.6 to 5 percents Staging—the sequence of stepwise reductions—varies by product; the most common pattern is yearly cuts over the period 1979-87 of about one-eighth the total negotiated concession. Likewise, duties on office and computing equipment will fall from an average of 5.4 to 3.6 percent. In certain cases, the United States did not grant reductions. Not surprisingly, these were generally products where imports have caused problems for domestic manufacturers. Tariffs on color TVs, for example, will remain at the current level of 5 percent. Indeed, for items subject to section 201 escape clause findings (discussed below), of which this was one, U.S. negotiators had no authority to offer concessions.

Tariff reductions agreed to by countries which have been important export markets for American electronics firms were generally somewhat larger—though with important exceptions, Many nations have maintained considerably higher tariffs than the United States; shipments of ICs into the European Community (EC), for instance, have been taxed at 17 percent—a duty that the Europeans declined to reduce.[4] The tariff wall has been steep enough that both American and Japanese firms

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[2]]. Robertson, "Japan Offers To Speed Up Tariff Cuts," *Electronic News,* May 31, 1982, p. 1.

[3] *MTN Studies, Vol. 6, Part 5, Agreements Being Negotiated at the Multilateral Trade Negotiations in Geneva— U. S. International Trade Commission Investigation No. 332-101,* Subcommittee on International Trade, Committee on Finance, U.S. Senate, August 1979, p. 251, Computer parts, as well as peripheral equipment, can be imported duty-free from some countries as a result of the Generalized System of Preferences (GSP), under which the United States, the European Economic Community, and Japan have agreed to give preferential tariff treatment to products manufactured in developing nations. However, imports of such products into the United States under the GSP are expected to remain small. Of those that do enter this country, many originate in American-owned facilities such as Texas Instruments' plant in El Salvador.

[4] A group of nations that did not join the European Community—including Austria, Switzerland, Portugal, and several of the Scandinavian countries-have formed the European Free Trade Association, EFTA. In contrast to the EC—which has common tariffs on imports-each EFTA member sets its own duty levels. Once inside an EFTA country, however, goods can move freely within either EFTA or the EC *without* further tariffs. To keep exporters from channeling all goods through the EFTA member with the lowest duties, the Association has adopted a complex set of rules of origin. U.S. firms have sometimes charged that these rules are significant trade barriers. See *Consumer Electronics Market in Europe* (London: Frost & Sullivan, Inc., 1978), p. 95.

have built plants within the EC to avoid it. European countries did cut tariffs on a variety of other electronic components and on communications equipment—but for communications especially, nontariff barriers remain a strong impediment to trade. Average EC tariffs on office and computing equipment will drop from 6.9 to 4.9 percent. Overall, the Community's reductions will have little effect on competitiveness because American electronics products generally had significant price (or technology) advantages in the European market even at the old tariff levels. The European case is a general one: reductions in tariffs by other countries will seldom have large net effects on U.S. exports of electronics, if only because nontariff barriers have usually been more significant (nontariff measures and their impacts are discussed in more detail in a later section).

Reductions in Japan's tariffs must also be kept in perspective, The protective barriers that shielded the Japanese computer industry during its earlier years have been coming down for some time. In 1978, duties on mainframe computers were cut from 13.5 to 10.5 percent, tariffs on peripherals from 22.5 to 17.5 percent. The further reductions to which Japan agreed are no surprise given that Japanese computer manufacturers are now highly competitive in their home market. Likewise, accelerated staging for ICs is evidence of the domestic industry's strength; Japan's Government was therefore willing to grant concessions in order to reduce trade frictions with the United States. EC countries did not feel they had this option.

Although both the EC and Japan have lowered some of their tariffs on consumer electronics—but not on color TVs—this will have little effect on U.S. exports, which have not been large. In Japan, prospective importers of color TVs face, in addition to tariffs, a commodity tax levied on 17 categories of consumer goods—including automobiles, home appliances, and cameras—that adds 15 to 20 percent to the cost of imported as well as domestically produced TV receivers.

Secondary Effects of Tariffs

In addition to raising the costs of imports compared with domestic goods, tariffs can have a variety of less direct impacts on trade and production; for instance, they may stimulate local investment by foreign manufacturers seeking to avoid the extra costs borne by imports. The complex patterns of U.S. direct investment in electronics have been shaped by tariffs among many other factors. Foreign electronics firms have also invested in the United States, particularly in the consumer sector; European and Japanese firms hold majority or partial ownership positions in U.S. electronics companies ranging from producers of color TVs (Magnavox, Quasar) to those designing and manufacturing sophisticated ICs (Advanced Micro Devices, Fairchild) and computer systems (Amdahl).

Tariff barriers are seldom the sole cause of foreign investment—and may be minor factors compared with the desire to locate R&D and/or production facilities closer to markets, or to acquire state-of-the-art technical knowledge. Still, tariffs can sometimes be a major consideration, In 1978, Nippon Electric Co. (NEC) opened a semiconductor plant in Ireland specifically to be within the European Community.[5] production from this factory is not subject to the 17 percent EC duty; semiconductors can also be sold in European Free Trade Association (EFTA) nations free of tariffs. NEC, like the many American firms that had made earlier European investments, took advantage of what is in essence a single market in Western Europe. The opportunity to reduce costs in such a market, combined with the investment incentives provided by the Irish Government—which was seeking jobs—sufficed to attract NEC. Ironically, while both U.S. and Japanese firms have been able to treat Europe as. one large market, local manufacturers have seldom been able to manage this. The rather parochial attitudes of both corporations and governments

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[5] R. H. Silin, *The Japanese Semiconductor Industry: An Overview* (Hong Kong: Bank of America Asia, Ltd., January 1979], p. 161.

within the EC have hindered indigenous development. The Japanese case is quite different. There, relatively high tariffs on imports of electronics were combined with restrictions on foreign direct investment—imposed by the Foreign Investment Law of 1950 as well as stringent exchange controls—to protect the local industry,[6]

Secondary effects also arise when imports subject to tariffs are incorporated into final products. While intended to shield domestic manufacturers, say of components, these tariffs may have the unintended consequence of raising costs for firms making the final product—perhaps harming their competitiveness and eventually leading to demands for further protection. Protection extended to the American steel industry, for instance, has increased costs for U.S. automobile companies.

In the electronics industries of some countries tariffs and other trade barriers have created incentives for internal production and vertical integration. When selecting vendors, companies weigh prices along with such factors as quality and delivery schedules. High product manufacturers to integrate backward, particularly where domestic suppliers have been protected because they were too weak to compete effectively, Such factors have been at work in both the EC and Japan, where many firms whose primary end products have been computers or communications systems have established internal semiconductor operations. The tendency has been especially pronounced in Japan, where American semiconductor products were not as freely available as in Europe,

In the longer term, vertical integration—where semiconductor facilities produce for internal as well as external sales—could lead to scale economies that smaller U.S. merchant firms may not be able to match. While American firms have had the advantage in flexibility compared with their integrated Japanese competitors, and in products where innovative design has been critical for market success, they-have not fared so well in mass-produced commodity-like products such as memory circuits. To the extent that such patterns continue, they will imply that the tariff walls which protected Japanese semiconductor manufacturers for so many years contributed to their eventual competitive success by making it expensive for these companies to import for their own needs.

On the other hand, price competition fueled by imported components has probably benefited U.S. electronics firms that manufacture final products. Sectors like consumer electronics and computers have gained from lower cost and better quality components—the consequences of heightened competition. Widespread foreign sourcing of components by American manufacturers points to the potential conflicts of interest with respect to import restrictions that often arise between purchasers and suppliers.

Tariff Treatment of Offshore Manufacturing

American-made components incorporated in imported goods have been exempted from tariffs for almost 200 years. The current version of the law is embodied in items 806.30 and 807.00 of the Tariff Schedules of the United States. Under specified conditions, shipments from overseas plants benefit from duty-free treatment of the value of materials or parts sent abroad for processing or assembly and then returned to the United States. Without this provision, re-imports after offshore assembly would be subject to tariffs on their full value. Because the tariff exemptions in items 806 and 807 lower the cost of overseas production relative to the no-exemption case, they implicitly encourage American corporations to split production between domestic and foreign plants. U.S. electronics firms began investing in production facilities in developing countries as early as the 1950's. While central to cost competition among TV and semiconductor manufacturers, offshore production has been a secondary element in the strategies of U.S. firms making computers and business machines. Although labor unions have tended to oppose 806/807 on grounds that they encourage "exports" of jobs, the evidence concerning the actual extent to which this occurs remains ambiguous (see app. B).

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[6] *United States—Japan Trade: Issues and Problems* (Washington, D.C.: General Accounting Office, September 1979), p. 27.

The 806 and 807 provisions differ in scope. Item 806.30 is restricted to metallic articles, sent abroad for processing, which undergo still more processing after their return to the United States. Silicon wafers qualify under the typical manufacturing sequence outlined in chapter 6. Item 807.00, on the other hand, requires neither that the articles be metallic, nor that they be further processed upon their return. However, there are three other conditions, not required under 806, 30: 1) the items must have been exported in a state ready for assembly, with no additional fabrication needed; 2) they must not lose their physical identity; and 3) they must not have been advanced in value or improved in condition except through the assembly process.[7] By value, the largest category of 807 imports consists of automobiles incorporating parts originating here. Other major items include clothing made from fabrics cut in the United States. Under both 806 and 807, tariffs are levied at rates equal to those for equivalent articles made wholly overseas but are based only on the value added abroad.

Of the two statutes, 807 accounts for the greater value of imports by far, in electronics as in other product categories. Total value of all 807,00 imports in 1980 was $13.8 billion, compared with $237 million for 806,30.[8] Total value of 806.30 electronics imports in 1980 was only $55 million, continuing a steep decline from more than $250 million 3 years earlier.[9] The major electronics imports under both statute items are semiconductors and parts, some of which qualify under either provision, Item 807.00 imports of semiconductor devices increased nearly threefold during the period 1978-80, reaching $2,45 billion—something over three times the value of color TV shipments entering under 807.[10] Imports under 806.30 are being replaced by those under 807.00 because of the 806 requirement for further processing, Offshore plants owned by American semiconductor firms have been extending their operations downstream, shipping completed rather than semifinished ICs back to the United States.

Semiconductor devices and TVs are not the only electronic products to enter under 806 and 807. Modest volumes (in dollar terms) of capacitors and vacuum tubes come in under 806.30, Under 807,00 the list is much longer; it includes office machinery, communications apparatus, watches, stereo and high-fidelity equipment, and many types of components.

As the size of **806/807 flows** indicates, the tariff exemptions have had significant impact on the global structuring of the American electronics industry. Companies have rationalized production by shifting manufacturing to parts of the world where costs are lower. In only a few cases have the tariff exemptions been deciding factors, but they have certainly made it easier for U.S. firms to move abroad. As discussed in chapter 9 and appendix B, the effects on employment of such transfers are difficult to evaluate, Depending on the assumptions, they can be negative or positive. Even so, in at least some cases the choice may not be production here versus production there, but production there or no production at all.

In any event, much of the electronics industry today is globally integrated-a trend to which items 806.30 and 807.00 have contributed. The consequences span a considerable range, U.S. firms have retained competitiveness in product lines where they would otherwise face marked cost disadvantages. Less-developed countries have been helped to industrialize, while outward flows of American technology have been accelerated. Some domestic employment opportunities may have been sacrificed. From a policy perspective, many of the impacts by now appear irrelevant, The laws have been on the books in one form or another for decades, and are not likely to be rescinded, As tariff levels continue to come down, such exemptions become more marginal to decisions on production locations; indeed, wage levels rather than tariff exemptions have nearly always been the determining factor.

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[7] *Imports Under items /?06.30 and 807. 00 of the Tariff Schedules of the United States, 1977-80 (Washington, D.C.:* U.S. International Trade Commission Publication 1170, July 1981], p. 4.

[8] Ibid., p. B-2.

[9] Ibid., pp. B-46, B-48. The duty-free values run about two-thirds of the total value.

[10] Ibid., pp. B-15, B-17. Color TV imports under item 807.00 can be found in ch. 4, table 14.

Other Tokyo Round Agreements

Ten distinct understandings—comprising the Multilateral Trade Agreement (MTA)—came from the Tokyo Round negotiations. Some of these, each covering a particular subset of trade issues, are irrelevant to electronics—e.g., that on dairy products. In other cases, little of substance is changed under the new language; this is the case for the antidumping and subsidies/countervailing duty provisions discussed in later sections.

Other MTA provisions pertinent to international trade in electronics deal with:

- government procurement,
- technical barriers to trade, and
- import licensing procedures.

These agreements *could* yield dividends in the form of increased exports by U.S. electronics manufacturers, but are not likely to have much effect on imports of electronics products. "Could" because the rather general nature of the MTA makes infractions difficult to pinpoint. A series of test cases is likely, focusing at first on more blatant departures from the intentions of the codes.

The first of the three provisions listed above, that covering *government procurement,* calls in essence for nondiscriminatory treatment of foreign firms seeking access to government purchases. That is, foreign and domestic bidders are to be treated the same. Exceptions related to military sales and national security will doubtless be interpreted broadly. The stipulations—which cover purchases above about $200,()()()-are" rather far-reaching; they include, for example, state and local as well as national governments. On the other hand, developing countries are not bound by this part of the MTA, and virtually none have signed it.

The government procurement agreement also addresses matters such as technical specifications and notification of bidders, which have considerable impact in practice. Technical specifications are, where possible, to be based on international performance standards, Bidding is to be opened to the broadest possible group of qualified suppliers, the agreement stating that invitations to bid should allow adequate time for foreign companies to respond, Obviously, considerable latitude remains for hindering foreign respondents, but grievance machinery is to be established for handling the complaints of parties alleging discrimination.

The MTA procurement code could have far-reaching effects if it functions as written. The governments of industrialized nations are major customers for many types of goods; if the provisions are fully implemented, these markets would be opened to foreign suppliers. In actuality, this is not likely to happen very rapidly, Imagine the repercussions in the United States if the General Services Administration bought 5,000 Toyotas for the Federal motor pool.

The second of the listed agreements—that relating to technical *barriers* to trade—tackles, or presumes to tackle, the collages of policies used by governments in many countries to reduce import volumes via discriminatory technical standards or regulations. This code is *not* tightly written, and leaves a number of loopholes that could easily be employed to evade meaningful compliance, For instance, governments can promulgate regulations or product standards different from international standards for national security reasons, to prevent deceptive practices, to protect health and safety, to preserve the environment, and finally to help with "fundamental technological problems." Such rationales have been marshaled in the past to defend regulations that discriminate against foreign firms and, without much question, will continue to be so used in the future. This agreement, it is fair to say, is long on rhetoric but short on substance.

With the exceptions noted above, technical regulations and standards are to be written so as not to discriminate among potential suppliers or be undue impediments to international trade. Where a country's regulations cannot be harmonized with international standards, GATT and other interested parties are to receive full notification of differences. Likewise, laboratory or other testing procedures should not place foreign manufacturers at a disadvantage, Such provisions indicate that the parties to the MTA were at least in principle willing to accept the notion of relatively free access for foreign suppliers.

Whether or not the MTA code on technical barriers will have significant effects on commercial practices remains to be seen, In terms of U.S. exports, the extent to which standards and regulations elsewhere impede shipments has not always been clear—leaving aside such well-known examples as the procurement practices of NTT (Nippon Telegraph and Telephone) in Japan, U.S. exporters, in electronics as in other industries, have generally attempted to sell goods abroad that are as close to their domestic production as possible. In some cases, exports have been stifled not by foreign standards but by the unwillingness of American firms to cater to foreign market conditions.

The third agreement relevant to trade in electronics is that on *import licensing.* The text sets forth rather general stipulations intended to simplify procedures associated with permits and licenses, making it more difficult to use licensing procedures as nontariff barriers—and especially to single out and discriminate against particular countries. Because import quotas or Orderly Marketing Agreements frequently involve licensing requirements, companies attempting to gain or hold market share when such quotas are in effect have a special interest in equitable treatment, Perhaps the most important provision in the import licensing code states that any enterprise fulfilling the importing country's legal requirements "shall be equally eligible to apply and be considered for a license. " The only exception relates to applicants in developing countries, who are given preference, Governments signing the MTA also agree, in awarding licenses, to take into account: 1) economic order quantities or lot sizes, 2) past import performance of the applicant, and 3) "reasonable" distribution of licenses to new importers.

This brief review of MTA provisions points out the central difficulty now faced by international trade negotiators—nontariff barriers. The Tokyo Round was the first to comprehensively address such questions. As a result, the MTA is wide ranging—not surprising given the immense complexity and diversity of nontariff barriers in various parts of the world-and should be regarded as no more than a first step. It represents an attempt to broaden the common ground among participating nations, moving beyond questions of tariffs and other direct impediments to trade while holding to the premise that has guided negotiations since the original Reciprocal Trade Agreements Act, before World War II—that free and open trade is good for all concerned, with the distribution of benefits improved by concessions to less-developed nations.

The ultimate impact of the Tokyo Round on nontariff barriers, and on future trading patterns, remains to be seen. As a statement of intentions, the agreements—including the new subsidies code—are commendable. From an operational perspective, the verdict is less clear. Governments seeking politically acceptable reasons for eliminating some of their regulatory clutter can begin; countries intent on maintaining trade protection will not find themselves severely constrained. The course of the world economy will also play a role; governments are loathe to reduce nontariff barriers during periods of stagnation.

In the context of electronics, the Tokyo Round agreements have already had some effect. For example, the U.S. Government has been able to convince Japan to soften its stand on exempting NTT from the provisions of the new procurement code. NTT, a major purchaser of high-technology communications and switching equipment, is not—strictly speaking—an agent of the Japanese Government. But its exclusion from the government procurement agreement created a whirlwind of protest from spokesmen for U.S. industry, who believed the exemption to be symbolic of continuing efforts by Japan to evade the intent of the MTA while subscribing to its language, After prolonged discussions, the Japanese Government persuaded NTT to open its procurements to foreign bidders.[11] Thus far, there

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[11] See, for example, T. J. Curran, "Politics and High Technology: The NTT Case," *Coping With U.S.-Japanese Economic Conflicts*, I. M. Destler and H. Sato (eds.) (Lexington, Mass.: Lexington Books, 1982), p. 185; U.C. Lehner, "U.S.—Japan Phone Gear Pact Totters," *Wall Street Journal*, July 27, 1983, p. 26.

have been few foreign sales to the communications giant.

In electronics and other industries, the eventual consequences of the MTA for nontariff barriers will depend on factors such as awareness among exporting firms of the possibilities opened by the agreements, Without this awareness, and without the pressure on foreign governments that such awareness can generate, the agreements will have less effect. Equally important will be attitudes of officials in importing countries who have responsibilities for monitoring and enforcement.

Dumping

The practice of dumping—selling goods in export markets at less than their home market price, or under some circumstances at less than cost—is one of the unfair trade practices restricted by GATT. In essence, dumping is a form of price discrimination; it is proscribed in export markets for the same reasons as in domestic markets—because price discrimination can be used to drive out competitors and construct monopolies, In recent years, as American industries have faced stiffer competition from imports, the number of dumping complaints has climbed—from 11 in 1974 to 44 in 1982.[12]

In electronics, most of the dumping cases have involved consumer products; there have been lengthy proceedings concerning TV receivers, as well as products like CB radios. Antidumping complaints were among the first attempts by American TV manufacturers to stem the rising tide of imports in the late 1960's and early 1970's. As other portions of the industry face increasing import competition–not only from Japan, but in lower technology products from developing countries–the number of filings may continue to grow. In recent years, American semiconductor firms have frequently accused Japanese manufacturers of dumping, but have not filed formal charges.

The Law and Its Administration

U.S. antidumping law is now contained in two statutes: the Revenue Act of 1916 and the Trade Agreements Act of 1979. While the 1916 Act contains strong sanctions against predatory dumping—that intended to eliminate competition and increase market power—its application is narrowly circumscribed. An action filed in consumer electronics under this statute remained before the courts for some years, but more generally the stipulation that the plaintiff demonstrate predatory intent makes it unlikely that the Revenue Act of 1916 will form the basis of future dumping findings.[13] This leaves the Trade Agreements Act of 1979 as the primary mechanism for antidumping enforcement. The 1979 Act modified U.S. law to conform to the revised GATT antidumping code negotiated during the Tokyo Round.[14] Although the Antidumping Act of 1921 was repealed and the Tariff Act of 1930 amended, with a few exceptions the substance of the changes was minor.

According to U.S. law, dumping is the sale of foreign goods in the United States at less than "fair value. " The 1979 Act transferred responsibility for less than fair value determinations to the Department of Commerce; earlier, the Department of the Treasury had investigated dumping complaints and made fair value determinations. The new act also shortened the timetable for investigations, and changed the definition and determination of fair value somewhat; fair value had formerly been defined as foreign market value–basically

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[12] Information from Department of Commerce, International Trade Administration. During 1982, 136 countervailing duty cases were filed as well.

[13] U. S, *Administration of the Antidumping Act of 1921* (Washington, D. C.: General Accounting Office, Mar. 15, 1979).

[14] "The Agreement on the Implementation of Article IV of the General Agreement on Tariffs and Trade, " *Agreements Negotiated Under Section 102 of the Trade Act of 1974 in the Multilateral Trade Negotiations Submitted on June 19, 1979, for Approval by Congress* (Washington, D.C.: U.S. Government Printing Office, July 1979).

the selling price in the country of origin, or, where such information was not available (the goods might not be sold at home), the selling price in third countries. Prices formed the basis of comparison; the law allowed sales at less than cost provided the manufacturer also sold below cost elsewhere. If goods were sold *only* in the U.S. market, the old law specified that a "constructed value" based on estimated production costs be determined, In essence, current law extends the use of cost-based constructed values to cover fair value determinations where goods are being sold below cost either at home or in third-country markets.[15] Foreign firms that, for whatever reasons, sell below cost at home cannot do so in the United States without risking dumping convictions, even under circumstances where this would not otherwise be judged an unfair competitive tactic—e.g., when cash flows remain positive even though full costs might not be covered. Earlier, sales at less than cost constituted dumping only in narrower circumstances, This provision of U.S. trade law, which is not consistent with definitions of dumping in most other countries, has meant that the Department of Commerce—now responsible for antidumping enforcement—often finds itself estimating overseas production costs, an exercise fraught with uncertainties and possible distortions.[16]

Statutory relief is available only when sales in the United States at less than fair value are found to cause or threaten to cause "material" injury to a U.S. industry, or to materially retard the establishment of a domestic industry.[17] Responsibility for establishing injury or threat of injury rests with the U.S. International Trade Commission (ITC)--an independent agency of the Government—which weighs factors such as actual or potential declines in output, sales, market share, profits, and employment. In the usual course of events, the ITC staff prepares an analysis based on such considerations, after which the six commissioners (appointed by the President and confirmed by the Senate for 9-year terms) vote—each making their own judgments as to injury or threat of injury. Commissioners, singly or jointly, prepare written opinions that explain their reasoning, If a majority of Commissioners find injury, the remedy is assessment of a special dumping duty intended to equalize prices between home country sales and those in the United States. These antidumping duties are assessed and collected by the Department of Commerce (formerly Treasury).

The Color Television Case

The long and complex history of antidumping complaints in consumer electronics—still not fully resolved—was no doubt one of the reasons for provisions in the Trade Agreements Act of 1979 transferring responsibility for enforcement from the Department of Treasury to Commerce; advocates of stricter administration of the law felt that Treasury officials had been less than diligent, in part because of the Department's traditional commitment to open trade.

Complaints that Japanese firms were dumping TVs in the United States began in 1968 with a filing by the Electronic Industries Association (EIA). This initiated what has perhaps been the lengthiest case in the history of U.S. antidumping law.[18] The EIA complaint alleged that the Japanese were able to maintain low prices in the United States for predatory purposes because prices in Japan were kept artificially high by import barriers. The Japanese manufacturers acknowledged that retail prices were higher in Japan, but held that the differences were caused by higher taxes and by a complex and costly system of marketing and distribution.

It took 3 years for the Department of Treasury to complete its investigation, finding—in March 1971—that the Japanese had indeed

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[15] Section 773, Trade Agreements Act of 1979. Also see J. Sklaroff, "United States Antidumping Procedures Under the Trade Agreements Act of 1979: A Crack in the Dam of Nontariff Barriers," *Boston College International and Comparative Law Review*, vol. 3, winter 1979, p. 223,

[16] "Commerce, ITC Officials Discuss Continuing Problem Areas in Cases," *U.S. Import Weekly*, Sept. 29, 1982, p. 800.

[17] Section 731, Trade Agreements Act of 1979.

[18] The events are summarized in *Television Receiving Sets From Japan* (Washington, D.C.: U.S. International Trade Commission Publication 1153, June 1981), pp. A-4 to A-12.

Photo credit RCA

Color TVs undergoing long-term tests

dumped TVs in the American market. The case then went to ITC for determination of injury. Later that year, ITC returned a positive finding, concluding that the dumped TVs had injured the U.S. industry and clearing the way for the assessment and collection of antidumping duties–at that time still the responsibility of Treasury. Importers of TVs from Japan were required to post a 9 percent bond toward these duties.

Fixing the size of the antidumping duties—intended to elevate prices of imports to the level of TV prices in Japan–proved another lengthy process. The wholesale price information provided by Japanese manufacturers was judged inadequate and in some cases false, leaving Treasury without a means of calculating the duty rate. Eventually, the Department resorted to constructed value estimates based on commodity taxes collected by the Japanese Government.

An extraordinary number of claims and counterclaims accompanied the efforts of Treasury and the Customs Service to determine and collect these duties. Not only were American manufacturers of TVs and components involved, but also the unions representing their employees. Arrayed on the other side were the Japanese manufacturers, their U.S. representatives, and the American firms which had been importing TVs from Japan—mostly large retailers such as Sears and J. C. Penney. The protracted course of the disputes also mirrored conflicts within the Federal Government—e.g., between the Customs Service and other parts of the Treasury Department.[19] By 1980, only about $13 million in dumping duties had been collected. Moreover, assessment of duties for 1975 and later years has never been completed, pending final resolution of disputes covering earlier periods. Not only have duties been at issue, but also civil penalties for alleged illegal rebates to importers as a means of circumventing the added duties.

With the transfer of antidumping enforcement to the Department of Commerce in 1980, a new agreement was negotiated with importers. Commerce agreed to accept a total of about $75 million, rather than pursuing in the courts duties which the Department estimated at nearly $130 million for the period 1971-79. The EIA—original plaintiff in the dumping proceedings—and its allies then claimed that the actual dumping liability was $700 million or more, and challenged the Commerce Department's proposed settlement in the courts; a 1981 decision allowing the settlement to stand was appealed to the Supreme Court. Late in 1982, the Supreme Court denied the appeal; evidently Commerce's negotiated settlement can now proceed.[20]

This 15-year history—which has still not come to an end, and during which the complexion of the American consumer electronics industry changed irreversibly—dramatizes the inadequacies of U.S. antidumping procedures as a means of relief from "unfair" import competition. The lessons hold for other industries as well-witness the example of steel. Not only is enforcement slow, complex, and susceptible to delay by various parties, but the legal definitions of dumping–which, in the United States as in many other countries, predate GATT--seem remote from the realities of business competition, No one argues that predatory practices should not be outlawed, but what relevance, for example, does the relationship of home market price to export price have to predatory pricing? Would Japanese firms for a dozen years or more willfully cut the prices they charge in the United States below those the market would otherwise set because in some still longer term they seek to monopolize the market? Does selling imported goods at less than cost—now effectively prohibited by the 1979 Trade Act—always constitute an unfair business practice? Still, regardless of how these questions are viewed, the fact is that Japanese firms were found under U.S. law to have dumped TVs. Injury to the domestic industry was established. *American manufacturers of TVs have been entitled to trade protection but have not received it.* The uncertainty and confusion created by the these long and convoluted proceedings has probably done more damage to the industry than the dumping itself.

The modifications to U.S. antidumping law incorporated in the Trade Agreements Act of 1979 address some of the procedural problems illustrated by the TV case. Not only has responsibility for dumping determinations and the assessment of duties been transferred from Treasury to Commerce (by Executive Reorganization Plan No. 3, effective Jan. 1, 1980), but the ITC injury investigation now begins immediately, rather than awaiting a positive finding of dumping. The concurrent investigations —for which the act sets relatively short time schedules—are intended to speed the process. If future dumping investigations are shorter because of the 1979 Act, this will limit uncertainties and disruptions, reducing costs for both defendants and plaintiffs. This would also make it more difficult for domestic firms to use dumping proceedings in "strategic" fashion to deter foreign competitors from entering U.S. markets; dumping complaints can discourage market entry through the threat of future penalties as well as by imposing legal costs on defendants.

Prospects for Dumping Actions Elsewhere in Electronics

Antidumping proceedings-and other trade actions discussed later—have been major events in U.S. consumer electronics markets

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[19] R. Wightman, "Charges U.S. Blocks $400M Duty on Japan TVs: Government Infighting Seen," *Electronic News*, Aug. 17, 1978.

[20] "Review is Denied in Zenith's Action Challenging TV Dumping Duty Settlement," *U.S. Import Weekly*, Oct. 20, 1982, p. 72.

but rare in semiconductors or computers. The single case involving semiconductors, in 1972, led to a finding of dumping but not injury. Imports of computers into the United States have been at low levels, leaving little reason to expect complaints. If computer imports were to rise and dumping to be alleged, less than fair value pricing would be difficult to establish, at least for large systems. The complexity of such systems, the difficulty of establishing comparability in performance, and the high R&D expenses that must be borne, complicate pricing comparisons. Moreover, selling prices for data processing systems often include service or software charges that are hard to isolate. pricing structures in the computer market—particularly the establishment of "quality-adjusted" pricing—have already created formidable difficulties in purely domestic antitrust actions where predatory pricing has been at issue.[21] Less than fair value determinations based on foreign market prices or constructed values would be still more troublesome, at least for mainframes. The problems are not so intractable for small systems and peripherals, where significant import penetration is in any event more likely, while personal computers sold at retail could be treated much like other consumer products.

The characteristics of the semiconductor industry also work against antidumping proceedings. Large-scale ICs—including computer memory chips, where import sales have increased rapidly—experience relatively short product lifetimes, Coupled with the large economies of scale in IC production, and the importance of yields, deep market penetration—with resulting cost advantages from the learning curve—might well occur before dumping proceedings could be resolved, even under the accelerated timetable of the 1979 Act; moreover, the same factors lead to advance pricing—which is not in general illegal. Therefore, while antidumping actions may continue to be filed in more mature sectors of the electronics industry—e.g., consumer products, where the technology is relatively stable and price competition based on low production costs intense—dumping allegations in high-technology sectors seem less likely to escalate from verbal attacks on imports to formal complaints. *In high-technology industries, products can be obsolete by the time dumping actions have been resolved.*

Photo credit Perkin-Elmer

Plasma etching system used in semiconductor fabrication

Subsidies and Countervailing Duties

Where along the spectrum from advertising a country's goods to giving rebates to exporters does promotion turn into subsidy? Or is that no longer a relevant question? Export subsidies in the form of credits or guarantees extended to purchasers through institutions such as export-import banks have become accepted tools of industrial and trade policy. International

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[21] See, for example, R. Michaels, "Hedonic Prices and the Structure of the Digital Computer Industry," *Journal of Industrial Economics*, vol. 28, March 1979, p. 263,

agreements limit interest rates—to levels that can be below the market rate but not too far below. ” In such forms, export subsidies have become one of the most common nontariff measures affecting international trade; subsidies with domestic objectives also have consequences for exports,

Although important in capital goods industries, neither export financing nor export promotion have played major roles in electronics outside of telecommunications. ’s In contrast, subsidies with ostensibly domestic objectives have become a major tool by which governments promote their electronics industries; these have less direct and visible effects than export credits, making them difficult to countervails or to negotiate over, While revisions to the GATT subsidies code were a central item on the agenda for the Tokyo Round negotiations, little progress was made; the changes were basically matters of procedure. Distinguishing export from domestic or internal subsidies—the latter of many forms but universally employed—is central to a workable code but fraught with practical difficulties, Measures adopted by governments that have the effect of subsidizing domestic electronics industries range from grants for basic research to regional development incentives. Because *any* such policy, even relocation assistance for displaced workers, could in principle help firms to export–by cutting costs, raising profits, or improving technical capability—the dividing line between measures that most people would agree are domestic subsidies (e. g., R&D support) and what are clearly export subsidies (e. g., low-interest loans to foreign purchasers) will always be ambiguous. As nations pursue increasingly sophisticated industrial policies, it becomes still more difficult to draw that line.

Countervailing Duty Law and Its Administration

GATT and U.S. law provide remedies paralleling those for dumping where American firms and industries are injured by export subsidies. In dumping cases, private firms set the prices at issue, while prices are distorted by direct or indirect government action in the case of subsidies. Importing nations then impose countervailing duties for essentially the same purpose: to eliminate price differentials created by the unfair trade practice. In principle, the countervailing duty is set at a level that balances the effect of the subsidy. In practice, the administration of countervailing duties in the United States is even more problematic than for antidumping duties,

U.S. countervailing duty legislation is found in two statutes—the Tariff Act of 1930 and the Trade Agreements Act of 1979. As in the case of antidumping law, responsibilities in countervailing duty cases are split—the Department of Commerce investigates foreign export subsidies (this responsibility was again lodged with Treasury until 1980); ITC determines injury. If ITC votes any of three findings—injury to a U.S. industry, threat of injury, or impediments to the establishment of a new U.S. industry—then a countervailing duty equal to the net value of the subsidy is to be imposed on the imports.

Under the 1979 Act, the test turns on “material” injury—including actual or potential declines in output, sales, market share, cash flow, profits, productivity, capacity utilization, employment, wage levels, or the ability to raise capital.[24] In earlier years, U.S. law did not require that injury be found before countervailing duties could be imposed; the existence of

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[22] When Canada proposed a financing package for New York City subway cars at an interest rate of 9.7 percent—well below the agreed international minimum of 11.4 percent—the Canadian Government defended this as necessary to meet France's offer. See "Reagan Decides U.S. Should Not Match Financing on New York Subway Car Sale," *U.S. Import Weekly*, July 14, 1982, p. 448.

[23] For a discussion of export financing, see R. E. Shields and R. C. Sonksen, *Government Financial Institutions in Support of U.S. Exports* (Washington, D.C.: Center for Strategic and International Studies, Georgetown University, September 1982). A more general review of U.S. export policies is *Report of the President on Export Promotion Functions and Potential Export Disincentives* (Washington, D.C.: Department of Commerce, September 1980). Also see the discussion of alternative industrial policies for the United States in the next chapter, where questions of export promotion and their effects on trade competitiveness are discussed in more detail.

[24] Section 771, Subtitle D, Trade Agreements Act of 1979

subsidies was enough. Although differing from GATT language, this provision had preceded the establishment of GATT and been retained under a grandfather clause. The original law had been passed before the turn of the century, but no countervailing duty was imposed by the United States until 1967.

The Question of Indirect Taxes

What then is a "subsidy" under GATT and/or U.S. law? As might be expected, the definitions have been controversial. There has been a major legal action in consumer electronics, the case hinging on whether exemptions or rebates of indirect taxes on exported goods constitute a subsidy, Both the old and new GATT subsidies codes permit indirect taxes—e.g., value-added taxes—to be rebated, but not direct taxes. (Direct taxes—such as corporate income taxes—are levies based on factors of production like capital or labor, indirect taxes are those levied on the product itself.) The assumption underlying this rule is that indirect taxes can be easily included in prices and passed along to consumers, while direct taxes cannot (they depend, for instance, on annualized profit levels). If the full indirect taxis passed through to the purchaser, profits to the seller are unaffected. Under these circumstances, a rebate or exemption of such taxes on export sales would not constitute a subsidy under the usual definitions.

Compared with its trading partners, the United States relies less heavily on indirect levies—sales, excise, and value-added taxes—and more heavily on direct taxation, primarily of corporate and personal income. Many European nations impose a value-added tax (VAT) at each stage of the production process. In Japan, consumption taxes of 5 to 30 percent apply to items such as automobiles, electrical appliances (including TVs), and a variety of luxury goods, while excise taxes apply to other classes.[25] Under GATT rules, countries that levy such taxes can exempt or rebate them as they wish. The United States has less latitude than nations with extensive arrays of indirect taxes.

After the Trade Act of 1974 had been passed, Zenith challenged rebates of Japan's commodity tax on exported TVs under the act's provisions. The American manufacturer sued the Department of Treasury, claiming that rebated indirect taxes in Japan constituted subsidies and that Treasury had failed to properly interpret the new law.[26] Treasury countersued, claiming that decades of acceptance by all parties of its past practices had effectively ratified these practices, Four years later, in 1978, the Supreme Court upheld Treasury's position, ruling that rebated commodity taxes do not constitute subsidies under U.S. law.

Countries with commodity or value-added taxes generally levy them on imports as well as domestic production. Thus, within a country having indirect taxes the impacts are, at least in principle, neutral: both imports and domestic goods are subject to a tax based on their value. However, matters are not really this simple. Exports *from* a nation like the United States that relies on direct taxation may be burdened with higher selling prices reflecting higher corporate taxes, thus at a disadvantage in markets where indirect taxes are the rule (countries with substantial revenues from indirect levies normally tax personal and corporate income at correspondingly lower rates). Furthermore, foreign manufacturers shipping to the United States may reap benefits: after receiving rebates on indirect taxes at home, such firms face no compensating border tax adjustments when their goods enter the United States—though they generally must pay tariffs. They are free to sell in a market where the prices charged by domestic firms may well have to cover higher corporate taxes. As a result, *nations that rely heavily on indirect taxes can be presumed to have advantages in international* trade—although the size and

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[25] *Export Stimulation Programs in the Major Industrial Countries: The United States and Eight Main Competitors,* Congressional Research Service, prepared for the Committee on International Relations, [J, S. House of Representatives, Oct. 6, 1978, p. 66.

[26] D. A. De Rosa, J. M. Finger, S. S. Golub, and W. W. Nye, "What the 'Zenith Case' Might Have Meant," *Journal of World Trade Law,* vol. 13, January-February 1979, p. 47.

significance of the advantages can be difficult to judge,

VAT systems have sometimes been suggested for the United States, in part because of their potential for stimulating exports (assuming corporate taxes were reduced at the same time). The effects of such a shift in U.S. tax policy on specific firms and industries would depend on factors such as:[27]

- compensating reductions in income taxes, as well as the overall tax liabilities (and profitabilities) of the firms in question;
- the extent of vertical integration characteristic of the industry, along with the place of particular firms in the chain of production;
- fractions of revenues stemming from exports;
- price elasticity of demand for each product affected; and
- design and implementation of the system for collecting the VAT or other indirect tax and (optionally) rebating it for exported goods,

While the merits of VATS have thus far not been seriously debated in this country, since 1971, U.S. law has provided a mechanism—the Domestic International Sales Corp. (DISC)—intended to put American exporters on a more even footing with manufacturers in countries having indirect taxes. DISCs—subsidiary corporations whose activities are confined to selling goods in export markets—permit U.S. firms to defer a portion of tax liabilities from profits on overseas sales. Several thousand DISCS have been established, primarily by larger American corporations with substantial volumes of export business. In recent years, more than half of all U.S. exports have been channeled through DISCs.[28] For exports of electronics, however, the proportion is much lower—perhaps in the range of 10 percent.[29]

Other countries have registered complaints with GATT against the DISC mechanism, arguing that it functions as an export subsidy but does not qualify as an exemption from indirect taxes.[30] Despite a finding by GATT that DISCS do constitute subsidies, no country has yet imposed countervailing duties on U.S. exports, nor has the United States offered to repeal the legislation that permits DISCS. (Recently, the Reagan administration has proposed an alternative to DISCS, as pointed out in the next chapter.)

Other Unfair Practices

Section 337 of the Tariff Act of 1930—which was amended in 1979 but has seldom been used—deals with unfair competition in international trade not already covered by anti dumping or countervailing duty laws. Most of the complaints filed under section 337 have concerned patent infringements, as in Apple's complaint to ITC over counterfeit computers, but in yet another case concerning imported TV receivers, two American manufacturers accused Japanese firms of illegal predatory pricing practices—specifically, of cutting prices in the United States below costs in an effort to drive American firms from the market.[31] When imports are involved, price-cutting complaints are usually filed under antidumping or countervailing duty statutes, but section 337 actions can also be brought if conspiracy or intent to monopolize is alleged. In this instance, ITC proceeded with a section 337 investigation even though the Department of Treasury

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[27] See *A Value-Added Tax for the U. S. ? Selected Viewpoints* (New York: The Tax Foundation, Inc., 1979).

[28] *Export Stimulation Programs in the Major Industrial Countries*, op. cit., p, 319,

[29] This estimate is based on a survey of 325 member firms by the American Electronics Association. Because most of the members of the Association are smaller companies, it probably understates the actual fraction for electronics. See *Capital Formation, Part I*, hearing, Senate Select Committee on Small Business, Feb. 8 and 10, 1978, p. 53.

[30] See J. M. McGuire, "The GATT Panel Report on Domestic International Sales Corporations: Illegal Subsidy Under GATT," *International Trade Law Journal*, vol. 3, 1978, p. 387,

[31] ITC Investigation 337-TA-23, filed Jan. 15, 1976.

claimed exclusive jurisdiction under countervailing duty law. The theory behind the complaint was that assistance given Japanese TV manufacturers by their government—though not necessarily bounties or grants within the definitions of countervailing duty statutes—might still constitute a conspiracy to restrict trade, an unfair practice under section 337. The case was terminated when ITC issued consent orders prohibiting predatory pricing and special purchase inducements for color TVs. Future section 337 complaints by American electronics firms are perhaps most likely as attempts to expedite relief, given the slow pace of past antidumping and countervailing duty investigations.

Quantitative Restrictions and the Escape Clause

Over the past two decades, tariff levels have been reduced by international agreement to the point that, for many goods and in many advanced economies, they are no longer a major factor in market outcomes. Nowhere is this movement plainer than in electronics. With tariffs largely closed off as a legitimate vehicle for protection, industries exposed to the rigors of international competition—together with their employees and political supporters—have sought other forms of relief. Along with many other nations, the United States has increasingly fallen back on import quotas. By whatever name—Orderly Marketing Agreement, Voluntary Restraint Agreement—quotas limit shipments originating in particular countries. Under GATT, unilaterally imposed quotas are explicitly disallowed except to correct persistent balance of payments deficits, and then are to be temporary. Nonetheless, quotas have proliferated—typically on a negotiated bilateral basis–with the path often cleared by “escape clause” actions permitted under GATT. An outline of the escape clause mechanism in U.S. law—section *201* of the Trade Act of 1974—follows the discussion below of quotas on color TVs.

Orderly Marketing Agreements for Color Television Imports

The only direct quotas on U.S. electronics imports have been termed Orderly Marketing Agreements (OMAs). Like the earlier Voluntary Restraint Agreements on steel shipments, or the Japanese automobile quota—in appearance, the result of unilateral action by Japan rather than negotiations between two governments—exporting nations have entered into OMAs of their own volition.

The United States negotiated its first OMA covering imports of color TV receivers in 1977 with Japan, Under the conditions, Japan agreed to limit shipments of color TVs to this country for a 3-year period; no more than 1,560,000 complete sets and 190,000 incomplete sets were allowed each year. Except for being the outcome of bilateral negotiations, the color TV OMA was equivalent to a quota of the type outlawed under GATT.

The stop-gap nature of this first OMA—covering a single troublesome exporter—was illuminated when Taiwan and South Korea took up the slack (ch. 4). It quickly became necessary to extend quotas to these two countries if the U.S. industry was to be effectively shielded. OMAs were negotiated with Taiwan and South Korea late in **1978,** to expire at the same time as the Japanese quota—June 30, 1980. Imports from Taiwan were limited to roughly half a million units, plus twice as many incomplete sets (without picture tubes), over the year-long period beginning July 1, 1979. Korean shipments were restricted to about 300,000 TVs.[32] This extension to other countries illustrates a common failing: when initially directed against a single exporter, quotas must often be widened as new competitors step in—the series of bilateral agreements under the umbrella Mul-

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[32] *Television Receiving Sets From Japan,* op. cit., p. F-2. Several adjustments were made over the course of the agreements.

tifiber Agreement being the classic case. Note that table 14 in chapter 4 shows imports from Mexico more than doubling over the period 1976-80—during which time the OMAs with Japan, Korea, and Taiwan took effect—while shipments from Singapore increased more than seven times. Virtually all the imports from Mexico enter under item 807.00 of the Tariff Schedules–meaning they are shipments by American-owned firms—while both 807 and non-807 imports from Singapore have gone up sharply; Singapore now ships more TVs to the United States than Korea did at the time the OMA with that nation was negotiated (table 14). Might there be pressure for quotas with Singapore at some future time? Or other Asian countries? If so, could unrestricted Mexican shipments be justified simply because they are intracorporate transfers of U, S.-based multinationals?

As expected by the American negotiators, Japanese manufacturers responded strategically to the OMA. To avoid the new restrictions, they not only invested in Taiwanese and South Korean manufacturing facilities but opened assembly plants in the United States—a desirable consequence from the viewpoint of the Federal Government because these plants would help maintain domestic employment, diffusing some of the pressure from labor unions. As these U.S. plants came onstream, Japanese shipments of color TVs (but not of subassemblies) diminished. By 1980, Japan's exports of completed and nearly completed sets were no longer considered a threat, and the OMA with Japan was allowed to expire on schedule, Of course, the possibility of a new quota continues to shape business decisions by Japanese exporters.

OMAs with Taiwan and Korea, on the other hand, were renegotiated to cover the period through June 30, 1982 at new levels (Taiwan: 400,000 sets in the first year, 425,000 in the second; Korea: 385,000 sets in the first year, 575,000 in the second), after which they too were allowed to end.[33] One consequence, again predictable, were decisions by Korean and Taiwanese firms to follow the Japanese lead in establishing assembly operations in the United States.

Escape Clause Proceedings in Color Television

Why have the United States and other nations resorted to quotas? Partly because quantitative restrictions are administratively clean—simple to monitor. More important, for a harried government, quotas may seem the best choice among a set of generally unattractive alternatives. The color TV case illustrates the political dilemmas that often foster such decisions,

The OMA with Japan followed a series of legal actions initiated by the U.S. industry in attempts to stem rapid increases in imports. As discussed earlier, dumping charges against the Japanese came first, but for a variety of reasons duty collection was repeatedly postponed. American firms together with labor unions representing their employees continued to press for import relief via other avenues—one being Zenith's countervailing duty suit, mentioned earlier and destined ultimately to fail. The avenue that finally proved successful began with an appeal filed in October 1976 by a group of companies and unions for relief under the escape clause, section 201(b) of the Trade Act of 1974. This provision, following article XIX of GATT, permits trade restrictions—independent of questions concerning fairness—if imports are found to be causing serious injury or threat of injury to domestic producers. The purpose is to allow a temporary respite or escape from import competition while industries adjust to new conditions. The protective measures adopted in such cases, termed safeguards, need not be quotas—higher tariffs are one alternative.

In terms of the color TV OMAs, two features of the escape clause mechanism are noteworthy. First, remedies depend solely on demonstration of injury—not on any allegation or proof of unfair or discriminatory practices by exporters. Second, the Trade Act of 1974 removed earlier provisions in U.S. law requiring that increased imports be associated with trade

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[33] See "CIT Judge Denies Government Motion To Dissolve TV Settlement, " *U.S. Import Weekly,* July 7, 1982, p. 422, Since the expiration of these OMAs, imports from both countries have again jumped, leading to dumping complaints by U.S. interests—R. D. Hershey, Jr., "TV Import Charges Are Filed: Korea, Taiwan Dumping Seen, " *New York Times,* May 3, 1983, p. D13.

liberalization. Without this change, protection for the American industry via the escape clause would almost certainly have been precluded.

Another feature new to the 1974 Act—concerning the role of ITC in the investigation of injury—bore on the ultimate outcome of the color TV case. Under earlier law, when injury was found ITC recommended remedies to the President, who could either accept or reject them. The 1974 Act added a time limit, stipulating that the President respond within 60 days to an ITC injury finding. Further—and most significant—the act provided that whatever action the President took could be overridden by a simple majority of Congress, * Thus, the options available to the executive branch had been narrowed, the hand of those advocating import relief strengthened. The threat of reversal by Congress greatly increases pressures on the Executive, for whom the color TV case posed a dilemma. The ITC Commissioners determined that the U.S. industry had suffered injury, and—with only one dissenting vote—recommended a large tariff increase, If the President took this course, an international trade dispute of major proportions would almost certainly have been precipitated. On the other hand, rejecting the ITC recommendation would bring with equal certainty the prospect of reversal by Congress—even more embarrassing. Under these circumstances, the White House finessed the entire problem by negotiating with Japan for voluntary restrictions. Discussions carried out between the (then) Office of the Special Trade Representative and the Japanese Ministry of International Trade and Industry (MITI) led to the OMA.

What have been the consequences for the U.S. TV industry? That the political victory had any very substantial impact on its competitive vitality can be questioned. Imports were cut back, and the frontal assault by Asian firms arrested, The specter of U.S. manufacturers being totally overridden, which underlay the appeals by industry and labor (though the industry did not in fact stand together on this), receded. But the OMAs also accelerated a process begun earlier—the establishment of U.S. operations by Japanese TV manufacturers, and later Taiwanese and South Korean firms. Sony had initiated the trend in 1972; since then, many others have followed—as described in chapter 4—sometimes by taking over the plants of ailing American rivals. Wholly owned Japanese subsidiaries now supply perhaps one-third of the U.S. market (table 10). If American manufacturers expected to recapture the domestic market, or if they anticipated a slackening in price competition, they were disappointed.

The full range of consequences provides other causes for reflection. OMAs did not stop the transfer of U.S.-owned production facilities to foreign countries, a movement that had begun earlier. Zenith, for instance, continued to shift TV manufacture to offshore plants in Mexico and Taiwan. Still, if the industry does not appear to have gained materially from the quotas, it is likely that further losses were avoided.

That competition did not abate is shown by price data collected by ITC over the period of the initial agreement with Japan; retail prices for color TVs (19 inch and smaller) remained essentially constant during a period of severe inflation in the U.S. economy.[34] Even for large-screen sets, where U.S.-owned firms continued to dominate the market, prices increased only about 6 percent, While price stability also mirrors cost-cutting improvements in both product and process technologies, it seems clear that competitive responses by Far Eastern manufacturers were the chief cause. During the same period, many household appliances rose in price by 50 percent and more.

Nor did profits recover. While OMAs reduced import market shares–in the 18- and 19-inch categories, penetration declined from about 30 to 10 percent during the first year—

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*A Supreme Court decision in June 1983 ruling legislative vetoes unconstitutional has, for the moment, rendered this provision of the act moot.

[34] *Color Television Receivers: U.S. Production, Shipments, Inventories, Imports, Employment, Man-hours and Prices, 4th Calendar Quarter, 1979* (Washington, D, C.: U.S. International Trade Commission Publication 1036, February 1980), p. A-8.

in terms of the competitive position of the U.S. industry, this apparent benefit was partly offset by the output of Japanese firms assembling TVs here. Capacity utilization rates of domestic firms improved but profitability did not follow. The ratio of net operating profits before taxes to net sales, which had declined from 8.7 percent in 1972 to a loss in 1974 of 1.2 percent, has been running at less than 2 percent in recent years, as pointed in chapter 4. While *OMAs helped preserve domestic employment opportunities, they provided no more than modest relief from competitive pressures.*

Effects of Quotas and Other Nontariff Restrictions

Many nations have utilized restrictions other than tariffs to regulate trade in electronics. Japan–a major beneficiary over the past three decades of vigorous advocacy by the United States of open international trade—has employed nontariff restrictions frequently and effectively as part of its economic development strategy. Among the more blatant nontariff barriers created by the Japanese has been MITI's definition of domestically produced computers. These are confined to systems manufactured by firms in which majority ownership is Japanese.[35] Machines built within Japan by American-owned firms are "foreign' '-despite the fact that IBM-Japan, for instance, employs some 13,000 Japanese and only a handful of Americans. MITI has preferred that purchasers of computers chose "domestic" equipment, using controls over foreign exchange to help enforce its wishes; although exchange controls were dismantled in 1975, MITI continues to monitor the market, and reportedly advises customers to buy Japanese computers.[36]

That nontariff restrictions appear to have been more effective in achieving their ostensible goals in Japan than in most nations illustrates once again that evaluating industrial policy measures is seldom straightforward. One lesson of the Japanese experience appears to be that restrictions may work better in protecting what are essentially infant industries, at least if combined with other policies supporting industrial development. In the United States, on the other hand, quotas intended to protect mature industries—not only color TV, but automobiles or steel—have had ambiguous outcomes.

Could quantitative restrictions effectively shield other portions of the U.S. electronics industry should imports surge as they have, say, in semiconductor RAMs (random access memory circuits)? Probably not. Early in 1982, amidst consternation created by heavy import penetration figures for 64K RAMs, Hitachi, Fujitsu, and NEC all announced accelerated timetables for assembly in the United States. These moves were clearly aimed at heading off formal complaints. If dumping or escape clause proceedings had been instituted, the parallels with color TV would probably have been replicated still further. As for color TVs, Japanese firms already have enough volume in the U.S. IC market to attain the scale economies needed for standardized products. *In general, quotas are not a promising route to improved competitiveness for high-technology American industries like electronics.*

The Escape Clause

As mentioned above, GATT permits governments to come to the aid of domestic industries threatened by imports. But before protection can be extended under the escape clause provision in section 201 of the 1974 Trade Act, ITC must return a finding that "an article is being imported into the United States in such increased quantities as to be a substantial cause of serious injury, or the threat thereof, to the domestic industry producing an article like or directly competitive with the imported article."[37] Fairness or unfairness is not part of the text. The rationale is to provide a time interval during which the threatened industry and its workers can adjust to the (new) competitive circumstances associated with imports. Permanent protection or relief is not the intent.

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[35] E. J. Kaplan, *Japan:* The *Government-Business Relationship* (Washington, D. C.: Department of Commerce, 1972], p. 85.

[36] *United States-Japan Trade.. Issues and problems,* op. cit., p. 28.

[37] 19 U.S.C. *sec.* 2251(b).

Revisions to U.S. law in the 1974 Act made it considerably easier for an industry to demonstrate injury and thus qualify for protection. As noted above, relaxation of the provision that relief be contingent on a rise in imports stemming from tariff concessions or other forms of trade liberalization by the United States was instrumental in the color TV action. Furthermore, previous incarnations of the escape clause required that increased imports be a *major* cause of injury. The 1974 version changed the adjective to *substantial*, defined as "important and not less than any other cause, " This standard is considerably weaker, and all else equal makes it easier for beleaguered industries to secure protection.[38]

Other than the color TV case, only one successful escape clause action involving electronics products has been advanced since the passage of the 1974 Trade Act. This was filed in late 1977 after a fourfold increase in imports of CB radios. ITC worded its findings strongly: " ., . serious injury is clearly imminent and threatens the domestic industry with extinction unless remedial action is taken to enable U.S. producers to compete on more equal price terms."[39] The president responded by raising import duties from 6 to 21 percent. After the first year, the duties decreased in increments, reverting to their original level at the end of the third year, The impact of this period of tariff protection on the CB radio industry is difficult to judge, largely because sales dropped precipitously—from around 5 million units in 1978 to only 2 million the next year—as the CB fad tapered off. Nonetheless, imports captured the vast majority of 1979 sales.[40]

Despite questionable effectiveness in past cases in electronics, the escape clause remains a tempting vehicle for portions of the U.S. industry that find themselves harassed by shipments from overseas. First and foremost, it does not require that imports be linked to unfair behavior—a condition that has often proved difficult to satisfy in dumping or countervailing duty actions. Furthermore, injury can be defined in terms of narrow product categories. The law requires only that injury be demonstrated in "that portion or subdivision of the producer which produces the like or directly competitive article;" the market in which such injury occurs can be limited to "a major geographic area of the United States."[41] The implications can be appreciated by recalling the typical competitive strategies of Japanese exporters. In both consumer electronics and semiconductors, exporters selected specialized market niches where American manufacturers seemed vulnerable, the intent being to gain a substantial market share within this niche and then diversify. Thus Japanese semiconductor manufacturers concentrated on 16K RAM chips, taking advantage of a shortfall in U.S. production capacity to quickly gain some 40 percent of the American market, Under the provisions of the Trade Act of 1974, an export strategy of this type could be subject to trade restraints.

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[38] W.R.Cline, *N*, Kawanabe, T. O. ***M.*** Kronsjo, and T. Williams, *Trade Negotiations* in *the Tokyo Round: A Quantitative Assessment* (Washington, D. C.: Brookings Institution, 1978), p. 203.

[39] *U. S. Import Weekly— Reference File* (Washington, D. C.: Bureau of National Affairs, 1979), p. 58:0106.

[40] *Electronic Market Data Book 1980* (Washington, D. C.: Electronic Industries Association, 1980), p. 49.

[41] 19 U.S.C. sec. 2251(b). Dumping and countervailing duty statutes invite complaints on a narrow product line basis as well; during 1982, more than 120 separate investigations in carbon steel products alone were undertaken by ITC.

Prospective Effects of U.S. Trade Policy on the Electronics Industry

To what extent, then, might the panopoly of U.S. trade laws be exercised against imports in the future? The answer depends not only on the course of international competition, but also on the attitudes of Federal agencies charged with enforcing these statutes. One result of transferring responsibility for antidumping and countervailing duty provisions from Treasury to the Department of Commerce has been a more sympathetic hearing for American business—and as a consequence, the filing of more complaints. Much also depends on the complexion of ITC, which shifts as Presidentially appointed commissioners come and go. Changes in the definition of injury have made protection at least in principle easier to obtain; these too, in the ordinary course of events, serve to encourage demands for trade restrictions. Thus far in electronics, trade actions have centered on consumer products; as Japanese manufacturers step up their price competition in semiconductors and computer equipment, there may be filings in these product categories. Furthermore, complaints by the U.S. industry are increasingly centered on subsidies and other tools of national industrial policy—e.g., Japan's R&D programs. By and large, trade negotiations and the GATT have proved unable to deal with such issues.

Certainly protectionist sentiment has been rising over the past half-dozen years. Is a turning point in the American attitude toward trade a real possibility? For some 50 years, the United States has taken the lead in international negotiations to lower barriers to trade. From the first Reciprocal Trade Agreements Act in the 1930's to the Tokyo Round MTN, U.S. policies have supported liberalization as being in the Nation's long-term interests. Both major political parties have for the most part accepted the underlying premise of these policies: open trade leads to an efficient allocation of global resources, as a result of which the American people will, more often than not, find themselves better off. Other nations have benefited as well. The export-based economic growth of West Germany and Japan owes much to the openness of the large and affluent U.S. market, while American consumers have gained access to a greater variety of products, as-well as lower prices resulting from foreign competition, On the other side of the ledger are the costs of dislocation and adjustment that follow upsurges of imports. These costs tend to fall most heavily on a few firms and their employees; they stand out sharply, whereas the benefits are visible mostly in the aggregate. Is it possible that the U.S. economy is *too* open, given changes in the international marketplace? Does the absence of effective import controls in electronics make the domestic industry overly vulnerable to inroads by foreign industries?

Consumer Electronics

International competition has generated continuing pressures for trade protection in consumer electronics, yet the current situation of the U.S. industry is partly a consequence of domestic competition. Today, two American-owned firms, Zenith and RCA, account for roughly 40 percent of U.S. color TV sales—as they have, rather consistently, for many years. Although import penetration increased dramatically during the 1970-77 period, the brunt of the sales losses were borne by other manufacturers. In a single year, Magnavox and Motorola each saw their domestic TV sales drop by more than 15 percent. These market declines led rather directly to the sale of their TV operations—to North American Philips and Matsushita, respectively. While only four domestically owned producers remained in 1983 (compared with 17 in **1970),** they have been joined by more than 10 foreign companies manufacturing or assembling sets here. Concentration has not increased significantly and no one firm-American or Japanese—has come close to dominating the market. Policy decisions by the U.S. Government stimulated the influx of foreign capital, although OMAs probably influenced timing more than decisions to invest. Foreign-owned plants in the United States—together with continuing imports from Japan and other Far Eastern nations–created relentless pressures on American TV manufacturers, even while quotas were in force. U.S. firms shifted production abroad to reduce costs, at the expense of jobs here—but consumers have benefited via low prices and high-quality products. Still, only the largest and strongest American manufacturers managed to stay in business.

For other consumer goods, Federal policies have rarely come into play–and seem unlikely to, at least in a manner similar to events in the TV industry. Far Eastern firms are today the unchallenged leaders in most other consumer electronic products; there is virtually no U.S. manufacturing left to protect when it comes to portable radios, monochrome TVs, stereo/high fidelity equipment, the simpler pocket calculators, or electronic watches. More important for the future, the United States has lagged in the development of new products such as video cassette recorders (VCRs). At every step, Japanese manufacturers lead in product development or are working in parallel or in cooperation with American firms, the primary exceptions being electronic toys and games and home computers. If products like video disk players achieve mass-market success, the Japanese will be early and formidable competitors.

Under such circumstances, protection for American manufacturers would have to come through legal provisions that have not in the past been exercised. When applying the injury standard in antidumping proceedings, ITC examines whether imports are harming a domestic industry, are likely to damage it, or are *preventing such an industry from being established*. The last of the three possibilities has seldom been relevant because existing industries have normally sought dumping investigations. But in principle, the clause could be a basis for relief–if imports were priced at less than fair value—for products that are not even being made in the United States, such as VCRs.

On the other hand, the escape clause injury standard would have to be considerably stretched. Here, there are only two possibilities: an existing industry must be seriously injured or threatened. Given product leadership overseas, with imports achieving a sizable market share from the outset, serious injury to an existing industry probably could not be demonstrated (assuming new types of products) unless the standard was applied in a novel and unintended way. Given the general ineffectiveness of antidumping and countervailing duty remedies, it therefore appears unlikely that existing U.S. trade policies could shield domestic firms producing the consumer electronic products of the foreseeable future. Indeed, cost pressures will probably continue to drive a good deal of production by American entrants offshore.

Semiconductors

Unlike consumer electronics, where the efforts of U.S. manufacturers have been largely confined to the domestic market, production and sale of semiconductors is carried out on a global basis by the major U.S. merchant firms, as well as by Japanese and—to a far lesser extent—European producers. U.S. leadership has meant that domestic manufacturers have not, as yet, sought direct Government assistance in combating imports. For many years, sales expanded rapidly; American suppliers were often hard pressed just to keep pace. The number of domestic companies serving the market tripled during the 1960's, while imports were until recently almost entirely the interdivisional shipments of U.S. multinationals (ch. 4).

The picture began to change at the end of the 1970's. Aggressive competitive tactics and market successes by Japanese firms have had impacts in many parts of the world, but from the perspective of U.S. policy makers the domestic market has been the focus, Japanese companies are providing the first real competition from abroad in the experience of most of the American industry—competition that has driven them to seek the attention of the Federal Government. The most publicized examples of Japanese inroads have been the 16K and 64K RAMs sold in large numbers to manufacturers of computers and microprocessor-based systems. In 1980, Japanese manufacturers captured about 40 percent of the U.S. and world market for 16K chips, partly because of inadequate capacity in American plants, By 1982, the Japanese share of next-generation 64K RAM sales was running at about 70 percent. More than any other event, the rapid inroads of Japanese RAMs have led the American industry to seek counters.

The tempest over 64K RAMs in the spring of 1982 may prefigure future trade disputes in the high-technology products of this and other industries. As publicity mounted over inroads by Japanese imports, the Departments of Commerce and Defense began examining the implications for national security. At the time, only Texas Instruments and Motorola among U.S. merchant firms were producing 64K chips in quantity. prices had been dropping rapidly, driven not only by declining manufacturing costs, but by recessionary pressures leading to price cutting in the Japanese market as well as here. Worldwide production capacity for 64K RAMs may have exceeded demand for a time,

When the Semiconductor Industry Association—and Motorola specifically—accused the Japanese of dumping, though without filing complaints, the Japanese responded by announcing plans to move some production to the United States. Meanwhile, the Commerce/ Defense study had begun, evidently at the instigation of the latter agency. Among the possible outcomes of the Commerce/Defense study, three appeared at the time to be among the most likely:

1. A dumping complaint against the Japanese, self-initiated by Commerce.
2. A section 232 investigation, based on the national security implications of U.S. dependence on Japanese ICs.
3. A complaint through GATT, probably concerning issues of reciprocal market access.

The section 232 alternative is noteworthy for illustrating the variety of instruments that governments can bring to bear in trade-related matters. Part of the Trade Expansion Act of 1962, this rarely used statute permits the President to limit imports—e.g., by tariffs or quotas —where such shipments "threaten to impair the national security. " No section 232 proceeding was started in this case, but a recent investigation of ferroalloy imports by the Commerce Department, which recommended restrictions, may point to greater use of this provision by industries suffering from foreign competition.[42] Nor were antidumping proceedings initiated for 64K RAMs. Later in the year, growing demand caused prices to firm, defusing allegations of dumping and redirecting lobbying by domestic semiconductor firms toward reciprocity legislation. Nonetheless, following this turn of events, Japan got another unpleasant surprise: the Justice Department began an investigation of six Japanese semiconductor manufacturers, premised not on price-cutting but on restricting shipments to the United States in order to *raise* prices.[43] To considerable extent, such episodes illustrate the inability of the traditional tools of trade policy to deal with events in a fast-moving, technologically based industry like microelectronics; they also illustrate the multiplicity of actors populating U.S. trade policy and enforcement—a multiplicity that some would characterize as leading to confusion and disarray .44

In any case, the U.S. merchant semiconductor industry has not thus far sought direct protection. Rather, American firms and their trade association(s) have continued pointing to features of Japanese industrial policies and business practices they feel are unfair, urging the U.S. Government to exert pressures aimed at ending them.[45] In addition, industry executives have sought Federal actions that would improve their own ability to compete—lobbying in favor of R&D tax incentives and reductions in capital gains taxes, as well as calling attention to engineering manpower shortages. Many

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[42] See "Specialty Steel Industry Attacks Draft Report by Commerce on Ferroalloy Study, " *U.S. Import Weekly*, July *21*, 1982, p. *478*. Ferroalloys are used in making steels. The investigation was requested by a trade association of U.S. suppliers. Past applications of sec. 232 have been restricted to petroleum imports.

[43] A. Pollack, "Inquiry puzzles Chip Makers, " *New York Times*, July 7, 1982, p. D9.

[44] Two dozen or more Federal agencies exercise some degree of responsibility over foreign trade and investment policies— "Opening Statement of Senator Roth, " *Government Organization for Trade*, hearing, Committee on Governmental Affairs, U.S. Senate, June 4, 1981, p. 2.

[45] See, for example, "The Effect of Government Targeting on World Semiconductor Competition, " Semiconductor Industry Association, Cupertino, Calif., January 1983.

of the tax changes advocated by semiconductor firms were in fact implemented by the Economic Recovery Tax Act of 1981 (ch. 7). Industry leaders have also asked the Federal Government to negotiate for easier access to the Japanese market, claiming that sales in Japan are virtually impossible except for products that local companies do not make. The U.S. industry's position is that asymmetries vis a vis Japan result in a competition in which the two sides are playing by different rules, with the advantage to the Japanese.

As in earlier export thrusts, Japan's semiconductor shipments have been concentrated in a few product types. The choice has been memory circuits—particularly dynamic MOS RAMs—in part because of the close coupling between Japanese efforts in microelectronics and computers. Worldwide, Japan's RAM sales have increased more rapidly than those of American firms, with European manufacturers the big losers. At the end of 1979, just four companies—two Japanese, two American—produced nearly two-thirds of the total world merchant output of 16K RAMs. Two years later, a pair of U.S. firms confronted six Japan producers in the battle for worldwide market share in 64K RAMs; while other American manufacturers were ramping up production or preparing to enter with their own designs, Japanese companies were investing heavily in additional production capacity.

Still, except for Mostek–-which is rapidly diversifying its product line–RAMs have not dominated the sales mix of any American company. Thus, while Japanese incursions have had drastic impacts on the RAM market-–affecting prices and profits, as well as market shares—similar shocks have not yet been felt in other products. A major concern of U.S. producers is that this experience will be repeated elsewhere, denying them the learning and scale economies so important for competitiveness, and cutting into the profits they need to generate cash for expansion. Moreover, MITI-sponsored R&D efforts like the VLSI project are seen as, first, activities that would be illegal here, and second, major subsidies. This program—and the difficulty American firms have faced in gaining access to patents and other technical results—is viewed as further evidence of asymmetries favoring the Japanese. In sum, U.S. semiconductor manufacturers believe that a closed market shelters Japanese competitors, leading to economies of large-scale production that translate into low prices. Investments in production facilities within Japan are one way the U.S. industry sees to counter the threat.

As the discussion above implies, trade outcomes depend on complex sets of competitive relationships. Consider, as an example, the question of scale economies—a matter more complicated than sometimes implied. A portion of the cost savings associated with production scale come via learning curve effects; he who gains an early edge in market share enjoys lower costs—perhaps permanently. The Japanese, in the simplest view, "learn" by producing for the domestic market, then penetrate foreign markets based on low costs and low prices. But learning economies are not quite so straightforward. Some cost reductions are functions of cumulative production volume; others depend on time as well.[46] In the latter case, obtaining a large early market share would not confer the same cost advantages. The extent to which market penetration results in lower costs, therefore, may be product-specific; for some types of ICs, cumulative volume might matter much more than for others. The limited evidence available suggests that costs for logic circuits depend more heavily on time, memory costs more on scale.[47] As a consequence, the advantages of access to the U.S. market could be considerably greater for products such as RAMs than for at least some other types of ICs—perhaps one reason Japan's exports have been so heavily weighted toward memory devices (the comparatively straightfor-

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[46] D. W. Webbink, *The Semiconductor Industry: A Survey of Structure, Conduct and Performance* (Washington, D. C.: Federal Trade Commission, Bureau of Economics, January 1977), pp. 49ff.

[47] "Management Committee Report to the Management Review Committee-CD Assessment Report, IBM, October 25, 1971 (PX 391 AZ-142)," cited in G. Brock, *The United States Computer Industry A Study of Market Power* (Cambridge, Mass,: Ballinger, 1975), p. 3.

ward design of RAMs and other memory circuits is also a major factor).

Even so, patterns linking design and development, manufacturing, and marketing tend to repeat fairly consistently from product to product (see app. C on the 4K RAM). Technology dominates production and marketing strategies in the early phases, because the first to offer a new chip design may possess a near-monopoly—whether the chip is an innovative product or simply an incremental advance. After introduction, prices decline slowly as firms recoup R&D costs by selling to customers willing to pay premium prices for leading edge devices. Eventually, other manufacturers enter the market, forcing prices down—sometimes to a point below production costs. The final phase in the product cycle finds prices low, with many of the earlier participants unable or unwilling to compete; as a consequence, prices may even begin to rise once more.

The competitive dynamics of the industry revolve around such factors, Some companies attempt to be leaders, bringing innovative products to market early and capitalizing on the higher prices they command; in the United States, Intel has become known for this strategy, which depends on heavy expenditures for design and development—as well as abandoning products when they begin to mature and margins fall. Other firms manufacture a diversified line of more mature devices, concentrating on process technologies as a route to low costs. For such companies—National Semiconductor has been an example—market penetration is vital; as a result, they are particularly vulnerable to import strategies that also emphasize market position, Still other entrants participate largely as a byproduct of internal operations. Semiconductors may account for only a small fraction of their business, but if they use substantial quantities in their other end products—as do Japanese manufacturers such as Fujitsu or Hitachi—they may be able to sell outside at low prices. Net revenue gained by putting otherwise idle capacity to work then makes a contribution *to* profits.

The vulnerability of the U.S. semiconductor industry to foreign competition is therefore a function first and foremost of technology. American firms with the ability to be consistently early to market with new products have generally had less to worry about. Thus far, most imports have been standard circuits—a situation that could certainly change if semiconductor manufacturers in Japan or elsewhere begin to design more innovative devices. At the same time, there are real limits to a technology-based strategy. Incremental payoffs from R&D may diminish over time. Although new types of microelectronics products could still open new mass markets, signs of technological slowdown have begun to appear. Inevitably, the industry will mature, with greater competition from imports a predictable consequence: slower rates of technological change make it easier for foreign firms to catch up and keep up.

Industry structure is also important, The high-volume merchant manufacturers in the United States have coexisted with a fairly large number of small firms for many years, the latter typically specialists filling market niches of less interest to bigger companies, Structural changes are underway in the domestic industry, partly in consequence of heightened international competition, partly because the capital requirements of advanced circuits make pursuit of VLSI difficult for small companies. The changes are of two types, as discussed in previous chapters, First, diversified American corporations are purchasing or merging with formerly independent semiconductor firms. Second, foreign enterprises are continuing to take ownership positions in U.S. manufacturers, Such marriages have occurred, on the one hand, because foreign electronics manufacturers want quick access to evolving technologies, and on the other hand, because the U.S. partners have needed infusions of capital,

How will these structural shifts affect competition? As American semiconductor manufacturers become larger and more diversified–in the extreme, merely divisions of powerful multinational corporations—they will be less vulnerable to price competition in particular lines of business. Such companies have the flexibility to shift resources internally, to meet the competition on a price basis, to invest more heavily in R&D and in production equipment. To the extent that American semiconductor firms have had difficulty in financing expansion, with possibly harmful effects for U.S. competitiveness, consolidation should help, Multinationals also tend to have "free trade" perspectives because they depend on doing business overseas, and are less likely to press trade complaints. On the other hand, some observers believe large firms to be less entrepreneurial and more cautious, and that consolidation will reduce the probability of innovation, making technical leadership more difficult to maintain. While small firms will continue to exist—many new ones have been started recently—structural shifts of the type visible in semiconductors have characterized the maturation of many industries; rather than focusing on the supposed virtues and liabilities of small and large firms, it is perhaps more pertinent simply to observe that they have different strengths and weaknesses in a given competitive context.

More to the point in terms of trade policy, what are the implications of greater numbers of foreign manufacturers with active semiconductor design and production facilities in the United States? This tendency—particularly evident in recent investments by Japanese firms to mitigate trade frictions-combined with universal foreign involvement by the larger American producers, has made semiconductor manufacture one of the more international of the world's industries. Attitudes toward trade and investment shaped by the traditional concerns of domestic firms and their workers may not fit the realities of such an industry. In microelectronics and computers, the notion of "our" firms versus "theirs" is an oversimplification when so many companies operate on a global scale. Corporations engaged in bitter trade disputes in one part of the world may establish joint ventures elsewhere; cross-licensing is the rule; firms cooperate with one another where they see advantages to be gained, compete fiercely under other circumstances. Such factors have no doubt contributed to the reluctance of American semiconductor manufacturers to press formal trade complaints against Japanese exporters.

The old ways—erecting trade barriers to shield domestic industries—can damage U, S,-based companies quite aside from any possibility of retaliation by foreign governments. Texas Instruments produces 64K RAMs in Japan for export to the United States. In consumer electronics, the OMA on color TVs from Taiwan restricted shipments by RCA and Zenith, both of which had substantial investments there. Japanese semiconductor manufacturers would quickly shift production to export platforms—in many cases, the same offshore sites favored by American firms—in the event of restrictions on shipments of ICs from Japan. They would also move more production here. When those affected include U.S.-based multinationals along with foreign firms having significant interests in the United States, traditional protective measures become less practical, Such dilemmas have arisen, or are likely to, in other industries as well—automobiles, computers, possibly aircraft, chemicals, energy, pharmaceuticals. Increasingly, firms in such industries are tied by a multitude of co-production and joint venture agreements, irrespective of the locations of their headquarters, As a consequence, the "inside-outside" or "good guy-bad guy" distinction becomes a difficult one for policy makers to draw; *in such a world, trade policies directed to an older order may simply be overrun by events.*

In any event, the American semiconductor industry has not attempted direct action to staunch the flow of imports, much less withdrawn to a protected position in the United States. Instead, while continuing to lobby the Federal Government, U.S. merchant firms have moved boldly to maintain their competitiveness worldwide. This is one reason the industry's leaders have been more vociferous over what they view as unfair domestic subsidies by the Japanese Government—and over impediments to their own attempts to sell or to manufacture in Japan—than over purely trade matters, such as dumping.

From the viewpoint of American companies that purchase semiconductors, the outcomes of intensified competition have been beneficial: a wide range of product offerings, low prices, high quality. Would these benefits have followed even if U.S. producers had chosen strategies of trade protection? This must remain an open question—but to the extent that other industries offer parallels, the benefits would have been smaller and slower to arrive.

As the technological leads of U.S. microelectronics firms narrow, and competition continues to mount, the industry's support for open trading relationships may diminish. Yet American semiconductor producers cannot back too far away from a free trade stance without jeopardizing their own overseas interests. Formulating equitable trade policies will continue to be difficult, with a wide range of interests to be balanced. A large fraction of U.S. exports and imports of semiconductor products will continue to be transfers between divisions of multinational corporations. Links among U.S. and foreign firms will certainly persist and may well strengthen. Trade policies dealing with dumping or countervailing duties are unlikely to be very relevant, if only because of the pace of technological change—which can render the products in question obsolete before the proceedings have run their course.

Computers

The picture is similar in the computer industry. U.S. firms have been undisputed leaders, with subsidiaries engaged in manufacturing and marketing around the world. Imports have been at low levels, even for personal computers and peripherals-although this could

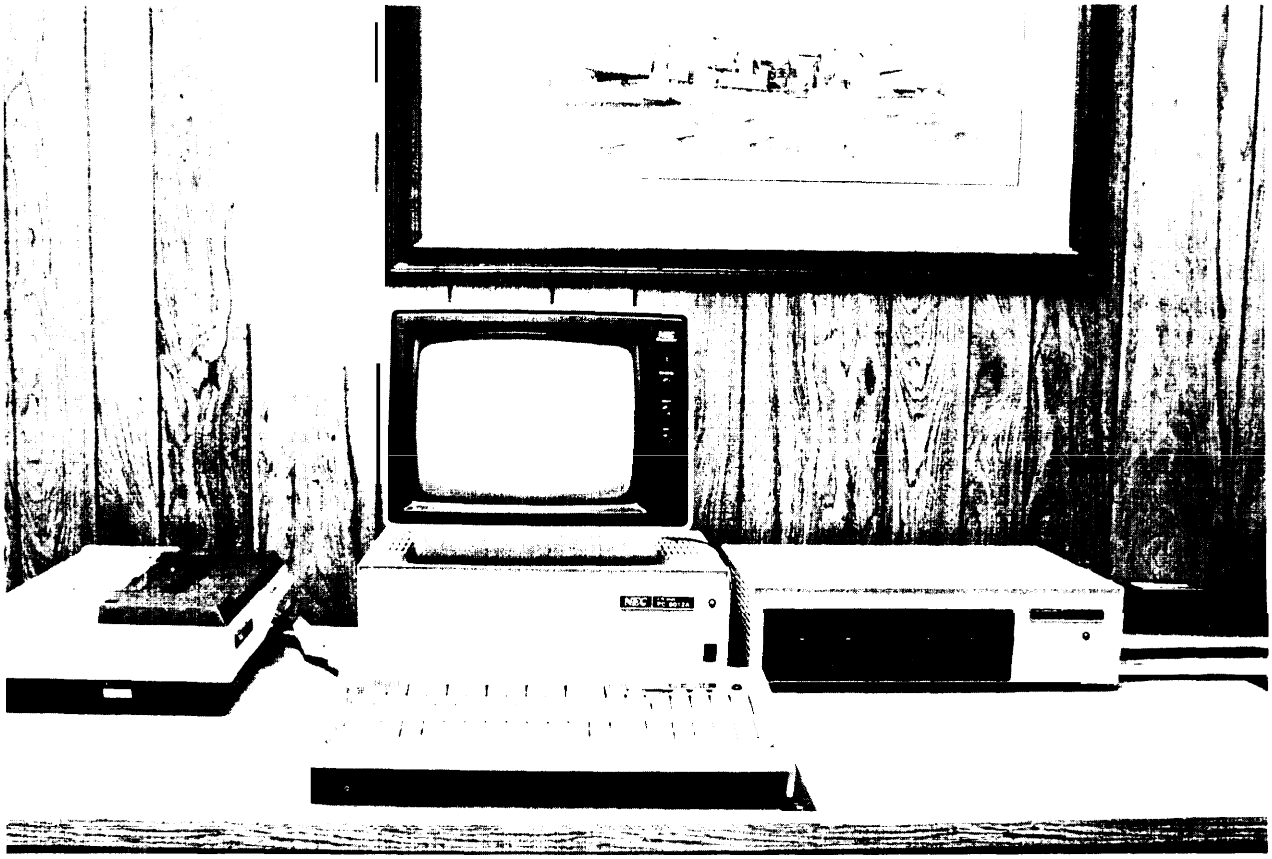

Photo credit Nippon Electric Co

Desktop computer made in Japan

certainly change. The consequence has been, until quite recently, a virtual absence of concern by executives of American computer firms with U.S. trade policy except as it supports an open international trading environment or affects transfers of components and subassemblies among subsidiaries. American manufacturers wish to see items 806.30 and 807,00 of the Tariff Schedules preserved, but dumping or escape clause provisions have seldom attracted their attention.

Yet here too the competitive picture is changing. Foreign governments, viewing information processing as vital to national interests, have found a variety of methods for subsidizing local firms, as well as an array of carrots and sticks for encouraging American corporations to transfer technology to local computer manufacturers.[48] And again as in semiconductors, foreign manufacturers have taken equity positions in American computer companies, in part to acquire technical knowledge, The technology gap between U.S. and foreign firms has diminished in both hardware and software, with several Japanese manufacturers beginning to ship mainframe machines to the United States either directly or in partnership with American firms.

What impact will such developments have on trade flows and on U.S. trade policy? Given that competition depends on much more than fast, reliable hardware, it is too early to make predictions. Manufacturers must be closely attuned to user needs; foreign computer firms lag well behind American companies in their ability to seek out and satisfy customer applications (ch. 5). This deficiency has not gone unrecognized; other nations are devoting substantial efforts to software, often aided by government subsidies. Furthermore, countries like Britain have always been good at software and may provide a resource that firms elsewhere can tap. The U.S. lead in software seems bound to narrow, following that in hardware. The fluidity of market structures emphasized in chapter 5 will leave room for aggressive foreign competitors.

As a result of the subsidies for computer technology that virtually all industrialized countries have employed, it is not hard to envision a scenario in which these subsidies—as well as the preferential treatment many governments have extended to local producers—become the targets of countervailing duty complaints. If a foreign firm benefiting from government largess were to establish a significant market position in the United States, can there be much doubt that American manufacturers would seek remedies under U.S. law? After all, the subsidies extended to foreign computer industries—albeit often rationalized on national security grounds—have been even more visible than in microelectronics. What, then, might be an appropriate response on the part of the U.S. Government?

The issue raised—and repeated in semiconductors, communications equipment, and other high-technology products—is that the *existing structure of national and international trade laws and agreements evolved in another era; it was not designed with current varieties of national industrial policies and subsidies in mind.* Countervailing duties were intended to offset export subsidies such as rebates or other payments contingent on sales to overseas customers, Subsidized financing via export-import banks has strained the system, Domestic subsidies with indirect effects on exports scarcely fit it. Indeed, U.S.-based companies maybe among those benefiting from industrial policies in other nations. Antidumping laws were drafted to counter explicit price discrimination by foreign monopolists, often involving governments and/or cartels that encouraged exports by charging higher prices to domestic than to foreign customers. Until recently, antidumping legislation was seldom called on where price-cutting was extended to all customers, domestic as well as foreign. Today, when France subsidizes the development of commercial aircraft, is it “unfair” if an American carrier selects such planes over those made by

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[48] Overseas governments have used investment incentives to attract American firms more actively in electronics and electrical machinery than in any other industry. See *The Use of Investment incentives and Performance Requirements by Foreign Governments* (Washington, D. C.: Department of Commerce, Office of International Investment, October 1981), p. 6.

Boeing? Or, more subtly, is U.S. support of research into solid-state electronics as part of military and space programs unfair—research that, after privately funded follow-ens, eventually results in commercial applications? Many other examples, in any number of countries, could be cited.

For computers or communications, governments have seldom proffered financial assistance simply to foster exports, although this has been one motive–a strong one in Japan. Rather, governments have targeted the information industry as vital to a multiplicity of national interests. Subsidies have been generalized, directed at industrial development over the longer term. *The question for trade policy becomes: As governments increase their involvement in economic affairs—and indeed in the actual operation of business enterprises—what types of trade policies and agreements will be needed so that participants can agree that the terms of competition are reasonably fair?* This will remain a central matter for international trade negotiations over the current decade and beyond, While the Tokyo Round trade negotiations addressed such questions, the substantive changes in procedures embodied in the new subsidies code are small, and unlikely to have much effect.

Summary and Conclusions

U.S. trade policy has been rather consistently oriented toward open international trade and investment over the last half-century, In the postwar period especially, the United States took the lead in eliminating both tariff and nontariff barriers—by reducing its own restrictive measures and pressing its trading partners to do the same. Some parts of the electronics industry, notably manufacturers of consumer goods like TVs and CB radios, have suffered as a result. But if import competition has hurt the manufacturers of such products, other sectors of the U.S. economy benefited from freedom to export and invest overseas. U.S. trade policy has helped American semiconductor and computer firms become leaders in markets all over the world. The exception has been Japan; barriers imposed by European nations have proved far less substantial, On the whole, the open trading environment resulting from successive rounds of multilateral negotiations has helped the competitiveness of the U.S. electronics industry.

More narrowly, trade policy impacts in consumer electronics have centered on longstanding complaints over unfair practices brought by American firms against competitors in the Far East, primarily Japan. The response of the Federal Government has been marked by delays and interagency conflicts. Fifteen years after the initial antidumping actions, the situation remains unresolved, duties uncollected. The uncertainty created by this long and convoluted history has made life difficult for both domestic firms and importers. To considerable extent, as the shape of the industry has altered, complaints over trading practices have become moot. Orderly Marketing Agreements—negotiated as an upshot of escape clause proceedings unrelated to unfair trade practices-accelerated what would probably have been widespread eventual movement by foreign firms toward assembly here. Plants owned by foreign interests have replaced failing domestic TV manufacturers. Meanwhile, the remaining U.S. producers have moved some of their assembly operations to low-wage offshore locations, helped by provisions of items 806.30 and 807,00 of the U.S. Tariff Schedules. These provisions —which allow tariffs on re-imports to be computed only on foreign value added—have been a target of labor interests. But if in some cases offshore assembly can be considered equivalent to the export of jobs, in others transfers offshore have been necessary to retain any domestic jobs,

As tariff walls in many parts of the world have slowly come down, the attention of both private firms and governments has turned to indirect and nontariff barriers. Ranging from implicit subsidies for domestic firms to uncooperative customs inspectors, such barriers pose much more complex subjects for international negotiations—as the Tokyo Round demonstrated. Some progress has been made, but it is too early to tell how trade in electronics may be affected over the longer term.

Among nontariff and indirect measures, subsidies for economic and industrial development ostensibly aimed at domestic objectives are perhaps the most difficult case, along with government procurement. As discussed in the previous chapter, many nations have used both types of measures consistently and aggressively as elements of industrial policy—especially in electronics. While progress has begun in opening up government procurements, subsidies will remain thorny issues for years. More and more governments, for example, are resorting to R&D incentives to support local electronics manufacturers; inevitably, these *function* to some extent as export subsidies, even if this is not the primary or avowed intent. While direct impacts on international trade tend to be small, the visibility of programs such as Japan's joint R&D efforts, or West Germany's spending on computer technology, draws frequent attacks by businessmen and political leaders in other parts of the world. The nations mounting these programs consider them vital for economic development; they will not disappear. As has been the case with complaints over unfair trade practices in consumer electronics, negotiations concerning indirect supports and subsidies are being overtaken by events; subsidies may in some respects function like other nontariff and indirect barriers to trade, but governments seldom institute them for such purposes. Nor do they view them as elements of trade policy. They are seen as vital tools of industrial policy—policies developed in response to an economic environment in which domestic and international dimensions can seldom be isolated,

Negotiations aimed at reducing such subsidies will make slow progress at best—indeed, although necessary, they may finally be rather beside the point. So long as governments regard high-technology industries like electronics as essential to industrial development and economic growth, supports and subsidies seem more likely to increase than decrease.

CHAPTER 12

Federal Policies Affecting Electronics: Options for the United States

Contents

List of Tables

CHAPTER 12

Federal Policies Affecting Electronics: Options for the United States

Overview

In 1982 electronics accounted for 10 percent of U.S. merchandise exports; manufacturers of electronic products contributed 4 percent of U.S. gross domestic product and 9 percent of total goods output; the industry employed more than a million and a half Americans. Beyond this, the electronics industry produces goods and knowledge that are vital for much of the rest of the economy and for society as a whole. Banks, insurance companies, and many other service sector enterprises could hardly conduct their businesses without electronic data processing. Entertainment industries like television broadcasting developed in conjunction with the manufacture of consumer electronic products. Before too long, prosthetic devices for the handicapped will routinely be built around "smart" microelectronic devices. Modern commercial aircraft depend as heavily on radar, computerized flight control systems, and electronic navigation aids as do military planes. Over the rest of the century, computer-aided manufacturing—shop floor management systems, automatic warehouses, smart robots—will help increase productivity and reduce costs throughout the Nation's manufacturing sector. If there is any single industry whose technological progress and competitiveness are critical to the economic growth and national security of the United States, it is electronics.

Yet even the most dynamic portions of the U.S. electronics industry—semiconductor production, where innovation is a way of life, computers, where markets seem to expand nearly as rapidly in bad times as good—find themselves increasingly challenged by foreign manufacturers, both here and overseas. Although few European firms have managed to capitalize fully on their technology—because of fragmented markets and less than inspired translations into commercial products—determined efforts, strongly supported by national governments, continue in countries like France and West Germany. Japan has moved swiftly from a position as technological laggard to being one of the leaders—not only in product development, but in the fundamentals of electronics technology. The strengths of the Japanese industry have been described in previous chapters: an ample supply of skilled and motivated employees; managements that approach markets on a global scale and have learned to do business effectively in countries ranging from Saudi Arabia to the United States; an economic system in which the tradeoffs between competitive rivalry and cooperation aimed at advancing common goals are well-managed; a government whose industrial policies consistently support and encourage the private sector. In the language of sports, the Japanese electronics industry has momentum. Elsewhere in Asia, developing countries can already make many consumer electronic products and components at less cost than Japan or the United States; these countries will continue to move into more sophisticated goods—though at first continuing to focus on consumer markets—supported by export-oriented industrial policies. Hong Kong, for one, has already made the transition from discrete transistors to integrated circuits (ICs)—computer chips as well as those for consumer products. This is not to say the American electronics industry risks overnight decline, It does mean that *competition will be difficult in the years ahead, and neither the technological leads that the United States still maintains nor the size and affluence of our domestic market will suffice to guarantee American primacy.*

Intensifying competition worldwide—in electronics, as in industries ranging from steel to biotechnology—is one reason the United States might choose to move toward a more explicit industrial policy of its own. If other countries are adopting policies in support of industries like electronics—and having some success, or, more tellingly, moving down learning curves leading to more consistently productive efforts–then it makes sense to ask whether such an approach could also work here. Such questions need to be addressed in terms of concrete policy objectives and prospective mechanisms for achieving them—matters to which this chapter is devoted.

The United States could afford to live without a consciously formulated industrial policy in years past, but the realities of international economic competition changed dramatically during the 1970's. The "information society" is here; industries are no longer defined by national boundaries; new jobs are opening for Americans who are computer-literate at a time when employment of other types is in decline. If new approaches to industrial policy are to be considered, what is the range of possibilities?

After a brief review of the ad hoc nature of past U.S. industrial policies, the chapter outlines five options for a more focused approach:

- protection of, domestic markets;
- a "critical industries" policy;
- an orientation toward infrastructural support—primarily for technological development—and adjustment;
- promotion of competitive U.S. firms on a worldwide basis; and
- Federal withdrawal, where possible, in favor of the private sector.

The five are intended to span the realistic alternatives; they overlap somewhat—in several cases specific policy measures would be similar if not identical. Still, if the five options themselves are not exclusive, they are distinct. Each is discussed in terms of prospective effects on electronics—and, by extension, other high-technology sectors.

The options are discussed in terms of directions and objectives; they are intended to offer a set of alternative signposts. All start from the same point: the patterns of worldwide competition outlined in the preceding chapters; the increasing capital-intensity of critical sectors of the electronics industry; its continued dependence on research and development (R&D); needs for skilled labor and imaginative management. But each alternative implies a different route to a different destination.

The Current Policy Environment

Chapters 10 and 11 summarized U.S. industrial and trade policies as they affect competitiveness in electronics, contrasting them with policy approaches abroad. Federal policies have been notably ad hoc, formulated and implemented by many different agencies, no one of which has overriding authority. Trade policies are neither very predictable nor closely linked with domestic industrial and economic policies.

Outside the trade arena, regulation of broadcasting and telecommunications has been a continuing influence on consumer electronics. Among the recent issues with potential impacts on U.S. manufacturers, either direct or indirect, are: the rights of owners of video taping equipment to copy off the air; the fate of AM stereo broadcasting (where the Federal Communications Commission has avoided decisions on a standard system); regulation of home information services and data communications (videotext and teletext may be slow in coming, but will eventually be integrated into home entertainment and information systems). As with regulation of cable TV and rights to satellite transmissions, such matters may have only indirect consequences for manufacturers of consumer electronics products, but impacts that are no less real for this,

The U.S. semiconductor and computer industries benefited in their early years from Government-funded R&D and procurements;

military and space programs drove developments in microelectronics until the 1960's, while both civilian and military sides of the Government have been heavy purchasers of computers and related equipment. Although Federal R&D is still significant for both microelectronics and computers, particularly in terms of more basic research—and in the case of the Defense Department's Very High-Speed Integrated Circuit (VHSIC) program, process technology and applied research as well—it is now decidedly secondary to the industries' own spending. Furthermore, the declining fraction of total markets for both semiconductors and computers accounted for by Government has made Federal procurement a much weaker force than 10 or 15 years ago.

Indirectly, a wide variety of public policies affect U.S. semiconductor and computer firms: support for education and training, particularly of technical professionals; regulation of data communications; the 1982 antitrust settlements with IBM and AT&T; copyright and/or patent protection for chip designs and software; tax policies as they influence competition for funds within U.S. capital markets. On the other hand, Government policies directed specifically at the semiconductor or computer industries—either in the domestic context or in terms of their international competitive positions—are remarkable by their absence, the vacuum a striking contrast with ambitious, comprehensive, and supportive (if not necessarily very cost-effective) public policies in other countries. A major exception to the absence of policy is antitrust.

American electronics firms have often complained that antitrust enforcement hinders cooperative R&D and joint ventures in international trade—which, if allowed, would strengthen this country's competitive position. The Department of Justice—and, to the extent that it is involved in antitrust enforcement, the Federal Trade Commission (FTC)—reply that such cooperative activities are, in fact, generally permitted. The dialog, which has been going on for years, is part of the problem: Justice and the FTC have helped create a psychological climate in which industry is reluctant to test the bounds of the permissible, The two agencies generally act as if this status quo is desirable, with their public pronouncements nicely straddling the relevant issues.[1] While the enforcement attitudes of the Reagan administration differ somewhat from those of its immediate predecessors, the more relevant concern—at least from the viewpoint of Congress—might be: Do the antitrust *statutes* need reconsideration in light of changes in the character of international trade and competition since the Clayton and Sherman acts were passed in the early decades of the century? Where would antitrust fit within a more coherent U.S. industrial policy?

Beyond the intangible effects of Federal antitrust enforcement—beginning with their force in restraining clearly undesirable forms of anticompetitive behavior—chapter 10 mentioned the two recent and major antitrust actions directly involving the electronics industry—suits against IBM and AT&T, both recently settled, In both cases, critics of U.S. antitrust enforcement had claimed, with some validity, that the Government was trying in the name of competition to break up enterprises that were mainstays of U.S. competitiveness.

Regardless of possible rewrites of communications legislation by Congress, the AT&T settlement will change the form and function of Bell Laboratories. A weakening of the basic research foundation that Bell Laboratories helped

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[1] Consider this quotation from the "Statement of William F. Baxter, Assistant Attorney General, Antitrust Division, Before The Subcommittee on Employment and Productivity, Committee on Labor and Human Resources, United States Senate, Concerning Antitrust Policy and Productivity, Apr. 16, 1982, " pp. 12-13, "Joint ventures may foster efficiencies not available to individual firms, and may promote technological progress and enhance productivity. Such joint ventures should not be deterred by rigid or overly-broad applications of the antitrust laws, The Department's recently published *Guide Concerning Research Joint Ventures* is intended to assist businesses considering joint ventures by clarifying our enforcement policies in this regard, For example, as the *Guide* indicates, an important factor is whether a joint venture leaves a significant number of non-participating firms free to engage independently in research. [f there are not a significant number of such non-participating firms, and the joint venture's research could be done individually by the participating firms, antitrust problems could arise. " Much of the lore of antitrust resides in such pronouncements.

lay for so much of the U.S.–and world–electronics industry seems inevitable. The reason is straightforward: Western Electric—the parent and main customer of Bell Labs—will be operating in a more competitive environment, It will lose some of its “guaranteed” markets, as well as implicit subsidies paid for in the past by all telephone subscribers. Western Electric and Bell Laboratories will have to learn to deal with a less predictable set of market conditions; basic research is likely to appear more in the nature of a luxury—and hence be deemphasized. Unless alternative mechanisms for performing basic research and diffusing the results evolve and thrive, one of the great sources of strength for the entire U.S. electronics industry will atrophy. The potential void is not restricted to microelectronics, but extends to communications and computer technologies as well; Bell Labs spawned the Unix operating system now so popular in small computers, as well as the transistor,

Leaving aside the special case of antitrust—and perhaps trade policies also, where activity has remained at high levels if without much sense of direction—Federal policies affecting electronics have been marginal, indirect, often simply absent. To those who regard Government involvement in the affairs of industry as a usually unnecessary evil, this may seem a blessing. But the reasons for the absence of policy are not so much conscious decisions that Federal initiatives would be counterproductive as a lack of agreement about what Government can and should do. The subject has been discussed—at considerable length, and in contexts ranging from trade reorganization to the Federal role in productivity improvement and the quality of working life. But the various parties disagree—beginning with the question of whether the U.S. Government should develop policies aimed at affecting the competitive position of American industries, and extending to questions of how the electronics industry, in particular, might fit into a more general framework for industrial policy.

On the one hand, some argue that the United States needs to search for new engines of growth to drive the economy into the 21st century. Others focus on organization, some advocating that the Department of Commerce be transformed into a more powerful agency—even a “Department of International Trade and Industry” modeled after Japan’s MITI and responsible for coordinating and implementing policies on a sectoral basis. Another view, while agreeing that new mechanisms are needed if the Nation’s de facto industrial policy is to be replaced by a more systematic approach, takes dispersal of responsibility for making and implementing policies to be a hallmark of the U.S. system, and sees a single centralized agency as impractical, if not dangerous. Still others, focusing on financial issues, argue that the first priority of the Federal Government should be to channel investment capital to speed “reindustrialization’’--for example, through a publicly operated investment or development bank, In any of these views, electronics would plainly be an early subject of attention,

The dominant attitude within the executive branch since the election of President Reagan has run counter to the more activist positions. The Reagan administration has held that the proper role of Government is to stay far removed from the affairs of industry. Those of such persuasion believe that businessmen, rather than Government officials, have both the right and the ability to make decisions affecting the futures of their firms—and thus the futures of the industries of which they are members, and the competitiveness of the U.S. economy—that Government is largely incompetent in these areas. The corollary is that decisions made by private interests will affect local and regional economies, as well as the interests and livelihoods of the people who work for or otherwise depend on private industry.

Those at the extreme end of the spectrum hold that Government should minimize its efforts at macroeconomic policymaking, claiming that the Keynesian economists—who, many years ago, defined a government role in managing the aggregate economy through fiscal and monetary policies—represent a bankrupt tradition, Tax reductions and other measures aimed at capital formation, rather than demand management, have been in vogue among the proponents of this view. Still, even advocates of supply-side economics or monetarism commonly maintain that—while Government should stay out of the affairs of business—it can and should ensure a climate conducive to economic growth.

There is a core of truth to the claims of those who advocate a Government pullback from micro-level involvement in economic affairs—this truth found in the past history of public policies that have affected U.S. industries with sometimes adverse consequences, to say nothing of the lack of relevant expertise and analytical capability in the executive branch. On the other hand, it is *clearly possible to devise a self-conscious industrial policy that does not depend on direct or extensive Federal intervention.* Thus, even if one feels that the political system in the United States works in such ways that Government involvements will always be riddled with mistakes and policy failures, this is more a counterargument to proposals for a strong, centralized industrial policy apparatus than to the *general* notion of a more explicit and coherent industrial policy,

In essence, two of the attitudes sketched above—centralized industrial policy versus Government pullback—represent extremes in opinion concerning the form and character of future industrial policies for the United States, Industrial policies have existed for several hundred years in this country; Federal Government actions will continue to exert influence over private sector decisions, On questions of how the process might be changed, as on specific policy issues, there are many shades of opinion, a variety of perspectives that fall between the extremes. These are illustrated in the remainder of the chapter.

Alternative Perspectives on Industrial Policies

Regardless of one's attitude toward Government involvement in economic affairs—when and where appropriate, for what reasons—policy choices will flow in part from analyses of the position of American industry, and the interpretations placed on these analyses, Each of OTA's five alternatives has as its foundation a somewhat different interpretation of the competitive situation of American electronics firms; while the discussion that follows takes its context from this industry, the policy options are not specific to electronics, or even to high-technology industries as a class. The five alternatives—which overlap to some extent while representing fundamentally different viewpoints—are:

1. policies intended to *ensure a strong domestic market base for U.S. industries*—without particular reference to the *nature* of the industries—along with preservation of existing jobs and job opportunities.
2. Policy measures designed to *protect and/or support a limited number of industries judged critical* on national security or other grounds.
3. Policies that will *support the technological base and institutional infrastructure for American industries,* particularly those undergoing structural change.
4. Policies designed to *promote the global competitiveness of U.S. firms and industries.*
5. A policy that *defers if possible to the private sector* when choices concerning industrial development are to be made.

All of these, even the last, accept at least implicitly that Government involvement in industry and the economy *is* inevitable—the questions being when, where, how, for what purpose. In each case, different sets of assumptions and goals underlie the policy orientation. From the repertory of policy tools available—outlined in chapter 10 and summarized in table 82—each of the five would call for a different mix and emphasis, The table is schematic, but gives an idea of the types of measures that

Table 82.—Measures Likely To Be Emphasized Under Alternative Approaches to Industrial Policy[a]

	Alternative				
	Protection	Critical industries	Infrastructure & adjustment	Global promotion	Minimum Government
Trade, foreign investment	✓	✓		✓	
Tax		✓		✓	✓
Competition (antitrust, merger)			✓	✓	
Human resources (education, retraining)		✓	✓		
Technology (R&D, innovation, diffusion)		✓	✓		
Investment (capital)		✓			
Government procurement		✓			

[a] This table is intended only to be suggestive; many possibilities exist under each alternative.

SOURCE Office of Technology Assessment

would be emphasized under each of the alternatives; a “critical industries” orientation, for instance, would entail a strong presence by Government compared to the other four.

Regardless of which of the five alternatives were chosen, a new approach to industrial policy for the United States would bring pitfalls as well as opportunities; experience in other countries shows that there is no substitute for good judgment in selecting and implementing individual policy measures. Table 82 stresses that it is not so much the individual policy tools but the way they are put together—the objectives pursued—that matters most, The remainder of the chapter treats the five alternatives in detail.

Ensure the Domestic Market Base for U.S. Industries

Protectionism is a loaded word. Not only does it imply reversal of the primary thrust of postwar U.S. foreign economic policy, but the arguments in support of open international trade are strong and widely accepted. Protecting domestic industries from import competition via tariffs, quotas, or other barriers distorts market mechanisms, decreases economic efficiency, and—by raising prices—results in a net loss in standard of living.[1] Hardly anyone disputes these general tenets; the issues more commonly raised concern the specific circumstances under which trade restraints might be justified to prevent or ameliorate greater harm to a few—vulnerable firms and their employees, communities and regions—at the expense of net benefits that, when spread over the Nation as a whole, are small.

Leave aside for a moment the political questions, as well as the use of protection to countervails the industrial policies of other nations, or unfair trade practices by foreign enterprises. The question is then an internal one: What are the impacts within the larger domestic economy of protection granted a particular industry? This is not only a matter of present-day costs and benefits—e.g., to consumers, to owners, managers, and other employees—but of the future prospects of industries granted protection. Some such industries may be in temporary decline, with reversal possible—others unequivocal victims of shifting comparative advantage. For example, long-term prospects for specialty steel manufacturers in the United States appear brighter than for makers of carbon steel. Not only do the technical demands of specialty alloys favor American firms, but the diversified, high-technology industries of the United States provide large and varied markets for alloy steels. Nonetheless, both specialty and carbon steel producers face short- as well as long-term problems. It is possible to argue on the one hand that trade protection will benefit specialty steelmaker by permitting them to rebuild their competitiveness so as to take advantage of longer term opportunities, while on the other that protection for carbon steel producers will

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[1] For a brief review, see *US. industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles* (Washington, D. C.: Office of Technology Assessment, OTA-ISC-135, July 1981), pp. 181-182.

Photo credit RCA

American consumer electronic plant complex

only retard the inevitable contractions. At the same time, for domestic industries as large as steel or automobiles, the adjustment problems stemming from long-term shifts in competitiveness can be so severe that strong arguments for temporary trade protection can be constructed on this basis alone, This is one of the reasons escape clause actions are sanctioned under GATT (the General Agreement on Tariffs and Trade),

Bilateralism in Trade

Protective actions other than tariffs, involving—as they generally do-bilateral discussions with exporting nations, represent something of a turn away from the postwar U.S. emphasis on multilateral trade negotiations. Persistent trade friction between the United States and Japan has led to bilateral negotiations covering goods ranging from cigarettes to telecommunications equipment. Similar bargaining has taken place with European nations exporting steel, among other products, to the United States, as well as between Japan and the European Community—e.g., in the case of video cassette recorders (VCRS). [3] To some, this revival of a bilateral rather than multilateral approach to trade is a sign of possible return to the prewar era of widespread protectionism.

Bilateral negotiations between the United States and Japan first found a prominent place in U.S. trade policy during the early 1970's, when market penetration by Japanese textile imports became severe; in one of the more re-

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[3] Faced with dumping complaints and informal import restrictions in France, Japan has voluntarily agreed to limit VCR shipments to the European Community. The ceiling will be 4.55 million annually, E, J, Dionne, Jr., "Japan Video Accord Leaves Europeans Wary but Hopeful," *New York Times*, Feb. 22, 1983, p. D5

cent cases, after a push from the U.S. side, the Japanese agreed in 1981 to accelerate tariff reductions on semiconductors (ch. 11). Further negotiations led to similar concessions on data processing equipment. Japan's continued reliance on tariff walls to protect domestic industries—whether or not they remain infants—and on an array of slowly crumbling and largely informal nontariff barriers, contrasts sharply with duties on imports into the United States that for many years have been low; as pointed out in the previous chapter, this country has only rarely imposed tariffs to protect domestic industries, preferring to negotiate quotas.[4]

Recently, those concerned with Japanese penetration into U.S. markets for products ranging from semiconductors to machine tools have been urging a variety of essentially protectionist responses. The mirror image of concern with imports lies in the persisting difficulties many American firms have faced in exporting to Japan, or investing there—even when the exports are goods in which the Japanese economy is uncompetitive. The paramount example has been agricultural products.[5] The perceived asymmetry has been a major force behind calls for reciprocity in trade.

While to some, trade reciprocity need not carry the implication of sector-specific bilateral concerns, to others it means just that: if nations such as Japan discriminate against U.S. exports or investment, we should retaliate swiftly and directly, During 1982, 20 or more bills related to trade reciprocity—and covering many shades of meaning—were introduced, with many re-introduced in the 98th Congress.[6] In April 1983, S. 144—the Trade and Investment Act of 1983, intended to strengthen the hand of the President in dealing with other nations—passed the Senate unanimously. House bills have made less progress.

Most broadly, reciprocity is a call for equal treatment, hence would entail measures to restrict imports originating in nations that themselves block the entry of American firms—particularly through indirect barriers. Spokesmen for the U.S. semiconductor industry, to take an example from electronics, object to unlimited imports of Japanese ICs at a time when they see themselves confronting a formidable array of obstacles to doing business in Japan—obstacles ranging from uncooperative customs inspectors to hidden controls on foreign investment.[7]

Pros and Cons of a Protected Market Base Strategy

Arguments for temporary as opposed to longer term or permanent trade protection turn on quite different points. Proponents of temporary protection for troubled industries often judge sharp upturns in import shipments, as for color televisions during the 1970's, to be particularly serious. Once lost, whatever the reasons, market share can be difficult to regain. Thus, a sudden penetration of U.S. markets—perhaps as a result of unfair trade practices—might devastate an industry, leaving it without the ability to recover. The remedy is to protect the industry. Whether the causes are lower costs for labor or other factors of production abroad, unfair trade practices such as dumping, or problems internal to the U.S. industry—which could range from outdated plant facilities to misjudgments of the market—the objective of Federal policy, in this view, should be to limit import penetration with the expectation that, after a limited period of relief, domestic firms will again be able to compete.

Preferred measures to achieve such goals depend on the circumstances of the import-affected sector. Examples from the recent past include tariffs, unilaterally imposed quotas,

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[4] An outstanding exception has been the levies of 45 percent, declining over a 5-year period, placed on large Japanese motorcycles early in 1983. These were imposed as the result of an escape clause action. See "President Imposes Sharp Tariff Increase on Motorcycles, Japan Criticizes Action," *U.S. Import Weekly*, Apr. 6, 1983, p. 5.

[5] See, for instance, *Report on Trade Mission to Far East*, Subcommittee on Trade, Committee on Ways and Means, U.S. House of Representatives, Dec. 21, 1981.

[6] See A. Reifman and R. Ahearn, "Reciprocity in Foreign Trade," Issue Brief No. IB82043, Congressional Research Service, Mar. 31, 1983. Most of these bills were intended to give the President added authority to impose restrictions on imports; several were directed largely at trade in services.

[7] On the latter, see U.C. Lehner, "Japan's Aversion to Selling Companies May Be Ultimate Barrier to U.S. Trade," *Wall Street journal*, Mar. 23, 1982, p. 38; also, S. Lohr, "Japan's Capital Market Has U.S. Critics," *New York Times*, June 1, 1982, p. D3.

negotiated Orderly Marketing Agreements (OMAs), and voluntary restraint on the part of exporters. In industries where allegations of dumping have been common—consumer electronics, and, though there have been no formal complaints in recent years, semiconductors—alternatives to antidumping proceedings might be sought because legal redress has proven slow, notably in the case of television imports. The Trigger Price Mechanism for steel illustrates a more novel mechanism.

Beyond temporary protection, the notion that the Federal Government should provide a haven for U.S. industry appeals to many interests, Ostensible goals might be to help the American economy grow, to protect jobs, to maintain the prosperity of cities, States, and regions. What are the arguments for more comprehensive or longer term import restraints?

Policies designed to ensure a domestic market base for American industries might be justified on the assumption that a certain level of sales at home provide the necessary foundation for international competitiveness. In essence a variant of infant industry, senescent industry, and critical mass arguments, at root this perspective views import penetration as inherently dangerous, hence worthy of Government attention. Keeping out imports permits domestic manufacturers to achieve scale economies and to earn the profits necessary for investments in new production facilities and R&D. A protected home market would also insulate them from sudden and unexpected competitive threats, originating not only in profit-seeking overseas firms, but in government-controlled enterprises seeking to create jobs, earn foreign exchange, build industries that can support military adventures. In short, this strategy would insulate the Nation from the disarrays of a world economy that is simultaneously more open to all comers and more susceptible to manipulation by organizations seeking ends other than those of private corporations in the American mold.

If industrial piracy is too strong a term to describe foreign tactics, it is nonetheless true that nationalized enterprises can with considerable impunity set goals quite different from those of firms that must live off their own profits, And if not all countries have nationalized sectors the size of that in France, in many economies the incidence of government subsidy and control is such that market signals become distinctly secondary. The preceding chapter stressed the relative impotence of the traditional roster of trade laws—and of international negotiations—for countervailing the wide range of supports and subsidies that some governments now resort to. Those who see world trade as moving toward a no-win situation for the United States sometimes urge that we shut our own borders to imports, accepting the consequences in terms of reduced exports while relying on the size and diversity of the U.S. economy to keep productivity—more generally, the gross domestic product—high enough to maintain living standards acceptable to most Americans.

A related justification for trade restraints starts with international differences in wage rates—a point emphasized in chapter 4 (see table 27), Low-wage countries, many with huge and mounting labor surpluses, can now produce many types of goods at costs below those in advanced nations. Increasingly, this is true over a range from primary metals to manufactures like automobiles or the simpler electronics products that were mainstays of countries industrializing earlier. Although labor productivity in developing countries is often very low, if wages are also low, costs of production can be less than elsewhere. Even Japan–with pay scales in manufacturing industries little more than half those here, and labor productivities in some cases better—faces competitive difficulties in sectors like consumer electronics or steel.

How can the United States hope to compete under such circumstances? One answer is to offer products that are beyond the technological capabilities of low-wage countries. In more conventional products, it may be possible to improve labor productivity-through automation or other advanced manufacturing technologies-enough to offset existing wage differentials. Advocates of trade protection point out that these avenues may not guarantee enough jobs to keep the American labor force employed. The alternatives are then to let wages in the United States drop, helping to maintain competitiveness across a broader range of production, or to keep out imports from low-wage countries. Given the levels to which U.S. wages might have to fall—depending on how swiftly developing countries can improve their own labor productivities—the first alternative is far from acceptable, The plight of unemployed auto and steelworkers in California, where plants in both industries have been shut down, illustrates the difficulty. Some if not all of the laid-off workers—many of whom had been making $12 to $15 an hour exclusive of fringe benefits—could find employment in Silicon Valley electronics firms. However, unskilled or semiskilled electronics work pays in the range of $6 per hour; and even at this level, Atari, for one, is moving some 1,700 jobs overseas. Given such a picture, trade protection and industrial self-sufficiency begin to seem attractive.

What is the other side of this scenario—the argument against either temporary or longer term trade restrictions? First, import restraints almost always result in higher prices for American consumers, Witness the automobile price increases following Japan's voluntary limits on exports in 1981. Indeed, under such circumstances price increases are generally intended; the common rationale is that import-affected U.S. firms must be temporarily shielded so that they can raise prices, generating increased profits to be invested in restoring their competitiveness. Of course, rising prices often ripple through the economy—causing inflationary pressures. To the extent that protection for domestic steelmaker has raised steel prices, costs have gone up for automobiles, consumer durables, roads, bridges and buildings, military hardware—everywhere steel is used.

Should these higher prices be considered the necessary costs for reviving import-affected industries? Where there is good reason to expect revival, the answer might be yes. Unfortunately, experience—e.g., in the case of color television—provides little evidence in support of trade protection as a road to recovery for sectors that have lost competitiveness internationally (which is not to say that protection might not serve other objectives, or be a necessary if not sufficient prelude to recovery). Industries and/or their employees may claim that import penetration stems from unfair trade practices, dubious management decisions, adverse effects of Government regulations, or other transient problems. If so, the argument runs, recovery is possible, given time. The reality is generally more tangled. Complaints of unfair competition or adverse regulations maybe well-founded but nonetheless only secondary factors; decline may result more fundamentally from long-term trends in the world economy—i.e., shifting comparative advantage, Where this is the case, trade protection will be ineffective if temporary, costly if permanent.

When a good argument can be made that revival is possible—that longer term trends favor the United States or at least do not run too strongly the other way—the question remains: How long will protection be necessary? Where the Government has imposed or negotiated import quotas, these have typically been for 3- or 4-year periods—with renewals not unheard of. Fixed periods are desirable so that domestic as well as foreign producers face a relatively predictable situation. Protection granted for an indefinite period risks de facto permanency, decreasing incentives for domestic firms to make new investments or alter their business strategies.

To illustrate some of the factors involved in decisions on protective mechanisms, consider the situation in early 1982 as concern mounted over imports of 64K RAM (random access memory) chips, Japanese penetration of the U.S. market—running at about 70 percent—was the outcome of a complex of factors: rapid capacity expansion in Japan facilitated by ample supplies of capital for investment; production problems at the plants of several prospective U.S. suppliers; price-cutting by both Japanese and American firms striving to build market share (accompanied by accusations of dumping leveled at the Japanese). At a time when only two American merchant firms—

Texas Instruments and Motorola—were able to produce 64K RAMs in large quantities, as opposed to six Japanese manufacturers, the first question from the standpoint of competitive dynamics became: How long would it be before other U.S. suppliers entered the arena? Given the learning and scale effects characteristic of RAM production, too great a head start might be virtually impossible to overcome. On the other hand, if American companies came in later but with superior designs, would they be able to turn the tables? These are nontraditional kinds of questions for U.S. policy makers, indeed difficult for governments anywhere to deal with; as emphasized in the previous chapter, the fast moving events characteristic of high-technology industries do not fit very comfortably into the existing framework of international trade policy. But effective Government action depends on grasping such facets of competition.

To return to the question of the costs associated with trade protection, note first that—regardless of rationale—import restrictions function as implicit subsidies for protected industries and their employees. The costs are paid by other sectors of the economy—i.e., by the public at large. Beyond direct costs in the form of higher prices, a protected industry may be able to attract resources such as capital away from other parts of the economy; in attempting to help one industry, Government policies can harm others.

These are not the only indirect effects for policy makers to worry about. Foreign competitors often pursue inward investment as a way around trade barriers—the pattern in color television, now also taking place in industries as different as microelectronics and automobiles. In contrast, foreign investment in U.S. steelmaking capacity has been small—no doubt because overseas investors do not see long-term trends favoring the production of iron and steel here. Direct investment is particularly attractive where companies feel they have competitive advantages that can be exploited regardless of location. American semiconductor and computer manufacturers invest overseas in part because their technological advantages are easily transportable.

At about the time Texas Instruments announced it was transferring all of its 64K RAM production to Japan, Hitachi, Nippon Electric, and Fujitsu revealed plans to move—or speed up previous timetables for moving—some of their own 64K RAM assembly here.[8] One motive was to dampen trade frictions; despite the absence of constraints or even formal complaints concerning RAM shipments, the color TV case appears to prefigure that in semiconductors. Is this an outcome that U.S. policymakers—whose actions accelerated onshore investments in consumer electronics—should welcome? Certainly there are major differences between the two industries. Competition in television manufacture is cost-driven, with technology playing a relatively minor role. In microelectronics, moving closer to markets is one way a company can capitalize on its technology to meet customer demands. Although decisions by Japanese semiconductor manufacturers were spurred by concern over trade, they see many other advantages to their presence here. For instance, they can learn from American technical expertise more easily—one way is to hire American engineers—if they have bases in this country, especially now that U.S. companies are guarding their own technology more closely. In the same way, technology acquisition has been one of the motives behind efforts by U.S. firms to set up R&D and manufacturing facilities in Japan.

When foreign firms invest in U.S. plants, they employ American workers—unskilled as well as skilled—although a substantial fraction of value added tends to remain overseas. But from the perspective of U.S. semiconductor firms, sales by Japanese-owned competitors—regardless of where the products are manufactured—represent a loss to the domestic industry. The numerous joint venture and technology exchange agreements that U.S. and Japanese electronics firms have entered into complicate matters further. With Hewlett-Packard getting RAM technology from Hitachi, National Semiconductor sharing with Oki, the computer firm Amdahl joined to Fujitsu, easy national distinctions vanish. Such trends are still

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[8] M. Kanabayashi, "64K Ram Chips At Plants in [J. S.," *Wall Street Journal*, Mar. 2, 1982, p. 35.

more advanced in consumer markets; "American" consumer electronics products contain many parts and subassemblies produced overseas—in the extreme, VCRs made entirely in Japan are sold under leading American brand names. The U.S. workers who benefit are primarily those in distribution and servicing; sales of such products—even TVs, where foreign value added may be 50 percent—can hardly be counted as simple gains for the domestic economy. More such agreements can be expected in high-technology electronics, adding to the ambiguity facing policy makers.

Could a Market-Protection Strategy Work?

The patterns described above create a fundamental dilemma for an industrial policy founded on trade restrictions. How does one ensure a domestic market base when the boundaries between U.S. and foreign industries and interests blur, even disappear? In a given and narrow circumstance, it may be possible to turn trade policies to the strengthening of U.S. industry through protection. In the general case, the result might become less a policy than a collection of case-by-case decisions (such as we have now in the trade area) with decidedly mixed impacts. As industries and markets become more international in character, an industrial policy oriented toward preserving domestic markets rests on assumptions that are increasingly difficult to sustain.

More broadly still, attempting to ensure domestic markets for some types of goods may work against underlying shifts in comparative advantage; industrial policies that attempt this are seldom very successful. To the extent that a domestic market strategy attempts to freeze patterns of sectoral rise and decline, it may conflict with powerful forces outside the control of Government—in the end, a losing battle.

Most advocates—including those in organized labor—of a strategy that would emphasize the U.S. position in traditional markets focus on tangible goods, particularly manufactures. Trade in services—more generally still, international flows of capital—is often left out of account. Yet while the U.S. trade deficit on merchandise came to $36.3 billion in 1982, this figure was almost precisely balanced by a *surplus* on trade in services; the Nation's net deficit on goods and services in 1982 was but $225 million. Moreover, this follows a year in which the U.S. surplus on goods and services totaled $11 billion, the 1981 surplus on services far exceeding the merchandise deficit.[9] Stressing bilateral imbalances such as that between the United States and Japan—even more so particular products, whether semiconductors or automobiles—obscures these broad patterns still further. While the aggregate picture does nothing to blunt adjustment problems created by shifts in trade—nor the political dimensions of a merchandise deficit with Japan totaling $17 billion in 1982—that dislocations are severe and potentially long-lasting does not mean that protection is the best or even a viable remedy.

Finally, the reasons that trading nations have for many years been moving away from protectionism and toward an open system of world trade—albeit haltingly and with many counterexamples—should give pause to those who would advocate a market protection stance for the United States. This country led the movement for open trade in the belief that everyone would benefit, at least in the longer run. Historically, restrictions on trade flows have often led to retaliatory measures; in the 1930's, these contributed to both the depth and the length of the Depression. Retaliation need not be direct and obvious to have genuine impacts on U.S. interests. International negotiations may involve tariff concessions on computers in exchange for concessions on wheat; one outcome may be tariffs that differ among nations on a product-by-product basis, giving the appearance—and often the reality—of asymmetries. But if industrial policies intended to preserve domestic markets begin to provoke strong retaliatory measures, the entire system of international trade agreements, imperfect as it is, could be weakened.

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[9] C. L. Bach, "U.S. International Transactions, Fourth Quarter and Year 1982, " *Survey of Current Business,* March 1983, p. 42. Including financial flows reduces the surplus for 1981 and increases the deficit for 1982.

Fear of retaliation has been a very real factor in the choices made by the United States—e.g., concerning trade in steel, particularly imports from Europe. If the United States makes it too difficult for European steel to enter the American market, it risks restrictions on [J. S. exports of electronics products, or financial services—even military goods. Trade wars seldom benefit those involved so much as those in position to pick up the spoils.

Support for Critical Industries

Rather than attempting to preserve domestic markets in general-which would in large measure reward those able to build the strongest political constituencies—the Federal Government could decide to support and if necessary protect only those industries judged critical to national security. Security might be broadly or narrowly defined. Either way, such a policy would find deep historical roots. Governments support transportation technologies and systems—canals, railroads, highways, aviation—in part for reasons of national mobilization and defense; other examples range from armories and shipbuilding to telecommunications regulations and space exploration. A national security criterion—restricted to military security or extended to "economic security"--would narrow the focus compared to the market preservation alternative, helping to control the political pressures that will always bedevil efforts at industrial policy in a country like the United States.

Manufacturing sectors suffering from import competition frequently argue for Government remedies on the basis that their products—or their plant and equipment—contribute to national security. Some clearly have better cases than others. The end products of some companies and some industries consist of military hardware: armaments, communications systems. In other cases, end products may be used only indirectly for national defense, though no less critical for that. This is true of supercomputers, needed in the design of some types of military systems. In still other cases, the goods produced by an industry may be vital, but only some fraction of the industry's production capacity would ever be consumed in meeting military needs. Examples include the steel and machine tool industries.

The assumption underlying a critical or strategic industries alternative is that only a subset of the economy—perhaps relatively small-is indispensable for national defense; unless the list is kept short, this approach would differ little from the first option discussed above. Critical industries would begin with, but not be restricted to, the traditional defense sector: aerospace, suppliers of armaments, military electronics firms, R&D contractors—enterprises that, along with large numbers of suppliers and subcontractors, sell to the Department of Defense (DOD). Beyond this, other portions of the electronics industry would be obvious candidates for any critical industries list--computer hardware and software, integrated circuits, communications equipment. Indeed, numerous manufacturers of computer systems and semiconductor products have divisions devoted exclusively to military sales. In contrast, consumer electronics, as a sector, would have a weak case despite the fact that firms like RCA and GE are major defense contractors. Just as Chrysler's tank business was largely divorced from the automobile side of the corporation, so electronics suppliers that engage in military production generally do so through separate divisions or subsidiaries.

What is Critical?

The difficult questions in identifying "critical" firms and industries involve those that do not engage directly in defense-related research or production, but whose products or R&D might still have vital military applications under some circumstances. Synthetic fibers like nylon and Kevlar provide an example. Used in clothing, parachutes, body armor, and fiber-reinforced composite materials for structures ranging from missile casings to stealth aircraft, these materials are obviously critical to the defense base. But would this have been predicted when synthetic fiber technology was in its infancy? That is the nexus of the problem if the Federal Government is to support critical industries—identifying those that will be vital in the future, If the criteria are to be extended to embrace economic strength, then the matter of identifying critical industries—without being so inclusive that support and protection go to everyone who asks—becomes still more perplexing. One reason is simply that terms like "economic strength" are not very meaningful. In practice, virtually any industry threatened by foreign competition would attempt to declare itself critical. The difficulty in recognizing industries that will be critical in the future would arise here as well—where it is a variant of the "sunrise industry" problem. Once the sun is up, and everyone knows it, Federal policy may not be especially important; opportunities will be evident, investors will be attracted. Although Government might be able to nurture the growing industry, its role could well be peripheral—more so in an economy like that of the United States than in Japan or France. But when an industry is truly an infant, its prospects for the future uncertain, then Government may be no better able to recognize its potential than the private sector (some would say less); the primary difference will be that Government's time horizons need not be constrained by the desire for quick returns on investments as for private suppliers of funds.

In any event, a strategic or critical industries approach implies that the Federal Government can and should identify such industries, then adopt policies to:

1. Ensure that the United States maintains an indigenous production capability sufficient to meet direct military needs, particularly in the event of national mobilization or crisis.
2. Support industries and technologies that have a substantial role in providing the underlying base—either in terms of R&D or production—for U.S. military strength,
3. Optionally, support industries and technologies that clearly and unambiguously contribute to *economic* strength.

In a context of growing East-West tension, advocates of such an approach—particularly those who emphasize direct military production—contend that the U.S. Government should take a more active role in ensuring the well-being of strategic industries.'" A primary strand in the argument is that if the United States comes to depend too heavily on foreign products or technologies the Nation's defensive capabilities could be impaired—not only in the event of war, but even in a rapidly escalating arms race.[11]

As table 82 indicated, a wide variety of policy instruments could be used to provide for the continued strength of critical industries, going well beyond tariffs or quotas for protecting domestic manufacturers and beyond the well-established relationships that already link DOD and the community of military contractors and suppliers, Multiyear procurements have been suggested as a means to strengthen the defense industrial base. DOD is also paying a good deal of attention to manufacturing technologies as one way of getting more for our money, as well as shortening procurement cycles. The attention to manufacturing will have spillover effects in the civilian economy that could be significant. Beyond such steps, sectoral policies could provide targeted supports and subsidies in much the same way that the American farmer has been given special consideration. Procurement could be steered to particular firms. DOD-sponsored R&D efforts like the VHSIC program and the other research and engineering activities of the services and the Defense Advanced Research Projects Agency—many of them related to electronics—might be enlarged and broadened still further, with the aim of strengthening the U.S. technological base and infrastructure, Manpower and education policies could channel institutional support toward engineering and relevant sciences, fund

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[10] For a detailed presentation of this view, see "statement of Gen. Alton D. Slay, Former Commander, Air Force Systems Command," *Revitalization and the U.S. Economy,* hearings, Part I, Subcommittee on Economic Stabilization, Committee on Banking, Finance, and Urban Affairs, House of Representatives, Feb. 25; Mar. 25, 26, 1981, pp. 258-479.

[11] Such arguments were advanced by opponents of the award of contracts to Fujitsu for a Boston-Washington fiber-optic communications link, After intense lobbying by the DOD and others, AT&T gave the contract to its own subsidiary, Western Electric. See E. Meadows, "Japan Runs Into America, Inc., " *Fortune,* Mar. 22, 1982, p. 56.

students majoring in these fields, reward people who choose to work in defense industries, provide incentives for retraining and continuing education in advanced technical subjects. The services have recently argued that, in the years ahead, they may be unable to meet requirements for skilled workers—electronics technicians, aerospace fabricators, aircraft maintenance specialists—as well as engineers; a strategic industries policy would aim to rectify such problems.

Critical Industries for National Defense

Nations traditionally give special attention to economic sectors on which military strength and security depend. Shipyards and armories are obvious examples; for many years, historians and economists have probed the symbiosis between military and civilian production, exemplified by the evolution of precision manufacturing and interchangeable parts. If 19th century production technologies were driven in part by military needs, certainly the relationship between military and civilian sides of the economy has altered greatly since. The pervasiveness and complexity of modern technology makes identification and support of strategic industries more problematic—ships, arms, even missiles and planes, hardly exhaust the requirements of modern warfare. During World War II, automobile plants could be retooled to make weapons, but in the past four decades, military and civilian technologies have diverged. As for commercial technologies, new demands and applications come in rapid sequence—chemical and biological warfare, terrain-following cruise missiles, surveillance satellites, war in space, cryptology, computerized translation of foreign languages. One need not stop here. Economic warfare, in various forms, has a long history. Wheat, cobalt and chromium supplies, energy—all can be weapons. Ultimately, a nation's military potential is a function of the size and composition of its economy, the fraction of gross national product it is willing to spend on defense.

Sooner or later, then, any policy based on a critical industries approach will face a series of decisions on what is really essential. Lines will have to be drawn—in some cases fairly arbitrarily—because in the most general sense nearly all industries and technologies contribute in some way to defense readiness. Corporations may produce the boots that soldiers wear, the food they eat, or small computers for battlefield command and control, When only a portion of an industry's output goes to the military—whether the industry be steel or semiconductors—how might the Government allocate its support?

The struggles of DOD with the "militarily critical technologies list" recommended by the well-known Bucy report and endorsed by Congress in the late **1970's** shed light on the practical difficulties of a defense-centered industrial policy. The first list of 15 militarily critical technology categories was published in 1980.[12] Included were computer networking, large computer systems, software, design and manufacture of very large-scale ICs, and a number of others related to electronics—of the 15 categories, only 3 had little or no electronics content. The thrust of the exercise was to develop a systematic approach to export controls; as a result, it was narrowly focused on military applications, Despite the well-defined purpose—in essence to update and supplant the Commodity Control List—progress has been painfully slow, Once the 15 general areas had been determined, the effort bogged down in details. Critics doubt that it will ever be possible to agree on procedures for reducing the case-by-case reviews of export licenses that are now necessary. If nothing else, the continuing debate over militarily critical technologies—which in principle seem relatively straightforward to define—indicates how difficult it would be to devise criteria for entire *industries*. After all, these industries would be rewarded—not with export licenses that might add a few percent to revenues—but in at least some cases with substantial subsidies and other Government favors.

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[12] *Technology and East-West Trade: An Update* (Washington, D.C.: Office of Technology Assessment, May 1983), p. 37. A detailed critical technologies list published in classified form at the end of 1981 ran to 800 pages. Also see *Technology and East-West Trade* (Washington, D. C,: Office of Technology Assessment, OTA-I SC-1O1, November 1979), pp. 92-94,

Looking more narrowly at the electronics industry, consider again the situation created by imports of 64K RAMs from Japan and the resulting flurry of activity in the Federal bureaucracy. In December 1981, the Cabinet Council on Commerce and Trade authorized an interagency study of high-technology industries—carried out largely by the Department of Commerce.[13] Several months later, the Departments of Defense and Commerce began their joint examination of the national security consequences of 64K RAM imports, considering the advisibility of a more formal section 232 proceeding.[14] As pointed out in chapter 11, this section of the Trade Expansion Act of 1962 empowers the President to restrict imports in the event of harmful implications for national security; the remedies available include quotas or higher tariffs. At the time, domestic manufacturers were accusing the Japanese of dumping 64K chips–in fact, industry lobbying appeared responsible for much of the concern over national security .[15] Simultaneously, DOD was trying to convince the same group of Japanese firms to transfer some of their technology to the United States, as well as to produce components and equipment that would help meet American military needs. This was also the period when Texas Instruments was moving its 64K RAM production to Japan and Japanese firms were announcing plans to make these parts in the United States. A little later, the Justice Department announced its price-fixing probe of Japanese importers—investigating prices that might be too high instead of too low (ch. 11). Meanwhile, Congress was flooded with trade reciprocity bills, some motivated by trade friction in semiconductors.

Such is the circus for which a critical industries policy would provide the rings. Despite the concern generated by 64K RAM imports, the underlying national security question remains unanswered—a question which is in fact much broader than that of RAM chips or semiconductors in general. One way to frame the question—in the context of microelectronics—is as follows. As technologies become more complex and industries expand, opportunities for different countries to specialize in certain kinds of products grow; Japan's semiconductor manufacturers, at the moment, are specializing in RAMs. As a consequence, U.S. production might decline, with the result that the Nation could find it difficult to meet future defense needs, particularly in a situation calling for rapid mobilization.[16] Again, the point is that the ongoing dynamics of international competition hold one of the keys to policy choices.

So long as questions such as these remain narrowly defined—concerned with particular products or with classes of technology—it should be possible for policy makers to agree on priorities and make the necessary choices. In its recommendations for the fiscal 1984 defense budget, for example, the Defense Science Board ranked the following technologies in order of importance for future U.S. military systems:

1. Very high-speed integrated circuits, exemplified by the DOD R&D program (VHSIC) mentioned elsewhere,
2. Stealth aircraft.
3. Computer software.
4. Microprocessor-based teaching aids.
5. Fail-safe and fault-tolerant design methods for electronic systems.

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[13] *An Assessment of U.S. Competitiveness in High Technology Industries* (Washington, D, C.: Department of Commerce, February 1983]. The first paragraph of the summary states: "This study is being released as a Department of Commerce document. The methodology, findings and conclusions do not necessarily represent the views of other Executive Branch agencies" (p. iii).

[14] C. H. Farnsworth, "Japanese Chip Sales Studied, " *New York Times*, Mar, 4, 1982, p. D1. Also see ch. 11.

[15] On lobbying efforts by the industry, see "Horror Story, " *Electronic News*, Feb. 8, 1982, p. 12. One of the reasons nothing came of the Section 232 study was simply that 64K RAMs—new products in the marketplace-had not yet been incorporated into any U.S. weapons systems, thus, the national security implications of a supply interruption remained matters of speculation concerning future weapons needs and designs.

[16] Part of the reason is simply that the military market does not attract that many manufacturers. The 20 percent of U.S. electronics sales that go to the military are unevenly distributed; in some product categories, defense needs account for only a small fraction of output—*Electronics*, Jan. 13, 1983, pp. 128-140. In semiconductors, the military market is perhaps 10 percent of the total (fig. 34, ch. 5), and heavily weighted toward less sophisticated devices; during 1982, any 64K RAMs going to DOD would have been embodied in commercially available hardware for use in offices or laboratories, not weapons.

[17] See R. Connolly, "The Big 17 Future Technologies, " *Electronics*, May 5, 1982, p, 98.

Photo credit GCA Corp

Direct-step-on-wafer system for lithographic fabrication of integrated circuits

6. Rapidly solidified materials--e.g., amorphous metals with high strength and resistance to corrosion.
7. Computer programs for artificial intelligence.
8. Supercomputers for nuclear weapons design and computational fluid dynamics,
9. Composite materials.
10. High-density focal-plane arrays for infrared imaging.
11. Radiation-hardening techniques for electronic systems.
12. Space nuclear powerplants.
13. High-power microwave generators.
14. Technologies for erecting large structures in space.
15. Optoelectronics.
16. Space-based radar.
17. Short-wavelength lasers.

As many as a dozen of these are electronics technologies, or systems for which electronics is a vital element.

Given some agreement on priorities--of which lists such as that above might form one starting point—and recognizing that priorities would have to be reexamined and updated more or less continuously, what policy measures, beyond decisions on R&D funding levels, might then be called for to ensure that military needs were met? Almost certainly, such questions would have to be approached much as for those dealing with research priorities--i.e., on a case-by-case basis; given past experience in trying to define critical technologies for export control, formulating general criteria for an industrial policy based on national security would seem a hopeless task, one compounded by uncertainties surrounding mobilization scenarios. Furthermore, quite apart from debates over the needs of high-technology sectors like electronics versus basic industries like steel or machine tools, an industrial policy that set defense priorities consistently above civilian needs would be politically painful, Like all sectorally based policies, such an approach is susceptible to the criticism that other industries—and economic welfare as a whole—would suffer relative to sectors chosen for support.

One of the underlying questions—for this and other industrial policy alternatives-becomes: Given the policymaking environment in the United States, would this framework contribute to good decisions at the level of individual policy instruments, or would it simply confuse matters further? The Nation's policymaking system is not likely to change very quickly or very dramatically. As a result, one of the primary objectives of a more focused industrial policy for the United States can be viewed simply as a movement of the system toward better decisionmaking on the average. From such a perspective, it would seem more desirable to regard national security-particularly direct military procurement and production—as one factor to be weighed when making industrial policy decisions, but not the centerpiece. Where military security is genuinely at stake, DOD and the defense community generally prove more than capable of marshaling strong and effective arguments,

Critical Industries for the U.S. Economy

Could the United States profitably adopt a broader interpretation of critical industries, taking a leaf from the books of Japan or France —countries that have consciously tried to pick industries that will drive economic growth? This would be akin to an industrial policy built around support for "sunrise" industries, whose products or technologies will stimulate and support other sectors of the economy.

Such an alternative has its attractions. In principle, the Government could steer resources to sectors that would have a multiplier effect on the rest of the economy—or simply to those expected to grow rapidly, increasing employment and exports. In essence, an industrial policy that aimed at targeting such industries would be based on the premise that Government can do a reasonable job of predicting where the Nation's comparative advantages will lie in the future. This is part of what Japan attempts.

To pursue such an industrial policy successfully demands:

1. Prediction of the sectors that will be vital for future growth and competitiveness.
2. The design and implementation of Federal policies that will effectively support these sectors—strengthening their competitiveness in ways that markets alone could not or would not—but without creating unacceptable distortions or misallocation of resources elsewhere in the economy.
3. The political will to pursue such policies in the ordinary circumstance—when the pressures generated by declining firms and industries and their employees outweigh public perceptions of rewards for encouraging nascent industries.

The first of these is relatively easy, at least on the gross level. When the ability of Government to "pick winners" is questioned, the second and third points are generally at issue.

It is only a slight exaggeration to say that everyone knows where the winners will come from, For the United States and other advanced industrial economies, the current list includes, to take the most obvious:

- computers and semiconductors, along with related "information" technologies;
- programmable automated manufacturing;
- applications of biotechnology and genetic engineering;
- materials whose properties can be tailored for desired applications, especially polymers and composites.

Electronics has been at the top in many countries for years. Robotics and other forms of programmable automation are getting government attention in Western Europe and Japan, as well as through the U.S. Defense Department. Biotechnology is everyone's favorite example of an industry that should be supported now to reap dividends later. New materials—those with origins in both military and civilian applications—are steadily expanding in production volume. Such lists can be expanded or amplified upon almost ad infinitum, Places could be found for medical technologies, energy conversion devices, agriculture,

Once past the gross selection of winning industries, good policy decisions require careful analysis—but defining candidates for support is not, in principle, an intractable problem, If the chief objective is to stimulate economic growth, comprehensive support would not be needed (as it might be for militarily critical technologies). In electronics, good cases could be made for examples like the following:

- continued development of device technologies for high-speed, high-density ICs (gallium arsenide circuits and Josephson junctions as well as silicon-based devices);
- processes for submicron lithography;
- computer-aided circuit design methods;
- automated inspection of ICs and printed circuits based on computerized pattern-recognition;
- automated generation of computer programs, together with other methods for en-

hancing productivity in software generation;
- natural language programing and related topics in artificial intelligence;
- fiber-optics and, more broadly, integrated optics.

Such a list, still quite general, would eventually have to be refined further, as is normal when planning R&D. At finer levels, uncertainties will mount, technical judgments diverge. From the Government perspective, this means primarily that payoffs in a number of areas might be possible, leading to strong arguments for supporting competing technologies. Several approaches to submicron lithography look promising—ion beams, X-rays, electron beams; it would be foolish for Government to “pick” one of these.

One of the implications of the discussion above is that the Federal role might be primarily a matter of technology development. How might the Government design and implement programs in support of commercial technologies? The United States has extensive experience in funding military research and engineering, but little background in civilian sectors; the principal exceptions are agriculture and energy, and the record in the latter is hardly flawless. One possibility is simply to find companies with expertise and good track records, then give them Government aid, This could be research funding (including further initiatives such as the Defense Department’s internal R&D program, which sets aside money for industry-performed R&D on a “no-strings” basis to encourage innovation), a protected market, Federal procurements, loan guarantees, direct grants of investment capital—the list of possibilities comes from chapter 10 (see also table *82).*

From time to time, a number of European nations, as well as Japan, have followed policies that select companies for support. One example is CII-Honeywell Bull in France. The French have also built their integrated circuit program around chosen firms rather than competitive grants, although West Germany has taken the latter approach, Great Britain has channeled funds and procurements to ICL, capitalized the semiconductor firm Inmos. In Japan, a good deal of political jostling goes into the selection of participants for joint research projects such as the VLSI program or the fifth-generation computer effort. Experience in all these countries illustrates the pitfalls of company-centered support schemes. The European record, in particular, has been poor. Siemens has garnered the lion’s share of funding in West Germany, with little evidence of significant returns in the form of enhanced competitiveness to the German electronics industry as a whole. Britain has recently been forced to bail out ICL. Although Le Plan Circuits Integres seems to be faring better, France’s earlier Plan Calcul must be judged a failure.

Still, as in most of the countries experimenting with industrial policies, France appears to be learning from its experience: Le Plan Calcul supported a single company, while the microelectronics program has been structured to include an element of competition among several participants. In Japan, the record is rather different, MITI excluded Oki Electric from the VLSI project, believing that the company could not compete in advanced integrated circuits, Oki prevailed on Nippon Telegraph and Telephone (NTT) for help, and managed to enter the 64K RAM market. Given the multiplicity of competitive semiconductor manufacturers in Japan, this can hardly be judged a policy failure—but might have been in a country with a thinner array of prospective entrants.

In any event, direct aid for selected firms would not be an attractive option for the United States, going as it does against so many of our traditional attitudes, It is a big step from dropping the Government’s long-running antitrust suit against IBM to making that company—or any other—the Nation’s annointed champion. Precompetitive support, the approach taken by the European Community’s Esprit program—which falls more naturally under the next alternative for a U.S. industrial policy—would fit the American system better.

Nonetheless, an industrial policy that focused on R&D—and perhaps technology demonstration, for mature industries as well as growth sectors—would begin with technical questions that can in principle be evaluated in relatively straightforward fashion. DOD experience with R&D contracts and procurements offers a model, at least for the case in which Government is the ultimate customer. This last is a major difference between supporting a defense industry and a commercial industry–and one of the chief reasons for sticking to technology; product development for civilian markets is a much riskier and less certain undertaking. Nevertheless, DOD's record–if littered with failures or partial failures in individual programs—does show that in an overall way the Federal Government can support and develop industries, particularly given procurement authority. On its results, the U.S. space program must also be judged a clear-cut success. Of course, that the Nation is militarily strong, or that the space shuttle flies, does not mean that the processes involved in reaching these objectives have been efficient, For an industrial policy aiming at economic development, however, efficiency is more urgent. If the ultimate goals include raising the standard of living—and this will always be one of the principal arguments in favor of an explicit industrial policy for a country like the United States—then improving productivity, economic efficiency, and international competitiveness become vital. As a spur to efficiency, competition for Government largess is a poor substitute for the marketplace. This does not imply that targeted R&D support for growth industries—where judgments can be made largely on technical grounds—might be counterproductive so much as that supports and subsidies going beyond technology could be.

Capital for Investment

Of the variants of supports and subsidies, channeling investment capital to selected industries has attracted a good deal of attention in the United States. The goal would be to enhance the competitiveness of industries that might be either growing or in decline. Advocates of such an approach—in essence, urging programs that would function as development banks or a Reconstruction Finance Corp.—focus on the cost and supply of funds as a bottleneck for critical or growing industries. Investments in ironmaking or integrated steelmaking, for example, have not been attractive in recent years; prospective investors can expect higher returns elsewhere. If the steel industry were judged critical, the Government could step in—as indeed it has in a very limited way—with loan guarantees or other forms of subsidized capital. Conversely, firms in some industries might be expanding so rapidly that they have difficulty in financing expansion—the case described in chapter 7 for portions of electronics. Venture capital markets tend to be spotty; at some stages in their development, entrants in high-risk sunrise industries may find themselves starved for capital because investors judge returns to be uncertain or too far in the future.

If capital constraints pose genuine problems for industries judged vital to U.S. interests, the Federal Government might indeed choose to respond with mechanisms such as a Reconstruction Finance Corp. or a publicly backed institutional supplier of risk capital. But *are* critical industries starved for funds? In countries where capital markets are less developed than in the United States, they may be—particularly where venture financing is hard to come by or simply unavailable, West Germany—even Japan—has experimented with government-financed venture capital programs, as has Great Britain with its National Enterprise Board.

That governments in some countries intervene in capital markets does not imply that public sector decisionmakers can do a better job of balancing risks and rewards than those in the private sector, but that the government has different criteria—namely, that the public welfare is paramount for government, rather than private returns to capital. Indeed, governments can set priorities ranging from maintenance of the defense base to employment stability or calming political turmoil. National defense and employment have been particularly strong motives in Europe,

In the United States, too, Federal assistance to troubled firms has occasionally taken the form of loan guarantees or similar forms of capital subsidy, An overextended corporation in competitive difficulty will sooner or later find its access to financing cut off: examples include Lockheed, Chrysler, McLouth Steel, Braniff, International Harvester, The Federal Government aided the first two; McLouth has been rescued, at least temporarily, by a private investor; part of Braniffs aircraft fleet has been repossessed; International Harvester's fate remains in its own hands, If the Federal Government decides—on whatever grounds—that established enterprises which have fallen on hard times are indeed essential, precedents exist for bail-outs on a case-by-case basis. Should it regularize procedures for bail-outs? What about the more general situation? Should the Government take steps to make capital cheaper or more easily available?

If the Government were to channel investment funds to growth sectors, one reason would surely be to interject criteria other than those applied in capital markets—e.g., some broader notion of the public interest, rather than simply financial returns; where this is the case, capital subsidies are but one among many policy tools that Government might choose. On the other hand, it might be that the market does not do a good job of evaluating long-term opportunities where rewards are far in the future, risks high.[18] In many instances of new technologies or entire new industries, social returns have exceeded private returns, creating a particularly potent argument for Government action where the developments in question would have a multiplier effect on productivity or competitiveness elsewhere in the economy—e.g., microelectronics or biotechnology. Innovating firms in growth technologies or growth industries may not, for a variety of reasons, be able to capture all the rewards of their work. In the extreme, they may go out of business; economic history is littered with examples of early innovators who have failed, but whose ideas have later been picked up by others. This is one of the ways in which markets work—some innovators are a few years ahead of their time. In other cases, a business failure may be quite unrelated to new technology. Many of the pioneering semiconductor firms have disappeared; while typically absorbed by other companies, the circumstances have occasionally been such that financial rewards were slim.

The case for an industrial policy that channels capital toward long-range technology development or growth industries–especially to sectors where the effects will spill broadly over into the economy at large, giving social returns in excess of private returns—is then quite different from that for subsidizing sectors having trouble competing for investment funds because of stagnation or apparent decline. In the end, this second class—decisions on bail-outs—hinges, not on questions of capital markets, but on the justification for Government aid of any sort. If troubled industries are judged critical, and deserving of support, then capital preferences are one of several tools Government can chose from. The high-risk, growth industry case depends largely on the ability of Government decisionmakers to evaluate social returns and spillover effects, and to determine when innovators are likely to go unrewarded because the nature of their activities makes full capture of returns unlikely. Such analyses must be made on a case-by-case basis. Given recent examples of venture funding in microelectronics, computer software, robotics, and biotechnology, it is hard to argue in *general* that money for new and promising startups is not available; as pointed out in chapter 7, some observers have concluded that risk capital has been going even to projects with rather slim prospects. The cyclicality of venture capital markets is another question, as is that of gaps at stages such as pre-startup.

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[18] The market failure argument for government inter rvention in capital (and other) markets is outlined in *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles,* op. cit., 1)1), 176-177. Basic research—where virtually by definition the rewards cannot be fully captured by the performing enterprise—is perhaps the plainest case.

In electronics, costs of capital—more fundamentally, sources of capital to sustain growth at high rates in the face of rising capital intensity—are matters of concern primarily for established companies that have already demonstrated their competitive ability. It would be difficult for Government to justify subsidies in the form of capital allocations, low-interest loans, or loan guarantees for such firms.

In essence, that brings back one of the points raised initially—the political context for selecting critical industries. Even for an industrial policy that devolved into a support scheme restricted to R&D and technology development, politics will perturb decisionmaking—decisions made by business as well as Government. As the experience of the Defense Department shows, company-funded R&D will tilt toward areas where eventual Federal support is more probable.

So long as the goal is relatively clear to all–i.e., military security—the political dimensions can be managed. National defense as an objective of public policy generates little controversy; disagreements center on the means. On the other hand, if the objective is competitiveness or economic efficiency—particularly in some nebulous future—then the less-than-concrete nature of this goal, and the intrinsic complexity of the supporting analysis, can easily contribute to obfuscation, confusion, and conflict. If the stakes are high, not only may politically powerful industries, if in decline, oppose programs that reward industries judged critical, but they will try to show that they are critical too. Growth industries might find themselves fighting among one other for the biggest slices of the pie. Can a board of experts inside the Government—or an advisory body including representatives of industry, labor, the financial community, the public at large—make decisions that will stick in such an environment? An "industrial policy advisory board" or "reconstruction finance board''—retired industry executives, leaders of Government and labor, well-known academics–might have the ability to make good decisions, particularly if backed by a competent staff.[19] They would have to be politically sensitive simply to keep the effort alive and pointed in the right direction. But is it realistic to expect that, even if good decisions were made, they could be implemented—given the political pressures—with any consistency? If not, such a process would be a poor substitute or supplement for U.S. capital markets. On the other hand, if Government support is modest enough to avoid conflicts, will not any positive impacts be equally modest?

Alternatively, the Government might choose simply to protect critical industries from trade pressures—adopting an essentially passive policy, rather than active support; one result might be to shift the risk/reward expectations of private investors. Protection for infant industries is a common element in the industrial policies of many countries, some of whom—notably Japan—have been accused of overdoing it. But in the end this is simply a variant on the more active approach, with most of the same pitfalls. It assumes, first, that protection will be—if not essential—at least a positive factor. Others would argue that exposure to foreign competition stimulates a nation's own industries, at least over the longer term. A country attempting to develop an industry where foreign enterprises are already strong may have a good case for protection. Even the United States—which is in a position to enter new industries at the same time as its competitors if not ahead of them—might choose to protect infants if competing nations try to protect their own. Absent this motive—and granting that it is counterproductive, if not impossible, to shield *all* industries—picking sectors to be protected would create much the same set of problems as picking some to receive capital preferences.

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[19] For a typical suggestion, see L. C. Thurow, "Solving the Productivity Problem," *Strengthening the Economy: Studies in Productivity* (Washington, D. C.: Center for Democratic Policy, 1981), p. 18.

Infrastructural and Adjustment Policies

The thrust of this policy alternative—of the five, perhaps the hardest to summarize concisely—would be to create an environment that would aid private firms in strengthening their own competitive ability. As table 82 indicated, it would do so by relying preferentially on measures that support the infrastructure for industry—technology development (including R&D, incentives for innovation, diffusion of technology within the domestic economy), human resources (education and training, particularly in technical fields and including continuing education and retraining), and structural adjustment (measures that encourage mobility of capital and labor, investments in growth industries, competition domestically and internationally).

By designing policy instruments that target particular industrial sectors only under special circumstances, instead relying preferentially on measures that affect the economy in more aggregate fashion—often policies that fall in the category of market promotion—the United States might avoid the pitfalls of an industrial policy with a strong sectoral thrust.[20] Aiming to build future competitiveness, the role of the Government under this alternative would be to encourage beneficial change, while smoothing the negative impacts of adjustment.

Central to such an industrial policy is a sense of dynamics—the reality of change over time in national economies, in the world economy. Government policies that run counter to ongoing shifts in patterns of trade, competition, or technology are seldom effective in more than a marginal sense; they rarely succeed in reversing ongoing transformations, although perhaps slowing them. They can aggravate the associated dislocations. In contrast, policies that work in parallel with—even reinforce—processes of economic and technological change, or that aim at smoothing adjustment and easing dislocations, are more likely to have positive effects. This third alternative for a U.S. industrial policy flows from recognition that comparative advantages shift over time, with the result that some industries in some countries will thrive while others decline. Often the arc of growth or contraction is obscured by short-term fluctuations; sometimes declines prove temporary, expansion resumes. The U.S. textile industry is a case in point; the emergence of synthetic fibers provided an opportunity for revitalization through new investments that greatly increased productivity.

As the textile example illustrates, new technologies are one of the forces that can spark renewal. Rather than trying either to anticipate or counter them, governments can accept the reality of such shifts and work toward maximizing their positive impacts, minimizing the negative, Public policies that function in this fashion include:

- Aid and stimulus for the *development of new technologies,* which might range from money for R&D to improvement of the patent system.
- Better mechanisms for the *diffusion of technology* to industry, particularly to smaller companies; one possibility is a network of federally supported centers with this mission.
- Tax incentives or other aid for firms that install *manufacturing technologies* aimed at improving productivity and competitiveness—whether new production processes or those that are well-proven; examples range from microprocessor-controlled heat treating furnaces to robots.
- Support for *training and retraining* of employees displaced by economic change—those in blue- and grey-collar ranks, as well as professionals; this might entail encouragement of company-sponsored *continuing* education programs, as well as policies that would support training and retraining irrespective of the boundaries of particular companies or industrial sectors.
- Improvements in *vocational-technical ed-*

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[20] Market promotion policies are defined and discussed in *U.S. Industrial Competitiveness; A Comparison of Steel, Electronics, and Automobiles,* op. cit. , pp. 155 ff; also pp. 175-182. Examples include antitrust, support for R&D and innovation, plus policies directed at labor and capital markets—e. g., for enhancing the mobility of capital and labor in response to changing economic conditions. The latter are commonly referred to as adjustment policies.

ucation at the post-high school level, with particular attention to skills that will be needed as a result of predictable changes in the composition of U.S. industry—e.g., computer-aided drafting and manufacturing, service and repair of electronic systems.

- Continued emphasis on high-quality *engineering* education—backed by renewed Federal resource commitments—in fields such as electrical and computer engineering, materials science and engineering, design for automated production, and the wide range of other specialties that will be needed for continued growth in high-technology industries.
- In particular, renewed emphasis in universities, supported by Federal funds, on *engineering design and on manufacturing engineering—aimed* at upgrading the quality of the work force in these professions and bringing them more fully into the mainstream of the engineering sciences.
- Tax and other policies aimed at increasing the rate of *capital formation,* more especially at encouraging investments in emerging or rapidly expanding industries, as well as investments in R&D and in manufacturing technologies that will increase productivity in industries already well established.

Depending on the design of the instruments, such a list could also-fit quite comfortably under several of the other policy orientations discussed in this chapter.

Infrastructural Support

Human resources—defined broadly to include management styles and techniques that maximize the contributions of individual employees—are crucial for competitiveness. Any industry depends on the skills and abilities of the people it employs; chapter 8 outlined the current problems in technical education in the United States, as well as the general decline in technical literacy among the public at large, Education and training are traditional domains of public policy. Declining emphasis on technical and scientific training in American schools—as well as high unemployment alongside unmet demand for those with skills—point directly to problems calling for Federal action, Among the questions to be faced are: What should people be trained in, beyond the obvious needs for at least minimal competence in reading, writing, and mathematics? *How* can retraining best be accomplished? Within industry? Through community colleges and vocational educational programs? Whatever the response, it must incorporate a foundation for continuing learning—on the job and off—if people are to keep pace with advancing technology. Widespread public attention focused on such matters over the past year or two, together with new initiatives emerging from Congress and the executive branch, are positive signs; the danger remains of a response that will prove too little and too late.

Tax policies can create incentives for private industry to train or retrain workers, engage in R&D, invest in new production facilities. Still, incentives alone do not always suffice—one example being long-term basic research of the sort that undergirds industries like electronics. Only the larger firms find it in their self-interest to support much basic research; the foundation for the semiconductor industry, for instance, came in considerable measure from Bell Laboratories. However, the unique circumstances that caused Bell Labs, first, to perform a good deal of basic research, and, second, to help diffuse the results, seem bound to change as AT&T restructures and adapts to its new circumstances. Other large electronics companies —IBM, Texas Instruments, General Electric— also perform substantial amounts of basic work, although it has been less accessible to the R&D community at large. At various times, Government laboratories and Government-funded research have made significant contributions—currently, the more basic elements in the Defense Department's VHSIC program, as well as the $20 million per year that the Defense Advanced Research Projects Agency is funneling into gallium arsenide.

Despite these examples, the level of research that supports the U.S. electronics industry is less than adequate. This is shown most graphically by plans, originating within the industry itself, for joint R&D. Both the Semiconductor Research Cooperative, organized by the Semiconductor Industry Association to fund university projects, and Microelectronics & Computer Technology Corp. (MCC), an independent profit-seeking venture, are aimed at similar needs—technology development that will benefit a range of firms. The aims are to avoid excessive duplication, help diffuse research results, and undertake projects with longer time horizons than individual companies feel they can afford. Still, it is not at all clear that such efforts will fill the research—as opposed to advanced development—vacuum. For example, MCC will concentrate initially on four areas: computer-aided integrated circuit design; computer architectures, especially those designed with artificial intelligence in mind; productivity improvement techniques for software generation; and interconnections and packaging for microelectronics devices.[21] Three of these, if not all four, are well removed from the basic end of the spectrum. Likewise, the Semiconductor Research Cooperative has announced plans to develop prototype large-scale RAMS–an effort quite divorced from basic research. In any event, as part of its industrial policy the Federal Government could find positive ways to aid such joint research efforts; if direct assistance were not forthcoming, at least the Government could takes steps to see that public policies—e.g., antitrust enforcement—do not hinder R&D that could be vital for the competitiveness of U.S. industry.

Antitrust, one of the fundamental varieties of market promotion policy, is indeed showing signs of strain in the United States. As good an example as any is the seemingly pervasive concern of business executives that behavior they regard as innocuous—for instance, multifirm R&D efforts such as MCC proposes to undertake—will be subject to antitrust complaints. More fundamentally, when U.S. antitrust laws were drafted, most economic competition was a purely national affair; now in many industries it is worldwide. When American firms seek to cooperate in R&D, what weight should be placed on cooperation as a response to foreign joint R&D activities--sanctioned by governments and often funded by them as well? The case for trying to reduce the duplication of effort accompanying simultaneous pursuit of similar R&D objectives is, of course, strongest at the basic research end, fading as development is approached. In industries like semiconductors and computers, companies typically *want* to compete at the development end of the spectrum, and Government in the United States has encouraged this; in these highly competitive fields, American companies find it difficult to cooperate and probably always will (Japanese firms are not dissimilar). Nonetheless, antitrust enforcement seems to be a constant in business complaints over Government regulation, and a real barrier—although perhaps as much psychological as legal—even when firms desire to cooperate only in basic research, The guidelines on joint R&D published by the Justice Department in 1980 have done little to lower this barrier, ” Moreover, the point at which cooperation in R&D moves from being efficient and productive to inefficient and counterproductive will be industry- and technology-specific. Neither the Department of Justice nor the Federal Trade Commission seems very well prepared to deal with such questions.

The Federal Government can also play an important role in stimulating industrial development by helping ensure an open trading environment—something individual firms are ill--equipped to do on their own. Open trade would complement this policy alternative as well as the last two to be discussed. Indeed, for the next alternative—support for U.S. firms exporting or operating on a worldwide basis—it would be the centerpiece. In contrast, for the policy approach under discussion here, export

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[21] C. Barney, "R&D Co-op Gets Set To open Up Shop," *Electronics*, Mar. 24, 1983, p. 89.

[22] See *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles*, op. cit., pp 184-185, for a review of antitrust law and enforcement, including the joint research guidelines As pointed out earlier in this chapter insight into executive branch intentions concerning antitrust enforcement must often be gleaned from sources which go unpublished—e.g., speeches at bar association meetings.

success would be ranked as but one among a number of goals.

Government efforts to reduce trade barriers —direct and indirect—contribute in immediate fashion to structural adjustment. An industrial policy intending to promote competitiveness should press for fair treatment of U.S. firms that export or invest overseas, as well as for vigorous competition within domestic markets. Thus, trade policies could take their place along with adjustment measures aimed at facilitating flows of capital and labor from static or contracting industries to those with good prospects for expansion and future competitiveness.

Adjustment

In many ways, facilitating structural adjustment lies, together with technology development, at the heart of this alternative, Adjustment policies are those that encourage movement of resources within the economy in response to market signals, as well as mitigating negative impacts—on sectors in decline, groups of workers affected by shifting competitiveness or technological change, particular communities or regions. While the United States has experimented with a variety of such measures in the past—ranging from Trade Adjustment Assistance (TAA) for employees who lose their jobs because of import competition to the many local and State development programs aimed at attracting new industry—few of these have functioned well. In particular, measures intended to aid workers or communities suffering from adjustment woes—TAA, administered by the Department of Labor, the Commerce Department's Economic Development Agency—have come to be widely regarded as failures.[23] This is one reason the current administration has turned away from Federal efforts at adjustment, arguing that markets—and those affected by them—should be left to their own devices.

There is no question that many Federal initiatives aimed at easing adjustment—including TAA, which functioned largely as a form of supplemental unemployment insurance rather than a positive aid to those seeking new skills and new jobs—have been less than successful. But the argument for falling back on the market, leaving those affected to shift for themselves, is weak; the people involved have little control over economic events or impacts, The plight of the individual is far different from that of the corporation. Rationales for adjustment assistance are well-accepted; they are grounded both in improved economic efficiency and in social equity.[24] It is true that market mechanisms will suffice for economic adjustment—in the long run and in an overall sense. However, the problems that adjustment policies are intended to remedy exist on a micro-level rather than in the aggregate. While U.S. experience with job training and retraining has not always been positive, the experiences of other countries (ch. 8) demonstrate that manpower policies can function effectively, If overall employment levels are a major objective, adjustment policies can play a mediating role between growing and declining sectors.

Consider the situation of an assembly worker in a color TV plant. As figures 57 and 59 in chapter 9 indicated, while employment levels have been declining in color TV, they have continued to rise in semiconductor production. But while the consumer electronics industry is concentrated in States like Illinois and Indiana, semiconductor firms have tended to locate in California. Since assembly labor in both industries is essentially unskilled, employers draw on local labor pools. It would make little sense for someone in Chicago who has been put out of work because of automation or foreign competition to move to Silicon Valley

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[23] Economic adjustment programs in the United States are briefly reviewed in *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles,* op. cit., pp. 155-156.

[24] Ibid., pp. 177-179. The efficiency argument is based largely on barriers to mobility that keep people from moving to seek work, also on the friction that retards wage declines in response to changing market conditions. The equity argument, in simplest form, holds that those who bear the brunt of adjustment suffer from causes outside their control while others prosper–also for reasons quite independent of their own decisions; under such circumstances, society as a whole has good reasons for easing the burden.

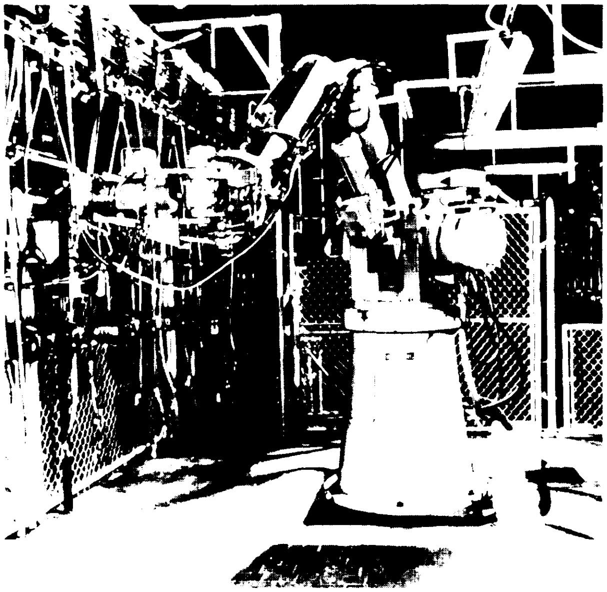

Photo credit Cincinnati *Milacron*

Robot transferring refrigerator compressors from one assembly conveyor to another

unless that person has specific skills that are in demand in the California labor market. Even then, relocation is a major hurdle, What sorts of assistance might Federal policies provide in this case? The obvious possibility is training in skills for which there is current need; even in the absence of relocation assistance, people would then have greater incentives to move to locations where jobs were available, The Government might operate the training program or simply provide financial assistance to those who could not finance schooling on their own.

Such programs can aid adjustment without introducing economic distortions. Much the same is true of supports for technology development and diffusion, Targeting the base and infrastructure for competitive industries—rather than targeting industries themselves—can contribute to economic efficiency without explicitly favoring some sectors of the economy, In this view, technology development and diffusion encompasses much more than simply R&D support. Indeed, diffusion—encouraging firms to utilize available technologies, particularly manufacturing processes that improve productivity—may, for many parts of the economy, be more vital than support for the development of *new* technologies.

Driving forces for technology diffusion and utilization vary dramatically across industries. Sectors at the forefront of technological change and international competition—semiconductors or commercial aircraft rather than consumer durables—must and do take advantage of the latest technical knowledge, There is less impetus in industries that are growing slowly or contracting; in the steel industry, American firms have often failed to install the latest production equipment, although this would save energy, improve labor productivity, and cut costs. One reason is simply that alternative investments promise higher returns. Yet it may not be wise, from the viewpoint of the economy as a whole, to wait until the need for more efficient production equipment mounts to very high levels—i.e., until payback periods are short. Manufacturing firms that lag in moving toward programmable automation or computer-aided design—perhaps because pressures to improve productivity and competitiveness build slowly at first—may at some point find themselves overwhelmed before they are able to react.

From a Government perspective, then, the primary objective of structural adjustment policies is to encourage resource flows-technological, human, material, capital—to the more productive and dynamic sectors of the economy, while providing assistance to workers and regions suffering from deteriorating competitiveness. For the United States, market promotion policies seem best suited to filling this role, but other countries have sometimes emphasized sectoral measures—picking winners and promoting them, for example—as a means to "positive adjustment. " This is much easier in simple economies, such as those of the newly industrializing countries.

Design and Implementation

What would be the likely effects on the U.S. electronics industry of an industrial policy oriented toward adjustment and infrastructural support? If one intent of such a policy is to encourage growing industries, the more dynamic sectors of electronics—computers (particularly smaller systems and software), semiconductors, instrumentation, robotics—would be logical beneficiaries. Electronics typifies ongoing structural shifts in the U.S. economy:

- growth in services, ranging from electronic banking and electronic mail to the production of computer software itself, many of these services made possible by cheap computing power;
- increasing relative demand for skilled workers—those with manual skills, as required for building, maintaining, and repairing advanced production equipment, and those with mental skills, as required of integrated circuit designers; and
- greater capital and R&D intensity associated with high technology.

Other growth sectors share similar characteristics.

The major assumption underlying an industrial policy oriented toward adjustment and infrastructural strengthening is that Government is capable in a general way of identifying the sources and impacts of economic change and designing policy measures that will speed the positive consequences while ameliorating the negatives. Government need not depend on sector-specific policies to accomplish this; much can be done with market promotion measures and other policies with aggregate objectives.

Industrial policies that call on Government to pick and choose among the sectors of the economy risk political defeat or deflection; furthermore, they depend on the ability of policymakers to devise programs tailored to particular sectors without gross sacrifices in overall economic efficiency, There are strong reasons for relying on market mechanisms where possible. Nonetheless, in many circumstances market forces alone are inadequate for achieving legitimate goals of public policy, Several of the cases were mentioned above: national defense, long-term basic research, Other times, Government actions may interfere with the operations of markets. Indeed, one of the fundamental tasks for industrial policy makers is to determine when markets are working well and when they are not.

The task of' devising policy measures appropriate to this third alternative for a U.S. industrial policy—what OTA has elsewhere termed macroindustrial policy—must therefore start with a strengthening of the Federal Government's analytical capability, Nowhere in Congress or the executive branch is there now the expertise to grapple with the evolving dynamics of industries or markets domestically, much less internationally, As in the case of a critical industries approach, the Government would need to begin by improving its abilities for identifying patterns of change, understanding the forces driving them, and formulating policy responses that would lead to desired policy outcomes. This is not an easy task, but it is certainly not impossible. Such a capability will be essential if U.S. industrial policies are to be redirected to support growth sectors, which almost by definition evolve in unexpected directions, As many examples in the short history of computers and microelectronics show, such industries follow paths that are full of detours and surprises, The reactive approach of the past, with Government policies are mostly responses to short-term economic and political pressures, is far from optimal.

Indeed, even if the goal were to defer as many decisions as possible to the private sector—the last of the five alternatives to be discussed—the Federal Government would still need a basis for deciding which responsibilities to retain. In any economy as complex as that of the United States, Government decisions influence business activities in many ways—often indirectly, and sometimes inadvertently, At the minimum, they do this through taxation, plus monetary and fiscal policies. To the extent that policy makers grasp the probable impacts of alternative courses of action, they can provide an environment that encourages international competitiveness. *Any of the five policy perspectives outlined in this chapter therefore implies an improvement in the Federal Government capability for analyzing industrial com-*

petitiveness and the effects of public policy on the activities of the private sector, Otherwise, industrial policy will be made in the future as it has in the past—by default—and other considerations will take precedence over competitiveness, productivity, and economic efficiency. In the absence of such analysis, successful implementation of a coherent and consistent industrial policy of any stripe would have to be judged something of an accident.

Promoting the Global Competitiveness of American Industries

An industrial policy directed at building the worldwide competitiveness of U.S. industries might be regarded as an extension of the longstanding thrust by this country toward open trade—a policy that would entail, not only continuing pressure to reduce tariff and nontariff barriers in all countries, but also active encouragement of exporting and foreign investment by American firms, Such an industrial policy would differ from the others discussed in this chapter first in its outward rather than domestic orientation. Drawing on past examples of industries that have expanded rapidly while marketing aggressively on a world scale—American manufacturers of computers or aircraft rather than steel or consumer electronics—a globally oriented approach to industrial and trade policy would be based on the presumption that active participation in markets all over the world is a primary route to maintaining competitiveness. Some advocates of such a policy would contend that if the U.S. consumer electronics and steel industries had, in fact, moved more decisively to export and invest overseas during the 1950’s and 1960’s, they would have been better positioned to maintain their competitiveness during the 1970’s. Worldwide marketing and sales, along with multinational production, are then viewed as central elements of this policy alternative—which is based on the premise that the most competitive industries and firms are those that prepare themselves to compete in the global marketplace,

The United States has been a leader in the movement toward an open world trading system since the later years of the depression. After the passage of the Smoot-Hawley Act in 1930, tariffs steadily decreased—from levels near 50 percent, to the range of 5 percent (ch. 11). Following the war, as the Marshall Plan helped to rebuild the Western European and Japanese economies, U.S. international economic policy was directed at promoting ‘‘free trade” through multilateral agreements such as GATT. This country provided much of the impetus for the establishment of GATT, and has almost always supported its efforts to lower barriers to international commerce; open markets have been viewed as an important objective of U.S. foreign policy, a vibrant world economy as central to the postwar political system.

Product Cycles and Structural Adjustment

This approach to industrial policy would take as a starting point the fact that some sectors of the economy, and some firms, will be better able to compete than others. Implicit are notions of product cycles and trade restructuring. The constant pressure of international competition, along with other forces acting on the world economy—particularly technological change—creates a dynamic of shifting comparative advantage. Manufacturers in countries at the leading edge of a technology introduce new classes of products first. In electronics, the obvious examples include digital computers, color television, dynamic random access memory chips, video cassette recorders—the first three commercialized by American firms, the last in Japan. As such products move through their lifecycles, the technologies they embody become better understood, easier for competing firms in other nations to duplicate, As a result, production costs grow more important—and manufacture spreads to economies that are not necessarily at the forefront of the technology Thus, terminals and small processors for computer systems are now made in many countries—although often by subsidiaries of American or Japanese firms; but while a nation like Brazil may have a burgeoning minicomputer industry, this does not mean it will manufacture larger mainframes. A few years after dynamic RAMs were introduced by American semiconductor firms, production was underway in Europe and Japan—by foreign manufacturers, as well as the overseas subsidiaries of U.S. multinationals; eventually, RAMs will be produced in countries like Hong Kong, South Korea, and Taiwan. The spread of color TV production has followed similar patterns; here, the comparative advantage of the United States has slipped further than for RAMs, and American firms have been able to maintain their competitiveness only by transferring manufacturing operations overseas, VCRs for consumer use were developed by Japanese firms, but as the technologies involved diffuse, production will begin in other parts of the Far East; it has already started in Korea,

Product cycles in most industries follow similar patterns; the common feature is specialization of production in parts of the world favored—at a given time—by comparative advantage. Thus the United States emphasizes agriculture and technology-intensive manufactured goods among its exports—along with services. Where wages are low, labor-intensive products are among the more competitive; to exploit high technology, countries need a well-trained work force—which normally will be well paid by world standards. An open system of international trade and investment is intended to allow product cycles to follow their natural course, with nations specializing in what they do best, Adjustment problems represent the darker side of the picture.

One rationale for an avowedly global U.S. industrial policy is simply the persistent concern that strains in the international trading system will undermine that system's openness. The most visible sign of strain is the proliferation of national industrial policies that, among other things, tend to protect local industries while discriminating against efficient producers in other countries. Another is the frequency of recourse to bilateral trade negotiations and agreements, rather than the multilateral appreach of GATT; prominent examples in the United States have included OMAs for color TVs, Western European nations have seldom been as committed to open trade as the United States, and disputes over steel, textiles, automobiles, and consumer electronics—ailing sectors in Europe as in this country—have led some observers to voice concern over revivals of protectionism, even trade war.

Slow and painful structural adjustments lie behind many of these pressures. Industries in advanced nations with large and complex economies seldom respond very quickly to change—increasing wages, escalating raw material and energy costs, technological advance, challenges from abroad, As living standards rise and social welfare programs proliferate, countries facing the need for rapid adjustment find that sudden and sharp dislocations bring equally swift political reactions, rather than the more or less resigned acceptance of earlier years and more primitive economies. Trade barriers are an easy response.

The Relation Between Open Trade and Industrial Policy

A global approach to industrial policy by the United States would find a natural anchor in the GATT system of multinational agreements. Absent special circumstances such as industries calling for protection, nations have tended to prefer the multilateral approach over bilateral negotiations—for consistency and to minimize discriminatory impacts on some nations, Advocates of a global approach stress the gains that producers in all countries can make if free to develop their own strategies, combining domestic and foreign resources in an open market system. A common corollary is to minimize restrictions on flows of technology, with barriers limited to those motivated by national security and arms control. Antitrust policies also fit naturally into an industrial policy oriented toward open trade and competition, Cartels and monopolies—international or domestic—are among the classic examples of market distortions, Because an industrial policy centered on open trade is motivated ultimately by faith in market mechanisms, antitrust would be an essential element. Domestic antitrust policies, along with multilateral agreements fostering competition, would complement reductions in trade barriers.

What would this fourth alternative for a U.S. industrial policy then look like? It might embody:

- international trade agreements, on a multilateral basis, aimed at further opening of world markets and at keeping them open;
- measures intended to ensure equal treatment of firms from all nations seeking to export or to invest beyond their borders;
- standardization of customs and other national regulatory procedures—product standards, as well as those those dealing with exports and imports; and
- competition policies aimed at preventing monopolization and cartelization in both domestic and world markets.

As the list implies, nontariff and indirect barriers to trade would need a good deal of attention—as indeed they will regardless of the direction of U.S. industrial policy. Measures such as those listed would have generally favorable impacts on the U.S. electronics industry—particularly if genuine success were achieved in dismantling nontariff barriers. Portions of the industry that are already highly competitive would be helped the most.

Promoting U.S. Trade Competitiveness

What else—beyond essentially passive measures aimed at opening markets—would be needed for an industrial policy that encouraged the global competitiveness of American industry? Compared to the early postwar years when GATT was organized, the environment for international trade has changed markedly. At that time, the economic and political strength of the United States was literally overwhelming. The United States was able to push its allies—some, such as Japan, rather reluctantly—into the international system. Japan's reaction was to establish a new set of government supports for domestic industry in anticipation of trade liberalization, but at least that country—and many others—made a commitment to membership in the international trading community.

Now, over 30 years later, political and economic power are more widely dispersed; the United States is still first among trading nations, but without the preeminence it once possessed, Forging international agreements is more difficult in a multipolar world. The electronics industry is no longer the province of a handful of technologically advanced Western nations, but the battleground for increasingly intense competition involving industrializing countries as well. With the traditional leaders exhibiting quite understandable concern, rapidly expanding economies in the developing world look both to invade the markets of advanced countries and to protect themselves from those a rung or two down on the ladder of economic advance. As nations at all levels adopt government policies in support of their own industries, severe trade frictions can easily develop–particularly when overall growth slows. In essence, the current system of international trade is suffering its own adjustment problems—it was conceived in a different era, and is showing unmistakable signs of age.

More concretely, negotiations of past years covered matters on which it was easier to reach agreement—primarily tariffs—than those of today. In the Tokyo Round, still lower duties were achieved. In a few instances, renegotiations on a bilateral basis have hastened reductions—witness Japanese concessions on tariffs for semiconductors and computers. While this process could certainly be pursued further—and might be expanded to include the European Community—many tariffs are already at low levels. As parity is approached, attention shifts to areas less amenable to international agreement: government procurement policies, R&D subsidies, indirect barriers. Here, discussions between the United States and nations like Japan have borne less fruit.

The protracted discussions over the procurement practices of NTT illustrate some of these complexities. After months of negotiation and debate NTT agreed, in 1981, to open bidding to foreign firms, but American companies have not had much success in selling to the corporation. While the Americans tend to ascribe this to informal barriers, the Japanese say U.S. firms are not trying hard enough.[25] Even rough symmetry in public sector procurement policies can be difficult to achieve when both corporate and government practices differ among countries. AT&T's decision, mentioned earlier, to give the Boston-Washington fiber-optics contract to its own subsidiary, Western Electric, is a case in point. Fujitsu, which entered the low bid, may (or may not) have offered a quotation below its reasonably expected costs in order to gain access to a rapidly expanding market, If it did so, the tactic is hardly unknown to firms outside Japan, AT&T's action was taken after intense lobbying efforts within the U.S. Government centering on claims that giving the work to a foreign enterprise would jeopardize national security.[26] After each such occurrence, it becomes more difficult for the United States to convince other governments that open trade is intended as a two-way street, Direct military procurement is, needless to say, an even more sensitive subject—one where national interests will necessarily remain paramount,

Given such considerations, a logical first step might be discussions on product standards and customs procedures, where differences tend to be visible and political controversy less intense. This is not to say that agreements would be easy or reach very far; the nations of the world have never been able to agree on standards for television broadcasting, electric power, or which side of the road to drive on. International discussions extending over many years aimed at settling on common designs for electrical outlets were abandoned in 1982 when it became clear that agreement would be impossible. Still, continuing progress in reducing nontariff barriers can be expected—albeit slow and painful. Many of these—e.g., government purchasing policies—are perceived as largely domestic issues; after all, people often feel that their own industries *should* be favored.

Export promotion—a recurrent theme in debates over U.S. trade policy—is another facet of the global approach to industrial competitiveness. Export incentives offered by the United States have often been criticized as weak and ineffective compared to those of other countries.[27] All trading countries employ export promotion measures of one form or another, even though these have generally been viewed as detrimental to a free and open trading system—particularly when they involve subsidies, as opposed to activities that function as advertising or related marketing aids. Subsidized export credits have been particularly controversial—e.g., the low-interest financing that Canada's Government offered to New York City for the purchase of subway cars (ch. 11).

The United States has recently taken a number of positive steps to help exporting firms. The Export Trading Company Act—easing restrictions on bank participation as well as providing protection against antitrust suits for firms that enter export joint ventures—which became law at the end of 1982 is one example. Estimates of the extent to which this act will help American exports and create new jobs vary considerably.[28] Consideration has also been given to finding replacements for the DISC (Domestic International Trade Corpora-

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[25] See R. Neff, "NTT's open Door Draws No Crowds," *Electronics*, Dec. *29, 1981*, p. 58.

‘e’’ Japan Runs Into America, Inc.," op. cit.

[27] See, for example, *Export Policy*, hearings, Subcommittee on International Finance, Committee on Banking, Housing, and Urban Affairs, U.S. Senate, especially *Part 3, Foreign Government Policies and Programs to Support Exports*, Mar. 9, 1978, *Part 6, U.S. Programs and Facilities Designed To Support Exports*, Apr. 5, 1978, and *Part 8, Oversight on Foreign Barriers to U.S. Exports*, May 17, 1978, Also *Export Stimulation Programs in the Major Industrial Countries: The United States and Eight Major Competitors*, prepared for the Committee on International Relations, House of Representatives, by the Foreign Affairs and National Defense and Economics Divisions, Congressional Research Service, Library of Congress, Oct. 6, 1978; H. L. Weisberg and C. Rauch, "A Comparative Study of Export Incentives in the United States, France, the United Kingdom, Germany and Japan, " International Division, Chamber of Commerce of the United States, Washington, D. C., 1979; and R. A. Flammang, "U.S. Programs That Impede U.S. Export Competitiveness: The Regulatory Environment," Center for Strategic and International Studies, Georgetown University, Washington, D.C., 1980.

[28] C. H. Farnsworth, "Measure Expected To Spur Exports, " *New York Times*, Oct. 5, 1982, p. D5; R. E. Taylor, "Law To Encourage Joint Export Ventures Is Expected To Be Signed by Reagan Today," ***Wall Street Journal***, Oct. *8, 1982*, p, 12. A particular aim is to help smaller companies wishing to export.

tion) mechanism discussed in the preceding chapter. DISCS have been determined to violate U.S. obligations under GATT, and tax incentives that might have comparable impacts on export competitiveness have been proposed.[29] In the United States, as concern over apparently slackening competitiveness has mounted, many in Congress—as well as the business community—have also called for changes such as modification of the Foreign Corrupt Practices Act. The resistance during 1981 to proposals for scaling back the Export-Import Bank illustrates the importance that many place on a more active approach to promoting U.S. exports,

Still, export promotion is a limited tool. The roots of international competitiveness lie in domestic industry—in the efforts of private firms to design, manufacture, and market goods. How these firms adapt to the realities of shifting comparative advantage and changing competitive circumstance outweighs government policies aimed at encouraging exports unless these policies function as subsidies of substantial magnitude relative to the costs of the goods in question. Even then, no government can promote all exports all the time. In the longer term, therefore, export promotion seldom has major effects on trade competitiveness. Of course, in a given case it may make all the difference: promotional measures can help firms and industries in temporary difficulty; they can be useful as a means of equalizing competition by matching the efforts of other governments; they can help private industry get a foothold in new markets. But export promotion cannot reverse the tides of competitive change,

It is precisely this point that an industrial policy aimed at promoting the global competitiveness of U.S. industries would have to confront—and on which it might founder. A nation can certainly promote its industries; but no matter how extensively it does so, all its industries cannot export at once. There will always be winners and losers in world trade. A strategy aimed at promoting fair and open global competition implies that the mix of American firms able to take advantage of opportunities in the world marketplace would change over time—perhaps rather swiftly. It also implies involvement of foreign firms in U.S. markets—through direct investment as well as exports. More so than the other four alternatives—and especially a domestic market preservation strategy, which would take penetration by foreign firms to be, in and of itself, cause for concern—a global approach placing high priority on market access for entrants from all nations could be politically difficult to implement. As pointed out earlier, when firms and their employees in declining industries combine, their influence can outweigh that mustered by the friends of open trade. The negative implications for some sectors of the American economy might be difficult for an avowedly global U.S. industrial policy to deal with—particularly given the poorly developed adjustment mechanisms the Nation has in place.

The United States is already experiencing the considerable hardships that cities, regions, and occupational groups face when industries lose competitiveness slowly, as happened with the American steel industry—or, even worse, rapidly, as in the automobile industry. Whether or not these declines are permanent or transitory, the hardships are debilitating, and an industrial policy encouraging open world trade could bring such changes more quickly. The primary argument against a global promotional strategy then lies with these short-term negative impacts; extensive promotion of U.S. industries—without better methods for dealing with questions of adjustment—could place a heavy burden on those sectors unable, for whatever reasons, to compete effectively. In the long term, a global strategy might increase economic opportunities at the aggregate level, but in the meantime the price could well be judged too high. This will be particularly true to the extent that economic growth is slow; rapid expansion gives companies, employees, and communities adversely affected by rising foreign competitiveness a broader array of alternatives.

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[29] "Administration's DISC Substitute Bill Introduced in Both House, Senate," *U.S. Export Weekly*, August 9, 1983, p. 685.

Progress toward an open environment for world trade has never come easily; today, the pace of change may have picked up, interdependence risen, but the basic arguments in favor of trade between nations have not altered. The fundamental assumption underlying this fourth alternative for a U.S. industrial policy is that an open world trading system is in the long run interests of all nations. In the United States, despite periodic bouts of protectionist rhetoric, both parties have generally supported the proposition—flowing directly from notions of comparative advantage—that if each country devotes its efforts to goods for which it is, relatively speaking, an efficient producer, net economic welfare will be maximized. provided that world trade is not greatly impaired by tariff and nontariff barriers, the exchange of products and services among nations will permit people everywhere to attain standards of living that are as high as their resource endowments and state of development permit. An industrial policy based on this premise—a premise as true today as a hundred years ago—could be viewed as an extension and reinvigoration of traditional U.S. attitudes.

An Industrial Policy Centered in the Private Sector

A fundamental reason why there has been no coherent or consistent industrial policy in the United States has been the widespread belief that corporate executives rather than Government officials have not only the ability but the right to make decisions that affect business activities. While many disagree with this view, the political power of organized labor, consumer groups, and others who advocate a stronger Government role has had more impact on relatively narrow questions such as rules for collective bargaining or environmental protection than on matters of trade and competitiveness,

One of the more pointed indications of the state of Government-business relations in the United States is the attitude of the business community toward the Department of Commerce. Nominally the center of advocacy for business interests within the Federal Government, the Commerce Department is a weak sister among Cabinet agencies—not because corporations in America are weak, but because business and industry do not take the Department very seriously, and often bypass it.

At a time when some Federal officials join with spokesmen for industry in anti-Government rhetoric, the feeling that public agencies can do nothing right naturally grows. A more positive view might acknowledge that performance varies in both private and public sectors—that the ups and downs of an International Harvester or a Chrysler Corp. may not be all that different from the ups and downs of a Government agency. Nonetheless, there are political and institutional realities—many reviewed in earlier sections of this chapter—that must be altered if the Federal Government is to design and implement a more coherent industrial policy. The most pressing need is for a better developed understanding among Federal agencies of how industries actually function. Advocates of this fifth and concluding policy alternative believe—at least implicitly—that Government cannot hope to succeed at this, and should not try; they want to "get Government off the backs of industry, " and leave the private sector free to compete with minimum interference .[30]

Of course, some Federal involvement in the affairs of industry will always exist—a minimal level is necessary, indeed is one of the reasons governments exist. But advocates of an approach maximizing private sector responsibility for industrial policymaking argue that the narrower and more limited the Government's role the better. Beyond the posturing that afflicts such questions, the argument becomes: Government involvement in economic affairs

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[30] When polled, corporate managers in the United States and Japan respond very differently on questions dealing with government "planning. " When asked whether their economy would benefit from: 1) more Government planning; 2) about the same amount; or, 3) less planning, 90 percent of American managers responded that less Government planning is called for; in Japan, the response was evenly divided among the three alternatives. See "Perspectives on Productivity: A Global View, " *American and Foreign Attitudes on Productivity,* hearing, Committee on the Budget, U.S. Senate, June 3, 1981, p. 64.

is counterproductive because it distorts market mechanisms; governments too often subsume or override the economic rationales for private choices, on both supply and demand sides.[31] Under these circumstances, economic efficiency decreases—to the presumed detriment of all. From this perspective, an industrial policy—whether intended to encourage economic growth and development or, at the other extreme, emphasizing regulations and constraints on business activity—must seem bound to weaken U.S. competitiveness. A related argument holds that Federal regulations cost industry and the public treasury more than the social gains set against them. The most extreme view is held by those who argue that *any* Government action impairs market mechanisms and hinders efficiency; a more moderate attitude grants the Government a place where market imperfections can be unequivocally demonstrated. A still more centrist perspective—the one to which the rest of this section is directed—holds that the appropriate role for Government lies in creating a climate conducive to economic growth, giving industry access to the tools for its own development. In many respects, this attitude is a traditional one in the United States, viewing macroeconomic policymaking—control of the money supply, taxation, Federal spending—as legitimate, but otherwise believing that Government intervention in economic affairs is to be tolerated mostly as a last resort.

Entrepreneurship has been a driving force for American industrial development, with business and Government coexisting rather uneasily, but an industrial policy that would defer where possible to the private sector does not, then, imply that Government plays no role at all, Public policies aimed at promoting capital formation would be consistent with such an approach; so would, presumably, regulation of business practices widely considered unfair or predatory, export promotion measures of at least some types, and a trade policy that otherwise supported American business interests overseas. What this alternative rules out first and foremost would be attempts to develop sector-specific policies targeting key industries—be these housing or semiconductors or energy,

Such an approach to industrial policy would be consistent with recent emphasis on reducing Federal spending and trying to control budget deficits, scaling back regulations, and cutting corporate taxes. This policy direction would, ideally, expand the financing available for dynamic and competitive firms while leaving them free to make their own business decisions. It would, at the same time, avoid subsidies for declining industries or firms, just as it would eschew attempts by public officials to select and support growth industries. To those favoring such a policy, it is the best hope of the United States for maintaining its international competitiveness into the future,

Central to this policy option might be tax and other measures aimed at capital formation. The rationale for the Economic Recovery Tax Act of 1981 (ERTA) was precisely this: Government policies aimed at promoting savings and investment were held to be the engines of growth for reviving the U.S. economy. As discussed in chapter 7, there is little evidence as yet that ERTA will serve this purpose, but its passage could be taken as a sign of movement in the direction of an industrial policy that would leave corporations to their own devices. Nonetheless, such a policy direction would have to be judged one that, rather than moving away from the fragmentation characterizing past U.S. industrial policies, reinforces this fragmentation. The reason is simple: without any evident justification, ERTA increases differentials in tax treatment across sectors of the economy (ch. 7).

On the other hand, movement toward deregulation of business activities represents a shift toward greater policy coherence to the extent that real progress is made in cutting back the total number of regulations, the conflicts that may exist among these, and the number of

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[31] One of the more thoughtful expositions of this viewpoint is *Redefining Government's Role in the Market System: A Statement by the Research and Policy Committee of the Committee for Economic Development* (Washington, D.C.: Committee for Economic Development, July 1979),

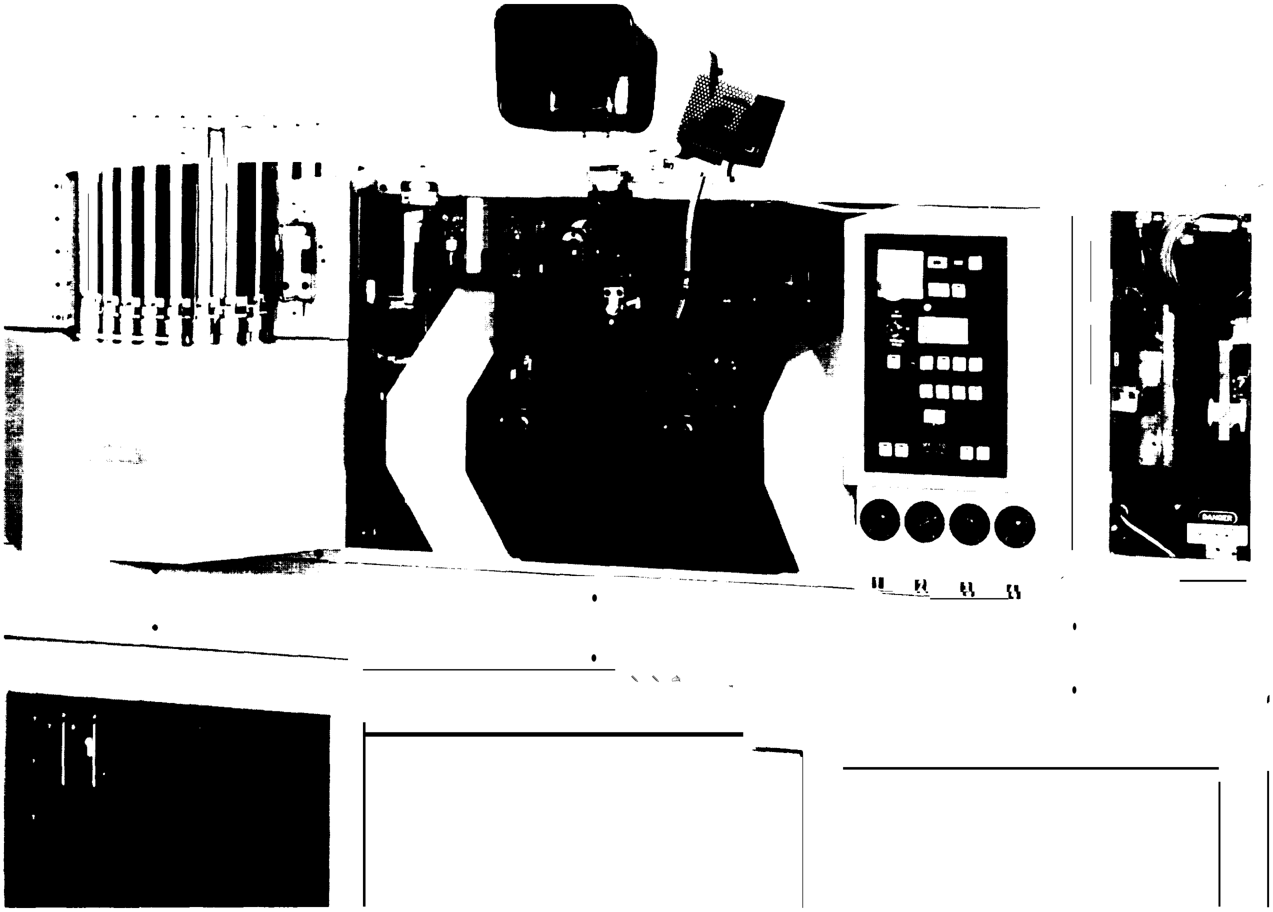

Photo credit Universal /instruments Corp

Automatic assembly machine for placing leadless carriers on ceramic substrates

agencies that administer them. Of course, to be effective in bringing a greater degree of consistency and harmony to regulatory policy, any move toward deregulation must proceed without creating a set of 50 differing regulatory policies at the State level.

In years past, Government regulations gradually developed into a set of constraints on private enterprise that—despite undeniable positive benefits—have often been judged inefficient. While the adverse impacts of regulatory policy on the competitiveness of American industries have frequently been overstated, regulations have had at least a small effect in dampening overall rates of productivity growth.[32] Even so, when Federal regulations are examined sector by sector, there are few cases of large and unambiguous adverse impacts on competitiveness. More often, the effects of regulation have been of the same general magnitude as for other public policies—having positive as well as negative effects on different sectors, different companies. At bottom, the most cogent criticism of Federal regulatory policy is simply that individual measures have too often been implemented without

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[32] E.F. Denisen, "Explanations of Declining Productivity Growth, " *Survey of Current Business,* August 1979, p. 1.

any explicit attention to the consequences for productivity, competitiveness, and economic efficiency—i.e., lacking even a rudimentary balancing of benefits against costs. This is hardly surprising given that most though not all regulatory policies are directed at objectives quite unrelated to competitiveness: clean air and water, safe products, minimization of workplace hazards. It may even be true that regulatory policy as a whole has come to be confused as well as sometimes inefficient, and that regulatory rulings have hindered industrial development while not always being effective in their avowed purpose-for instance, protecting consumers. Certainly, advocates of deregulation cast U.S. policies in an unfavorable light compared with approaches sometimes taken by other countries-where regulations may even be used, on occasion, to encourage economic development. Broadly speaking, however, most advanced industrial economies subject private business to regulatory requirements rather similar to those in the United States. Japan, for example, has instituted environmental protection measures that are restrictive by any standard. Nonetheless, many in the American business community continue to call for a rollback of safety and environmental regulations, as well as antitrust enforcement,

To some extent, this simply mirrors traditionally adversarial relations between business and Government in the United States—attitudes that in some cases must share responsibility for declining U.S. competitiveness. For instance, the differences in response among Japanese and American automobile firms faced by regulation of exhaust emissions and fuel economy in the U.S. market were striking. As might be expected from examining the corporate strategies employed by Japanese firms in other industries, automakers like Nissan, Honda, and Toyota have looked at regulations as new opportunities for finding a competitive edge. Within corporate headquarters, Japanese executives may regard Government regulation just as bleakly as their counterparts in Detroit—but they attempted to make the best of the situation, as a long string of new model introductions beginning in the *1970's* attests.

As the discussion above implies, financial, tax, and regulatory issues would no doubt comprise the core of a business-centered industrial policy. Tax reductions and deregulation have been at the head of corporate agendas for years, In the context of electronics, tax policy is much the more important, regulations having seldom had much impact. Chapter **7,** on financial issues, shows the ability to fund expansion in the face of rising capital intensity to be one of the key uncertainties for rapidly growing electronics companies. Fast-paced technical change—making manufacturing equipment obsolescent—together with high costs of design and development and rising levels of foreign competition create new financing pressures in computers as well as semiconductors. Other rapidly growing sectors of American industry, particularly where technology moves quickly, can expect similar problems—stemming in part from the common desire of U.S. managers to finance growth with internally generated funds, as well as the declining role of stock issues as sources of financing for American corporations.

Would an industrial policy that cut taxes and reduced regulations, leaving other matters to the business community, help high-technology sectors? The answer hinges on how they would fare compared with other portions of the U.S. economy. In terms of taxation especially, the issue comes back to differential affects. Tax policies, even when designed to be neutral across industries, will never fully achieve this. The depreciation schedules enacted by ERTA are only one example. These will probably help other sectors more than electronics, simply because many electronics manufacturers were able to depreciate production equipment quite rapidly under the old law; their capital cost recovery periods have sometimes been shortened, but not nearly as much as in heavy manufacturing or primary metals. Firms earlier required to depreciate newly purchased assets over many years get much greater benefits in terms of internally generated cash flows from ERTA. They may also find their ability to attract capital from external sources enhanced relative to electronics firms. Furthermore, accelerated depreciation tends to benefit companics with substantial profits rather than new and growing concerns that may still be spending more than they take in. The larger computer firms, for example, maybe helped more than software vendors or semiconductor manufacturers, consumer electronics, where profits have been low for years, is not likely to gain much,

Is the example provided by ERTA typical of what could be expected from an industry-centered policy approach? If only because older and larger firms and industries tend to have more accumulated political power, the answer is probably yes; these sectors of the economy might be able to skew the policy process to their advantage, with newer industries suffering—if only in a relative sense, This is a major liability of an industrial policy that would defer where possible to business interests. Advocates of this policy orientation must be prepared to accept outcomes like the altered depreciation schedules in ERTA. Policy directions would continue to be determined largely by the political process, and the greatest rewards would probably go to the sectors that—together with their employees—could muster the greatest political strength. These are likely to be older, well-established industries—particularly those whose employees are unionized. Where such industries are suffering from international competition, they will seek to shape policy in ways that preserve their markets, profits, and jobs.

Of course, the electronics industry has been active and successful in its past lobbying efforts, and would be able to look out for itself under an industry-centered approach. ERTA legislation included a number of measures that electronics firms had actively sought, including the R&D tax credit and changes in tax treatment of income earned by Americans working overseas, These offer direct benefits to the electronics industry, particularly the R&D provisions. In addition to the tax credit, which permits a writeoff amounting to 25 percent of spending for R&D above a base figure, equipment used in research can be depreciated faster, Deductions are also allowed for apparatus and equipment donated to universities. These measures are scheduled to expire in 1985; until then, at least, they will assist firms in portions of the industry with extensive R&D activities.

A further point that an industrial policy following this approach would have to confront is the extent to which firms pursuing economic self-interest may neglect objectives important to the Nation as a whole. Basic research—the sort that does not promise immediate payoffs—provides one example. Nor is it likely that the health and safety of either the labor force or the public at large would be served by an industrial policy that deferred product and workplace standards to industry, Regional impacts, along with questions of adjustment assistance for displaced employees are additional cases where an industrial policy too heavily oriented toward the desires of the business community might be perceived by other segments of society as inadequate.

In the end, the question comes down to this: If other countries are developing ambitious and comprehensive programs to support certain of their industries, can the United States assume that *absence* of Government action is the best response?

Summary and Conclusions

The competitive situations of the U.S. consumer electronics, computer, and semiconductor sectors differ greatly, but they do have common features. How then to summarize the policy implications? The technological and market leads of American electronics firms are narrowing. Manufacturers in Japan especially have successfully followed strategies based on selecting particular market niches, establishing themselves in these markets, then expanding. This was their mode of entry into the U.S. consumer electronics market, it has allowed them to deeply penetrate the American market for some types of ICs, and is the approach they will follow in computers. It has also helped Japanese firms to compete effectively in other parts of the world. Electronics companies in Japan have been aided by their government, although the form and impact of the aid has varied a good deal across the industry; still, the programs generated in recent years to stimulate the expansion of high-technology sectors in Japan, Western Europe, and several of the newly industrializing countries show a degree of concern for industrial development far outstripping that in the United States.

At this juncture, U.S. electronics firms face not only heightened competition, but also problems in financing continued expansion and in finding well-trained people to fill their staffs. The industry exemplifies the structural transformations taking place in the U.S. economy: ever-growing requirements for skilled labor and creative management; dependence on R&D and the commercialization of new technologies in order to establish new markets or retain old ones; rising capital intensity in the process technologies necessary to enhance productivity or simply to make state-of-the-art products; foreign competitors supported by the industrial policies of host governments. There are a multitude of problems ahead for the U.S. electronics industry, and for others at the forefront of economic development—biotechnology, robotics, communication and information technologies. Congressional interest in the international competitiveness of the U.S. electronics industry stems in part from the model it provides for other key sectors.

At the same time, it would be misleading to overemphasize the problems faced by industries like electronics. U.S. capital markets continue to function well. American semiconductor firms have made rapid strides in improving the quality of their products. The industry is still the world leader in technology, though not so far—nor so consistently—ahead. policies followed by the Federal Government have aided American electronics firms by opening world markets for makers of computers and semiconductors. Only infrequently have Federal policies been clear and direct obstacles to efforts by the industry to improve its competitiveness.

What is missing are the links between the bits and pieces of Federal policy that affect the various portions of the electronics industry. Government policies cannot and will not transform this industry or others: the private sector has provided the driving force for past development, a pattern that will continue. But public policies help create the environment within which competition takes place, they set rules, frame decisions. industrial policy could provide a setting conducive to capital formation, R&D, education and training, free market competition. To the extent that Government policies support technological development and structural adaptation, they work in the long-term interests of American industry and the American labor force. A more coherent and consistent industrial policy could make a significant contribution to the competitive position of the U.S. electronics industry.

In the United States, industrial policy still means different things to different people. To some, industrial policy is viewed much like supply-side economics was several years ago—as an untried theory. To others, it suggests government support for “sunrise” industries or trade protection for threatened sectors like steel or textiles. Some have argued that the American political scene is so disorderly that any attempt at a more consciously developed industrial policy would be pointless if not counterproductive. Despite the seemingly incessant debates over the successes and failures of industrial policies in Japan or Britain or Taiwan, all such views miss the essential point: *industrial policymaking is a routine activity of all governments*. In the United States, we can continue to leave industrial policy to the random play of events, or we can try to improve the system.

Politics lies at the heart of finding a more consistent and coherent approach to industrial policy for the United States. The starting point is to recognize that industrial policy decisions are being made all the time. The problems of American companies in consumer-electronics, automobiles, or clothing and apparel were not created by Government policy, but the *absence* of a coherent approach to industrial policy has virtually guaranteed a devolution to special interest politics. Faced with seeming chaos in the political arena, many have simply thrown up their hands, This implies accepting as inevitable long and torturous courses of events in industries like color TV—where final outcomes of trade complaints going back to 1968 have yet to be determined, or steel—where claims by the American industry of dumping by foreign enterprises go back at least to 1959. It also implies relying on the blunt instruments of macroeconomic policymaking. Neither supply-side economics nor public pump-priming of years past offer plausible remedies for the current dilemmas of American industry. It is certainly true that deregulation, lower rates of inflation, and higher rates of overall economic growth will help a wide range of U.S. industries, but urgent needs such as technology development and diffusion, education and training for displaced workers, and seed capital for entrepreneurial businesses also call for attention by Government.

An industrial policy response following one of the alternatives discussed in this chapter could represent an attempt to find concrete solutions to particular problems. Such a response needs to be based on careful examination of the situation of American industry at a given point in time. Advocates of a more coherent industrial policy for the United States understand that Government decisions affect the activities of industry in many and often subtle ways; they would encourage policy makers to include competitiveness and technology development more explicitly in the objectives of policy, more consistently in its formulation and implementation. At the broadest level of generality, this implies a "vision" of long-term economic development interposed in the policy process; it means creating political constituencies for industrial policy rather than standing by while the myriad of interested parties attempt to promote their own typically narrow and short-term designs.

There is no doubt that improvement is possible; policymaking can be a purposeful activity characterized by learning from past experience within a framework of empirically based analysis, Developing a more effective industrial policy must begin in this spirit, while recognizing that the process is inherently political and always will be.

Although a variety of policy instruments could be used in pursuit of industrial policy objectives, *in the U.S. context, it appears that special stress should be laid on manpower training, R&D and technology diffusion, plus measures aimed at stimulating investment in new and innovative firms and an open environment for international trade and investment.* Such policy initiatives, emphasizing structural adjustment, would help in building foundations for international competitiveness in electronics and other industries.

The form that such an industrial policy might take would have to be determined by Congress, along with the executive branch and the many interest groups with a stake in the outcome. To be effective over the longer term, industrial policy must be based on practical understanding of the functioning of the economy on a sector-by-sector basis, with forward-looking analysis of both problems and prospects. OTA has outlined five alternative approaches to this task; more than anything else, *an effective industrial policy for the United States requires a clearer view of where industrial development in this country is headed, and of the Federal role in aiding this development.*

Appendixes

APPENDIX A

Glossary*

acceptable quality level (AQL).—The fraction of defective items permitted in a group of parts (e.g., integrated circuits) that pass the statistical sampling tests agreed to by manufacturer and purchaser. An AQL of 0.01 percent, for instance, means that no more than 1 defect per 10,000 parts, on the average, is allowed.

access time.—The time required to retrieve the contents from a specified memory location in a computer system, commonly the average time to fetch a bit from an integrated circuit memory chip.

active device.—An electronic component that can control or regulate an electrical signal. Examples include most kinds of vacuum tubes, as well as transistors.

actuator.—Causes mechanical force or motion in response to an electrical signal. Examples include hydraulic cylinders (in conjunction with other control system components) and electric motors.

A/D converter (analog/digital converter).—A circuit that transforms analog electrical signals into the equivalent or proportional digital representation, commonly so that they can serve as inputs to a computer system.

advance pricing (also termed forward pricing).—Setting prices for manufactured goods below current costs in the expectation that these costs will fall as production experience accumulates and scale increases. A common pricing strategy for integrated circuits, where advance pricing has been used to gain early market share, sacrificing immediate profits for those in the somewhat longer term.

analog.—Refers to electrical signals that can vary continuously over a range, as compared to digital signals, which are restricted to a pair of nominally discrete values.

architecture.—The overall logic structure of a computer or computer-based system.

binary.—Number system in which all values are represented by combinations of a pair of symbols–e.g., “0” and “l. ” In contrast, the familiar decimal or base 10 system represents all numbers by combinations of the 10 symbols “O” to **“9. ”**

bipolar.—Transistors or integrated circuits in which electrical conduction takes place through the motion of both negative and positive charges. The negative charges are electrons, while the positive consist of the absence of electrons where these negatively charged particles would ordinarily be (the electronic vacancy, or “hole, ” leads to a net positive charge). Bipolar ICs are faster than unipolar (MOS) chips, but not as dense. They also dissipate more electrical power.

bit.–A binary digit, which can take on one of two values, typically written as “O” or “1 .“

bite (byte).–A group of binary bits, usually 8.

bubble memory.—A solid-state microelectronic device in which binary data is stored in tiny magnetic domains (bubbles) given one of two possible polarities. Bubble memories are nonvolatile but not random access; to read or rewrite data in a given location, a string of bubbles must be moved past a detector to reach the desired memory location. Thus the access time depends on where in the string with respect to the detector that location happens to be.

bus.—Circuit path by which electrical signals move between components (e. g., microprocessor and memory chip) or between circuit boards.

capacitor.—Passive circuit element that stores electrical charge, creating a voltage differential. Capacitors can be fabricated within integrated circuits, as well as in the form of discrete components.

captive.—A semiconductor manufacturer w’hose output goes primarily for intracorporate consumption.

chip.—An integrated circuit, either partially or fully completed.

circuit board.—A card or board of insulating material on which components such as semiconductor devices, capacitors, and switches are installed.

clock.—An electronic circuit, often an integrated circuit, that produces high-frequency timing signals. A common application is synchronization of the operations performed by a computer or microprocessor-based system. Typical clock rates in microprocessor circuits are in the megahertz range, 1 megahertz equaling 10^6 cycles per second.

core memory.—Computer memory in the form of magnets that can have one of two states, thus enabling storage of binary data. Now largely obsolescent as a result of integrated circuit memory chips.

CPU (central processing unit).—The portion of a

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* Many of the technical terms included in this glossary are explained in more detail, often with examples, in chapter 3. See, in particular, appendixes 3A and 3B at the end of that chapter.

digital computer where logical operations are performed under the direction of software—in other words, the portion of a computer system where the program is executed.

CRT (cathode ray tube).—Displays an image on a screen—as in a TV set or a computer terminal—in response to electrical signals.

D/A **converter (digital/analog** converter).—An electrical circuit that changes a digital signal into equivalent or proportional analog form. See *A/D converter.*

dedicated.—A piece of equipment—e.g., a computer processor—reserved for a single function, such as aircraft flight control or the operation of a microwave oven. Dedicated processors are often embedded within a more complex system so that they are invisible to casual users. This is the case, for example, with the computers used in electronic banking terminals.

digital.–Refers to equipment or systems which operate on electrical signals that can be represented as strings of binary bits. In electronic circuitry, a pair of nominally discrete voltage levels commonly stand for the two possible values associated with each bit.

disk drive.—Computer peripheral in which data is stored magnetically on a rigid or flexible (floppy) disk, In many cases, disks can be removed and replaced, A drive unit rotates the disk beneath magnetic heads for reading, erasing, and writing data; a typical drive also includes circuitry and control mechanisms for locating data and for interfacing with the processor.

distributed processing.—Refers to computer systems in which two or more CPUs are interconnected, with processing (program execution) carried out—or distributed—among the linked CPUs under the control of system software.

doping.—Adding to a semiconducting material small amounts of other elements (dopants) to change its electronic properties.

electronic.—Refers to devices, components, or systems in which electrical signals are used primarily to convey and manipulate information.

etching.—In semiconductor fabrication, surfaces are etched—e.g., with an acid—to selectively remove material.

European Community (EC); European Economic Community (EEC).–The EEC, established in 1958 by the Treaty of Rome, joins Belgium, Denmark, France, West Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, and the United Kingdom in a Common Market. The European Community links EEC, the European Coal and Steel Community, and the European Atomic Energy Community. The Commission of the European Communities is EC's principal governing body.

European Free Trade Association (EFTA).-–A common market consisting of Austria, Finland, Iceland, Norway, Portugal, Sweden, and Switzerland.

feedback control.-–Use of a signal generated at the output of a process to vary one or more process inputs so that the measured output is maintained within a specified range.

fiber-optics.-–Use of glass fibers to transmit light for communicating information as an alternative to electrical signals. Typically, the light is generated by lasers,

firmware.—Computer software stored in replaceable hardware components, generally integrated circuit memory chips such as ROMs (read-only memory circuits).

floppy disk.—A thin, flexible disk made of a plastic such as mylar and magnetically coated to be used for computer memory and data storage. See disk *drive.*

forward pricing.—See *advance pricing.*

gallium arsenide.—Semiconductor devices made from this compound promise higher speeds than silicon-based devices,

gate.—A simple electronic circuit that can implement a specified logical operation, In essence, gates act like switches. Computer processing units depend on large assemblies of gates, as do integrated circuit memory chips.

GATT (General Agreement on Tariffs and Trade). —The nearly 90 nations which belong to GATT have agreed to work toward reduced barriers to international trade. The organization, the rules of which also have the name GATT, serves as a forum for multilateral trade negotiations and for dispute resolution.

GDP (gross domestic product).–The value of goods and services generated *within* a national economy, generally on a yearly basis.

GNP (gross national product).–The value of GDP adjusted for revenues that enter and leave the economy as a result of financial flows associated with foreign investments (payments to foreign investors are subtracted from GDP, revenues from overseas investments added),

hard-wired.—Refers to an electrical circuit or system the operation of which is determined by the hardware elements—e.g,, components and interconnections—and cannot be changed without changing the hardware configuration. In contrast, the logical operations performed by a computer or a microprocessor-based system can be changed by loading a new software program.

input/output (1/0).—Refers to provisions for entering data into a computer system or for receiving output from the system. I/0 devices are pieces of peripheral equipment with this purpose, notably terminals and printers.

instruction set.—The group of logical operations that a microprocessor or computer can carry out.

integrated circuit (IC).—An electronic circuit manufactured on a single substrate. Most ICs are produced on small chips of silicon and are monolithic—i.e., fabricated on and within the chip rather than assembled to it.

integrated optics.—Refers to devices in which information is manipulated in the form of light rather than electrical signals. Such devices might be interconnected by optical fibers (see *fiber-optic],*

interface.—Circuitry, and often software, that allows one piece of equipment to communicate with another, as in the interface between a pair of computers or between a computer and a disk drive.

Josephson junction, Josephson device.-–Made from superconducting materials (which must be held at very low temperatures), these offer the possibility of logic gates with very high switching speeds, hence very fast computers,

learning curve, experience curve.—Graphical depiction of declines in manufacturing costs with time or with accumulated production volume. While often attributed to learning by factory personnel and engineers, the curves—which tend to show rapid cost decreases for semiconductor manufacturing, leading to competitive strategies based on advance pricing—also depend on many other factors, including product design changes.

lithography.-–Processes related to photography and printing by which patterns are formed on silicon wafers during the fabrication of integrated circuits.

LSI (large-scale integration).–Refers to integrated circuits which contain of the order of 10^4 devices.

main memory, primary memory.—The portion of computer memory that the processor can address directly (as opposed to mass or peripheral storage equipment such as disk drives), The main memory normally holds the program being executed as well as the data being manipulated.

mainframe computer.—A system, normally intended for general-purpose data processing, characterized by high performance and versatility. Mainframes have grown steadily in capability as smaller and less expensive machines have progressed.

mask.—Stencil-like grid used in creating lithographic patterns on semiconductor chips.

mass storage.—Refers to peripheral equipment for computer memory suitable for large amounts of data or for archival storage. Typical mass storage devices are disk and tape drives.

mean time to failure, mean time between failures.—The common measure of reliability—average time between malfunctions that disable a system or substantially degrade its performance. Normally determined through statistical estimating procedures.

microcomputer.—Refers to integrated circuits that contain a microprocessing unit plus memory, as well as to computers designed around microprocessors or single-chip microcomputers.

microprocessor.—An integrated circuit of which the major portion is a digital processing unit. Microprocessor *families* consist of groups of similar chips each intended for a somewhat different class of applications,

minicomputer. —A small computer system, intermediate in cost, size, and processing power between a microcomputer and a mainframe.

MOS (metal oxide semiconductor).—Oxide layers grown on semiconducting substrates are used to form transistors and other circuit elements. MOS integrated circuits are unipolar rather than bipolar—i.e., electrical currents are carried by either positive or negative charges but not both.

packing density.—VLSI circuits are packed more densely than LSI circuits by making the individual circuit elements and their interconnections physically smaller. This has required steady improvements in manufacturing equipment—e.g., for lithography—and careful control of the production process.

passive devices.—Circuit elements, such as resistors, whose characteristics affect electrical signals but which cannot be used to regulate or control those signals.

peripheral.—Equipment used in conjunction with a computer processor. Typical peripherals include keyboards and terminals, mass storage devices, and printers.

peripheral chips.—Integrated circuits designed to be used in conjunction with particular microprocessors or single-chip microcomputers, Common types include clock circuits, A/D converters, and keyboard interfaces.

PROM (programmable read-only memory).—An integrated circuit chip that stores data permanently, A PROM can be programed with this data *after* the chip has been manufactured; in contrast, data is stored in a ROM as part of the manufacturing process.

OEM (original equipment manufacturer).--OEMs incorporate computers and other system components into their own end products. As an OEM, General Motors purchases microprocessors to be used in engine control systems and dashboard computers.

quality.—Measures the extent to which products meet specifications dealing with performance and other functional parameters, and often appearance as well. Quality is determined at a point in time—generally before the product enters service—in contrast to reliability, which is a measure of the ability to continue meeting specifications over time. In most cases, quality is determined by statistical sampling procedures based on data from testing and inspection that accompany or follow manufacturing.

RAM (random access memory).—Most commonly, an integrated circuit that stores data in such form that it can be read, erased, and rewritten under the control of a computer processor, Any memory location in a RAM can be addressed directly (random access) as opposed to sequentially or serially,

real time.—Refers to computer operations that parallel (in time) related external phenomena, as in real time control of industrial processes (see *feedback control).* Real time processing often makes heavy demands on the hardware elements of a system, as well as the software.

register.—Location in a computer processor where binary information is manipulated, Programs are executed by operating on strings of bits brought to the registers.

reliability .-Measure of the extent to which a product or system functions satisfactorily in service, commonly quantified as the time between failures that impair operation or degrade performance.

resist, photoresist.—Chemicals used in lithographic processing of integrated circuits which, much like photographic emulsions, can be exposed by light, X-rays, or other radiation to form patterns.

ROM (read-only memory).-Computer memory, typically consisting of integrated circuit chips, the contents of which can be retrieved at any time but which cannot be changed by erasing or rewriting, Often used for program storage in microprocessor-based systems.

second-sourcing, alternate sourcing.—When one firm designs and develops a product that others begin to manufacture, the latter are referred to as second sources or alternate sources. Both military and commercial customers often insist on multiple sources for critical components such as integrated circuits, An IC produced by a second-source supplier may be identical to the original design or it may differ in detail while remaining functionally interchangeable. Popular chips are sometimes produced by a dozen or more firms, Second-source manufacturers commonly negotiate licenses or purchase technology from the originator,

semiconductors.—Materials from which semiconductor devices are made—e.g., silicon, germanium, gallium arsenide—so called because their electrical conductivities are lower than for good conductors such as metals but higher than for insulators such as glass. The devices themselves are also called semiconductors. Discrete transistors and integrated circuits are the most common types of semiconductor devices.

sensor.—Converts a pressure, temperature, or other physical parameter into an electrical signal, often for use in a control system. A digital speedometer for an automobile transforms the output of a sensor into a miles-per-hour reading, as does an airplane’s air speed indicator. In the case of the automobile speedometer, rotary motion is converted into an electrical signal, while an air speed indicator depends on the pressure created by the motion of the airplane.

smart terminal, smart machine.—In essence, a smart terminal is a small computer intended primarily for communicating with other, more powerful computers, It can perform some processing itself, in contrast to a dumb terminal which can communicate with a computer but cannot execute programs. A smart machine—e.g., a numerically controlled lathe—contains one or more computer processors; these might be microprocessors or minicomputers,

software.—Computer programs. More generally, instructions or procedural descriptions,

solid state.—Refers to electronic components such as transistors or integrated circuits in which the functions are carried out within a solid material (as opposed to a vacuum tube), or to systems (e.g., TV receivers) made with such components,

supercomputer.—At a given time, machines at the upper limit of computing power—as measured by computations per second or related measures of performance—are called supercomputers.

system development.—Software generation for microprocessor-based systems is often referred to as system development. Commercially available microprocessor development systems are frequently used to help in the preparation of programs that will implement the desired functions. Software accounts for a major portion of the engineering effort for systems that use embedded or dedicated microprocessors or computers.

terminal.—Generally includes a keyboard for data entry, along with a display such as a video screen for showing the input data, as well as output from the computer(s) that the terminal communicates with.

transistor.—A solid-state electronic device which can control or regulate an electrical signal in response to a second signal, thus enabling amplification of the first signal.

TTL (transistor-transistor logic).—Most common of the families of bipolar logic circuits.

VLSI (very large-scale integration).—Refers to integrated circuits with of the order of 10^5 devices. 64K RAMs are at the lower end of the VLSI range.

VCR (video cassette recorder).—Records and plays back TV images on magnetic tape. Common consumer models can record off the air or from video cameras. Also called VTRs (video tape recorders).

video disk.—TV images mechanically encoded on spinning disks can be played back using a stylus or laser beam. Current models cannot be used for recording.

wafer.—A disk of silicon (or other semiconducting material) on which integrated circuit chips are fabricated. Today, wafers may be 4 inches or more in diameter and accommodate hundreds of chips.

Winchester disk.—A hard disk for computer memory which rotates within a sealed enclosure and thus cannot be removed. Compared to removable disks of the same diameter, Winchester drives can store more data; however, they are not suited for archival storage.

word.—The basic unit of information—having the form of a string of binary bits—that a computer processor works with. Typical word lengths range from 4 to 64 bits; more powerful machines are generally designed to use longer words.

yield.—In the production of microelectronic devices, the fraction that survive all tests and inspection, function correctly, and can be sold or incorporated into the manufacturer's own end products. Production costs depend heavily on yields, which themselves depend on circuit design, fabrication equipment, and control of the manufacturing process.

APPENDIX B

Offshore Manufacturing*

During the past two decades, many American electronics firms have moved portions of their manufacturing operations overseas in search of lower labor costs. Offshore production has been a major element in cost reduction strategies, particularly in price-sensitive portions of the industry such as consumer electronics and semiconductors. Labor-intensive components and subassemblies for computers and many other products are also made in low-wage developing countries. In electronics, as in automobiles, foreign investment has been a major force in transforming national industries into international industries. Transfers of technology as well as capital contribute to internationalization.

American electronics firms invest in overseas plants to serve foreign markets, as well as reimporting goods to the United States (ch. 4). The former are often termed point-of-sale plants, the latter offshore manufacturing or offshore assembly plants. It is offshore investment to serve the U.S. market that is the primary topic of this appendix. Other arrangements—for instance, subcontracting with foreign firms—will not be covered. Offshore manufacturing thus implies ownership and management control by an American corporation, Virtually all the major U.S.-owned consumer electronics and semiconductor companies have offshore plants, mostly in Mexico and the Far East.

In both consumer electronics and microelectronics, the driving force for offshore investment has been cost reduction. U.S. consumer electronics firms—principally television (TV) manufacturers—have moved overseas to meet competitive pressures and preserve existing markets (ch. 5). Foreign investment has been largely a defensive tactic, a reaction to import penetration at home, In microelectronics, competition *among* U.S. firms has led to transfers offshore.

From the perspective of the United States, offshore production has both positive and negative impacts. Compared to the plausible alternatives, the net effects appear to be positive in most cases, much more so in the case of semiconductors.

Economic Impacts of Offshore Manufacture

Offshore investments in electronics affect domestic employment, the balance of payments, national income, and the future competitive abilities of American industry, The many studies of U.S. foreign direct investment, while seldom focusing on offshore manufacturing per se, yield insights into such investments. Even so, the evaluation of costs and benefits remains controversial, and the evidence gives no clear guide to public policy. Immediate impacts generally get the most attention, although longer term effects often prove quite different than short-term consequences. Table B-1 classifies the impacts.

Table B-1 .—Possible Effects of Offshore Manufacturing Investments

Effects within the ***Industry making the Investments***

A. Domestic employment
   1. Total U.S. employment in the industry (up or down).
   2. Changes in skill mix in the industry (increase or decrease in blue-collar job opportunities, expansion in professional categories, etc.).
   3. Regional employment shifts.

B. Domestic value added by the industry
   1. Changes in total wages and salaries paid to domestic employees of the industry.
   2. Profitability of companies in the industry.
   3. Tax payments by firms in the industry.

C. U.S. balance of payments
   1. Shifts in trade balance involving products of the industry.
   2. Other current account flows.
   3. Capital account flows.

Effects In related Industries (suppliers as well as customers)

A. Domestic employment (with same subcategories as above).

B. Domestic value added (with same subcategories as above).

C. U.S. balance of payments (with same subcategories as above).

Longer term effects

A. Shifts in international competitiveness of U.S. industries.

B. Changes in concentration and structure of U.S. industries.

SOURCE" "Effects of Offshore and Onshore Foreign Direct Investment in Electronics A Survey, " prepared for OTA by R W Moxon under contract No 033.1400, p. 5

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*This appendix is based largely on "Effects of Offshore and Onshore Foreign Direct Investment in Electronics: A Survey," prepared for OTA by R. W. Moxon under contract No. 033-1400.

Immediate Employment Impacts in the Industry Making Foreign Investments

Offshore investment by U.S. firms creates jobs in foreign countries. To what extent do such jobs replace employment opportunities in the United States? When a U.S. TV manufacturer moves its assembly operations offshore, some Americans lose their jobs. But *if* the firm stays in business as a result of the cost savings from offshore assembly—and if it might have failed without this move—then the net effect can be to preserve *some* U.S. jobs, In general then, if foreign investment improves the competitive position of the American firm, the effects on domestic employment can be positive; the investment may create foreign jobs while saving domestic jobs.

Demonstrating unambiguously that this has or has not happened is, unfortunately, seldom possible. The matter turns on a counterfactual question: *What would the outcome have been if the foreign investment had not been made?* Largely because of this, past studies of the employment impacts of the same investment have resulted in estimates ranging from losses in employment opportunities of more than a million to *gains* of half a million.[1]

Foreign investment may also affect the mix of jobs available domestically. Even if net employment increases, certain job categories may suffer. Most of the foreign workers in offshore manufacturing plants perform unskilled production tasks. These are the kinds of jobs that tend to be lost in the United States. Thus, the domestic skill mix generally shifts in the direction of the more highly skilled and professional jobs—technicians, engineers, managers. Unfortunately, unemployment in the United States is concentrated in the ranks of unskilled and semiskilled workers. Moreover, since the electronics industry is geographically rather concentrated, offshore investment can have significant local and regional impacts.

Immediate Effects on Domestic Value Added

Closely related to employment is the impact on U.S. national income, or value added. Value-added effects can, in turn, be divided into several categories: wages and salaries, profits, tax payments (table B-l). Offshore investments generally substitute foreign for domestic value added. The *magnitude* of these effects depends, however, on changes in the competitive position of the firm making the investment. In some cases value added may increase both in the United States and abroad.

Foreign investments can also affect the distribution of income among the categories of wages and salaries, profits, and taxes. If offshore manufacturing substitutes foreign jobs for U.S. employment, value added will tend to move from wages and salaries toward profits and tax payments. But a sharp enough swing toward highly paid skilled and professional workers in the United States could reverse this effect. Offshore manufacturing may also create opportunities for firms to reduce their U.S. tax bills. On the other hand, if the company's competitive position improves sufficiently as a result of offshore manufacturing, net tax revenues could go up.[2]

Effects on the Balance of Payments

Offshore investments are reflected in the U.S. balance of payments through both the current and capital accounts, Foreign manufacturing generates imports, which show up on the current account, but these will be partially offset by exports of materials or components to the offshore plant. In the semiconductor industry, wafer fabrication has generally remained in the United States, with wire bonding and other labor-intensive assembly operations moving overseas. The wafers shipped to offshore plants by American firms later return as finished integrated circuits (ICs); the latter are counted as imports, the former as exports. A substantial fraction of U.S. trade in semiconductor devices—roughly three-quarters in the case of imports (ch. 4. table 28)—represents intrafirm transfers of this type.

The U.S. capital account shows outflows when American firms invest abroad, but moneys may gradually return in the form of profits or other payments flowing back to the United States. Once again, the primary question is: What would have happened in the *absence* of the investment? Has it enhanced the competitive position of an American firm? Or has U.S. competitiveness declined? These questions are central to any evaluation of costs and benefits.

Some of these questions are seemingly imponderable—or at least subject to widely differing answers

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[1] J. Segall, "Introduction to the Conference," *The Impact of International Trade and Investment on Employment: A Conference on Department of Labor Research Results* (Washington, D.C.: Department of Labor, 1978), p. 5.

While overseas investment by American firms often displaces U S investment, resulting in losses of domestic. output and decreases in U. S tax payments, foreign earnings remitted to the United States can offset these losses The net result may be only a small net decrease due to the foreign investment Perhaps more important, the *distribution* of national income tends to be shifted toward capital, and away from labor. See P B Musgrave, *Direct Investment Abroad and the Multinationals: Effects on the United States Economy*, Subcommittee on Multinational Corporations, Committee on Foreign Relations, U.S. Senate, August 1975.

—thus estimates of the net impacts of foreign investment on the balance of payments cover a range just as broad as for employment effects.[3] Again, the crucial points involve the extent to which investment overseas displaces investment at home, and the extent to which offshore production may displace or, alternatively, stimulate U.S. exports. Such matters can seldom be addressed on other than a case-by-case basis.

Indirect Impacts on Supplier Industries

Offshore manufacturing in consumer electronics or semiconductors generally cuts into the sales of U.S. firms that supply these industries. Overseas plants normally buy expendable supplies and materials locally; they may also purchase parts, components, and subassemblies from foreign rather than American firms. U.S. firms supplying such components as switches, circuit boards, resistors, and capacitors to the TV industry suffered heavy losses in sales as American consumer electronics manufacturers moved overseas.[4] U.S. suppliers have seldom been able to meet price competition in overseas markets; when they lose sales to foreign companies, domestic employment and value added suffer. As their customers have moved offshore, some U.S. component manufacturers have, not surprisingly, followed.

Technology Transfer and Other Longer Term Impacts

Most of the effects outlined above have long-term, as well as more immediate, aspects. Beyond direct employment or financial consequences, what possible shifts in the competitive position of U.S. industry could result from transfers of technology through offshore plants? If U.S. investments accelerate processes of technology acquisition by other countries, the competitive advantages of American firms in electronics and related industries could erode. Such a result is more likely in rapidly industrializing countries like South Korea and Taiwan, which have already emerged as significant competitors in consumer electronics, helped to considerable extent by transferred technology.

When multinational corporations invest in developing countries, they must generally train workers, typically drawing on the local population not only for blue- and grey-collar employees, but for foremen and, often, middle managers. In electronics, the experience that these people get has proved to be a substantial benefit to indigenous firms; not only does a pool of workers, both skilled and unskilled, become available for locally owned companies to hire, but the managers of these companies are often people who got their start in a foreign-owned plant.

While it is easy to point to examples of this sort, where foreign investment has accelerated industrial development, technology diffusion is in any case inevitable. Offshore investments may speed the process, but consumer electronics technology was accessible to firms in Taiwan regardless of U.S. investments there. Technology moves internationally by multiple paths, some of which are quite independent of investment patterns. Furthermore, American electronics firms are not the only ones to invest in developing countries, Japanese companies have been quite active in moving electronics operations—particularly those that are lower technology and/or more labor intensive—to other Asian nations. In consumer electronics, developing countries can probably learn more from companies like Matsushita or Toshiba than from American manufacturers, Technology transferred abroad via U.S. investments often helps to build foreign competitiveness, but the recipients could generally get the same technology from other sources.

Evaluating Impacts

As pointed out at several places above, the underlying difficulty in trying to evaluate the consequences of offshore investment comes in the comparison of what did happen with what *would have* happened if the investment had not been made. The answer to such a question depends on judgments about how markets would have been served without the investment, which in turn calls for analysis of comparative costs and other factors in the competitive environment. Reaching conclusions on what has taken place can be difficult enough—witness the length of this report. But it is easier than determining what would have happened if a given investment had not been made. Still, logic and the available information can yield some insights.

Critics of offshore manufacturing by U.S. firms often assume, perhaps implicitly, that the products made abroad could have been produced here instead, contributing not only to domestic sales but to U.S. exports. If true, U.S. employment, national income, and balance of payments would all have benefited from continued domestic production. Critics also tend to assume that American compa-

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[3] G. C. Hufbauer and F. M. Adler, *Overseas Manufacturing Investment and the Balance of Payments* [Washington, D. C.: Department of the Treasury, 1968).

[4] L. Marion, "TV Parts Makers Face Offshore Threat," *Electronics,* May 24, 1979, p. 102.

nies choose foreign investment over domestic manufacturing in order to increase their own profits, and that the company's competitive position would not be seriously threatened if it chose not to invest abroad.

Most defenders of offshore investment acknowledge that jobs are transferred abroad in the short run, but argue that the situation would in the longer run be even worse without these investments. They emphasize that most such investments are defensive reactions to competitive threats, domestic or foreign. When the primary competitors are foreign, and American firms do not respond by moving offshore, supporters of offshore manufacturing argue that the United States would end up importing the same goods from foreign-owned rather than U, S.-owned plants. Offshore investment thus preserves at least some benefits for the United States, because exports will go to the offshore facilities, professional and skilled jobs remain here, and the balance of payments will look better than it otherwise would have.

The counterresponse of the critics is generally as follows. If the primary intent of the offshore investment is to help U.S. firms meet import competition, then the proper response is simply to restrict imports. Interest groups that accept this argument may then combine, as they did in the Burke-Hartke bill, a call for protection against imports with a call for restrictions on offshore investment. As in so many questions involving shifting comparative advantage and the consequences for industrial policies, when the economics of the situation are cloudy—as they are here—political considerations tend to become dominant.

Motivations for Offshore Investments

American electronics firms establish offshore manufacturing facilities to take advantage of low-cost foreign labor. Investing companies see cost reductions as critical for meeting competitive threats from foreign enterprises, or to expand output and sales in competition with other domestic firms, or both.

Cost Savings for Products Manufactured Offshore

American TV firms make monochrome sets offshore, as well as subassemblies and complete chassis for color receivers. Production is labor-intensive, with low skill requirements, involving such tasks as inserting components in printed circuit boards, assembling tuners, winding coils, and making subassemblies for picture tubes. Offshore semiconductor manufacturing has generally been limited to assembly, primarily wire-bonding and encapsulation. In recent years, some testing has been performed overseas as well, usually as an aid to quality control. Many U.S. semiconductor firms also subcontract to local companies in developing countries,

As table 18 (ch. 4) indicated, wages are much lower in developing countries than in the United States or even Japan. Although labor productivity in such countries may also be low compared to domestic plants, large savings also can still result. In 1980, the average hourly compensation for American workers in the electrical and electronic equipment industry was $9.59; in the more popular locations for offshore American subsidiaries, it ranged from $1.13 in Singapore to $2.40 in Mexico.[5] Although wages have been increasing more rapidly in offshore locations than here, offshore production has continued to be attractive in making both TVs and semiconductor devices. To some extent, firms have responded to wage increases by moving on to other countries. For instance, two American companies have announced plans to invest in Sri Lanka, where wage levels remain very low.[6]

Because costs for wafer fabrication and testing make up a much larger percentage of the total for complex devices, offshore manufacture yields greater savings for discrete semiconductors and simple ICs. Table B-2 illustrates this, based on rough cost structures for simple and complex devices, and applying two arbitrary ratios of U.S. to offshore wage rates. Substantial savings are possible at either a 10-to-1 or a 5-to-1 wage ratio, but the margins are much larger for the simple device.

In TV manufacture, the net savings are smaller as a percentage of total production costs. Nevertheless, for some kinds of subassemblies they can be substantial, and in a highly price-competitive market—as TVs have been—any saving can be important. Zenith estimated in its annual report for 1977 that the transfer to Mexico and Taiwan of circuit module and chassis assembly for color sets would lower its unit costs by $10 to $15.

Strategic Implications

In consumer electronics, offshore manufacturing was a reaction to severe import competition, pri-

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[5] Information from Bureau of Labor Statistics, Office of Productivity and Technology. Hourly compensation in Japan averaged $515.

[6] L Antelman, "Harris to Construct $19 (sic) IC Facility in Sri Lanka, " *Electronic News*, Feb 8, 1982, p. 39 Motorola is the second U.S. firm planning a factory there,

Table B-2.—Cost Comparison for Offshore Assembly of Semiconductors[a]

	Discrete devices or simple integrated circuits			Large-scale integrated circuits		
		Domestic assembly			Domestic assembly	
		Wage ratio[b]			Wage ratio[b]	
	Offshore assembly	10:1	5:1	Offshore assembly	10:1	5:1
Cost of chip	$0.015	$0.015	$0.015	$1.00	$1.00	$1.00
Assembly cost.	0.050	0.500	0.250	0.15	1.50	0.75
Packaging cost	0.050	0.050	0.050	0.50	0.50	0.50
Testing cost.	0.020	0.020	0.020	0.75	0.75	0.75
Reject cost.	0.015	0.015	0.015	1.00	1.00	1.00
Total	*$0.150*	*$0.600*	*$0.350*	*$3.40*	*$4.75*	*$4.00*

[a] The basic costs used in this table are from *A Report on the US. Semiconductor Industry* (Washington, D. C.: Department of Commerce, September 1979), p. 73 These costs do not apply to specific devices, nor are they necessarily current The purpose is simply to illustrate the magnitude of the cost savings available through offshore assembly

[b] Assumed' ratio of U S wages to wages in offshore plant

SOURCE "Effects of Offshore and Onshore Foreign Direct Investment in Electronics A Survey, " prepared for OTA by R W. Moxon under contract No. 033-1400, p 29

marily from Japan. Sales had been lost, and profits cut to low levels or to losses; a number of smaller American TV manufacturers succumbed during the period that RCA, Zenith, and GE were moving offshore. The story in microelectronics is quite different. Imports—exclusive of those from subsidiaries of American firms—were not a major factor while U.S. firms were transferring production overseas; in the 1960's, imports from foreign-owned companies accounted for only 1 or 2 percent of U.S. sales.

For semiconductors, the primary motives behind offshore assembly were:

1. *Cost Reduction as a Stimulus to Sales.* Price declines have led to a continuous stream of new applications of semiconductors—in other words, demand is highly price-elastic. As sales mount, costs drop through learning curve effects. Offshore assembly accelerated price declines still more, opening further markets.
2. *Capital Investment Constraints.* Semiconductor firms have had to continually increase capital spending to keep up with exploding demand and advancing technology, but have not always generated the profits needed to fund capital investment internally (ch. 7). Given the need for investment in costly wafer fabrication and testing equipment, offshore assembly offered an attractive way to expand capacity while conserving capital.
3. *Risks of Large Capital Investments.* Especially during the 1960's, when many offshore plants were established, semiconductor firms were wary of capital investments in automated production equipment, The fear was that technological change might quickly make them obsolete, For example, semiconductor packaging has changed a good deal, first as discrete devices gave way to ICs, later as ICs grew more complex. Several companies suffered as a result of automating at the wrong time. Offshore assembly offered flexibility without the risk of technological obsolescence. When technology and/or demand stabilizes for a given product, automation becomes more attractive, and assembly is occasionally brought back to the United States.

Once some American firms succeeded in cutting costs by moving offshore, others were forced to follow; later, Japanese semiconductor manufacturers did the same.

Alternatives to Offshore Manufacture

American firms invest overseas because to them this seems the best course of action given their competitive situation, If this possibility were foreclosed —e.g., by Government policy—what other avenues are open? The following appear to be the primary choices:

1. Maintain production in the United States, using labor-intensive processes similar to those that have been followed in offshore plants.
2. Maintain production in the United States, investing in automated equipment.
3. Subcontract production to an independent foreign manufacturer.
4. Discontinue production and sales of the product or products in question.

These four possibilities are briefly examined below.

Maintain U.S. Production on a Labor-Intensive Basis

For some consumer electronics products, where the savings from offshore sourcing have been relatively small, this would probably be the alternative chosen. Nevertheless, the loss of the cost savings from offshore assembly would hurt the competitive position of U.S. firms, some of which would probably move to lower cost areas within the United States.

This alternative has little to offer for semiconductor companies faced with increasing competition from foreign manufacturers. Substantial cost penalties would hurt sales, especially for mature products,

Automate Domestic Production

For many products that are now assembled offshore, automat ion is technically feasible. American TV manufacturers already use automatic component insertion to a considerable extent (ch. 6); investments in this and other automated manufacturing methods could be accelerated. Automation has been spreading rapidly in the semiconductor industry. Although automation is not at present feasible for all types of semiconductor products-sometimes for technical reasons, other times because production runs are short—finding the capital required is a more central issue for many firms in the industry. Smaller firms especially would have trouble financing extensive automation. As chapter 7 pointed out, funds are scarce and capital-intensity increasing in semiconductor manufacturing; managers' priorities place automation fairly low as long as there are feasible alternatives. Investments in automat ion would divert funds from advanced wafer fabrication equipment, as well as from research and new product development—without which, in this fast-moving industry, automated production equipment would be useless.

Subcontract Manufacturing to Foreign Enterprises

Subcontracting labor-intensive production operations to foreign firms has short run consequences for the United States not unlike those of direct foreign investment, and the U.S. semiconductor industry has in fact made considerable use of foreign subcontracting, Some American consumer electronic; s firms do the same. Subcontracting contributes to flexibility in responding to competitive pressures. Disadvantages come with respect to coordination in matters such as production schedules and cost or quality objectives. And while subcontracting saves capital compared to direct investment, direct production costs will be higher because oft he profits sought by subcontractors.

Especially in the semiconductor industry, but also in consumer electronics, this option might well be the first choice of American companies unable to establish their own foreign subsidiaries. The attractions are especially great for low-volume products where a foreign subcontractor with several customers might be able to achieve scale economies.

Discontinue the Product

Unless a firm had already decided on such a step, this would not be the first choice—but it might not be the last. Whether American companies would stop making some products if prevented from moving offshore depends on the extent to which their other opt ions are practicable and cost effective.

Offshore Manufacturing Compared to the Alternatives

Of the four options, U.S. consumer electronics firms would probably adopt a mix of the first three, depending on their product lines and competitive circumstances, In particular, the smaller consumer electronics manufacturers are much more limited in investment possibilities—i.e., in automation-- than companies like GE or RCA. In the semiconductor industry, the cost savings from offshore production are so large—table B-Z—that most American merchant firms would no doubt subcontract to foreign enterprises if they could not invest overseas themselves. Some production would be transferred back to the United States, probably high-volume products made by larger companies.

What would be the impacts on the U.S. economy of the four alternatives compared to offshore investment? To address this question, the effects on domestic employment, balance of payments, and the other categories listed in table B-1 could be compared. At least in principle, scenarios could be constructed for the alternatives, singly or i n combination, most likely to be chosen by a given company or industry. ideally, estimates would cover a period of years, because an offshore investment might, for instance, initially cause an outflow of capital which in later years could shift to an inflow. In any such procedure, assumptions would have to be made concerning the *future* competitive environment for American firms,

A Case Example

Rather than pursuing an abstract analysis like that outlined above, the methodology can be applied to a simple example, a real company which, for purposes of the case study, has been renamed Systek.[7]

Systek, in 1969, decided to build a plant in Taiwan for assembling both complete automobile radios and subassemblies. All production was to be sold to Systek's U.S. operations, where final assembly and testing would take place. The company's management chose to make this investment because of a deteriorating competitive position; by moving offshore, the company felt that it could cut its production costs and prepare for upcoming battles with Japanese producers. Automobile radios sold largely on the basis of price, and Systek's major customers, U.S. auto manufacturers, continually solicited and compared price quotations from various suppliers. By the late 1960's, the automakers had begun to receive bids from Japanese electronics companies; Systek's management felt that the company would soon begin losing sales to the Japanese unless it could significantly lower its own costs and prices.

Systek evaluated several alternatives before building its Taiwanese plant. The company had already automated its U.S. factories as much as it judged practical; the only option it saw for cutting costs while remaining in the United States was to move production from its urban site in the north to one of the Southern States, where costs would be lower. Management judged this to be no more than a temporary solution. Systek also considered subcontracting the assembly of its line of auto radios to a Japanese firm, but could see little advantage in this choice because Systek had the resources and expertise to establish its own foreign subsidiary, which would have lower costs than a subcontractor could offer.

After a detailed feasibility study, the offshore alternative was chosen; Systek-Taiwan began production in late 1969. Operations went smoothly for the first few months, but then sales began to suffer because of a decline in the U.S. economy. Production had to be cut back in Taiwan. As sales continued to fall, the manager of Systek's U.S. plant placed fewer orders with Systek-Taiwan; finally these orders stopped entirely, and most of the workers in Taiwan had to be laid off. At this point Systek-Taiwan's management was authorized to seek other business, and by mid-1971 had begun doing electronic assembly work for a number of Canadian and European companies.

Tables B-3 and B-4 examine the balance of payments and employment effects of Systek's investment in Taiwan. The tables are based on the company's pro-forma projections for the first 5 years of operations to illustrate the expectations of Systek's management at the time the decision was made. The actual results in terms of both employment levels and flows of funds turned out to be

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[7] The case was originally published, first in 1969 and in revised form in 1973, as "Systek International" by the Harvard Business School

Table B-3.—U.S. Balance of Payments Flows With and Without Systek Investment

	Capital flow (thousand of dollars)[a]								
Fiscal year	Capital outflow	Loan repayment	U.S. exports of capital equipment	U.S. exports of components	U.S. imports	Royalties and fees	Dividends and interest	Other payments to the United States	Net flow
With Investment *(Systek projection)*									
1969 (4 months)	-$5,900	+ $1,440	+ $1,140	+ $528	-$2,930	–	+ $41	+ $319	-$5,360
1970	—	+ 850	–	+ 1,580	-14,000	+ 238	+ 147	+ 1,140	-10,000
1971	–	+ 1,010	—	+ 1,310	- 17,100	+ 237	+ 147	+ 1,360	-13,000
1972	–	+ 700	—	+ 773	-19,900	+ 238	+ 174	+ 1,580	-16,400
1973	—	—	—	+ 858	-22,000	+ 242	+ 220	+ 1,760	-18,900
1974	–	—	—	+ 946	-24,200	+ 272	+ 241	+ 1,930	-20,800
Total	-$5,900	+ $4,000	+ $1,140	+ *$6,000*	$100,000	+ $1,230	+ *$970*	+ *$8,090*	-$84,500
Without investment (estimated)									
1969 (4 months)	—	–	—	—		—	—	—	
1970	–	–	—	—	$5,700	—	—	+ $570	$5,130
1971	—	—	—	—	13,400	—	—	+ 1,340	12,060
1972	—	—	—	—	- 23,000	—	—	+ 2,300	- 20,700
1973	—	–	—	—	-33,700	—	—	+ 3,370	-30,300
1974	–	—	—	—	-45,900	—	—	+ 4,590	-41,300
Total	–	—	—	—	-$121,700	—	—	+ $12,170	-$109,000

[a] Plus indicates inflow to the United States, minus indicates outflow

SOURCE "Effects of Offshore and Onshore Foreign Direct Investment in Electronics A Survey," prepared for OTA by R W Moxon under contract No 033-1400, p 44, based on company records and author's estimates

Table B-4.—U.S. Employment Levels With and Without Systek Investment

	Systek employment in the United States (number of workers)		
Fiscal year	Production workers	Other employees	Total
With investment (Systek projection)			
1969 (4 months)	1,480	452	1,932
1970	1,283	393	1,676
1971	1,204	368	1,572
1972	1,124	341	1,465
1973	1,120	341	1,461
1974	1,115	339	1,454
Without investment (estimated)			
1969 (4 months)	2,021	641	2,662
1970	1,767	554	2,321
1971	1,439	472	1,911
1972	1,025	340	1,365
1973	542	181	723
1974	—	—	—

SOURCE 'Effects of Offshore and Onshore Foreign Direct Investment in Electronics A Survey,' prepared for OTA by R W Moxon under contract No 033-1400, p 44 Based on company records and author's estimates

heavily influenced by the business downturn in the United States. In tables B-3 and B-4, Systek's projections are compared with estimates by OTA's contractor of the probable consequences if the investment in Taiwan had not been made. Table B-3 gives the estimated flows of funds, table B-4 the employment comparison. The assumptions forming the basis for the estimates are discussed in detail below. The net effect of the investment in Taiwan, obtained by subtracting the "without investment'" case from the "with investment" case, appears in table B-5.

Based on the assumptions made, the initial impacts of Systek's investment are negative—both capital and jobs are transferred to Taiwan—becoming positive as time passes. This is typical of foreign investments for purposes of offshore assembly; the short-term impacts tend to be negative, but over the longer term the trend reverses, provided the investment is assumed necessary for maintaining competitiveness.

In table B-3 the major flow of funds category is that associated with imports; other financial flows are much smaller. imports have been assumed to increase much more rapidly in the absence of Systek's investment in Taiwan; in fact, as can be seen in table B-4, by 1974 it has been assumed that Systek would no longer be making automobile radios in the United States under the "no investment" scenario, and its domestic employment would fall to zero. How realistic is this scenario?

Table B-5.—Net Effect of the Systek Investment in Taiwan on U.S. Balance of Payments and Employment

Year	Balance of payments flows[a] (thousands of dollars)	Employment (number of employees)
1969 (4 months)	-$5,360	–730
1970	-4,870	645
1971	-940	339
1972	+ 4,300	+ 100
1973	+ 11,400	+ 738
1974	+ 20,500	+ 1,454

[a] Plus indicates inflow to the United States, minus indicates outflow.
SOURCE: Derived from tables B-3 and B-4

Photo credit: *RCA*

Consumer electronics assembly

The assumptions, based on events elsewhere in the consumer electronics industry, are as follows:

- If Systek had not invested in Taiwan, it would have moved the same manufacturing operations to a lower cost region of the United States.
- If Systek had done so, foreign manufacturers would have had a cost advantage.
- Because of Systek's market knowledge, reputation, and established working relationships with U.S. automakers, it would have been able

at first to hold on to part of the market even with a cost disadvantage.

- Although foreign-owned firms suffer initial disadvantages in terms of proven ability to delivery high-quality radios on schedule, they would manage, over time, to penetrate Systek's market.
- Once the foreign producers gained a substantial foothold in the U.S. market, their takeover would be swift.

Past rates of penetration in products like monochrome TVs or radios for home use indicate that it might have taken Japanese and other foreign-owned companies about 5 years to penetrate Systek's market more-or-less completely, This is the assumption behind the estimates in tables B-3 and B-4, Of course, the actual rate of penetration by foreign auto radio manufacturers might have been somewhat faster or slower, but in the end this would not make much difference.

As a result of these assumptions—that the Taiwan plant helped Systek retain markets that it otherwise would have lost completely—the long run impact on U.S. employment and balance of payments turns positive. The Systek investment still results in jobs being transferred overseas; it even accelerates the process somewhat. But job losses, and increased imports, would most likely have occurred in any event, and could have been much greater.

The Systek case is also an example in which U.S. management acted to preserve American jobs by keeping some production in the United States. Faced with falling sales as a result of recession, and the need to cut output and lay off workers, Systek chose to stop production in Taiwan—where the average wage was less than one-tenth that in the United States—rather than reduce its domestic operations still further. The plant in Taiwan was shut down, with only the supervisors retained on the payroll, until the company's management found outlets in Canada and Europe for products that could be made in Taiwan.

Typical Impacts of Offshore Manufacturing

The Systek case by itself cannot be generalized, but it is suggestive; together with the earlier discussion of offshore sourcing compared to four alternatives, it points to some tentative conclusions. Table B-6 summarizes in a qualitative way the alternatives to offshore assembly outlined earlier, The table indicates the probable effects if alternatives *other*

Table B-6.—Likely Effects of Alternatives to Offshore Manufacturing

	Labor-intensive production in the United States	Automate domestic production	Subcontract to foreign enterprises	Discontinue the product
U.S. *employment* in *electronics* ***and related industries***				
Total domestic employment	Positive in early years, probably negative later	Small positive in early years, probably negative later	No major change	Negative
Proportion of skilled jobs	Small possible decrease	Small increase likely	No major change	Not relevant
Geographic distribution of jobs	Move to low-wage areas	No major change	No major change	Not relevant
U.S. value added in electronics and related industries				
Wages and salaries	Positive in early years, probably negative later	Positive in early years, possibly negative later	No major change	Negative
Profits	Negative	Possibly negative	Probably negative	Negative
Tax payments	Negative	Possibly negative	Probably negative	Negative
U.S. ***balance of payments for electronics and related Industries***				
Trade balance (exports-imports)	Positive in early years, probably negative in later years	Positive in early years, possibly negative later	No major change	Negative
Other current account items (principally investment income)	Negative	Negative	Negative	Negative
Capital account flows	Positive in early years	Positive in early years	Positive in early years	Positive in early years
Long-term effect on competitiveness of U.S. industry due to technology transfer				
	Slightly positive	Slightly positive	Slightly negative	Domestic industry eliminated
Changes in structure of domestic electronics industry				
	Weaker firms threatened	Smaller firms weakened	No major effect	Domestic industry eliminated

SOURCE—Office of Technology Assessment, based on "Effects of Offshore and Onshore Foreign Direct Investment in Electronics A Survey, " prepared for OTA by R W Moxon under contract No 033-1400, p 47 than offshore assembly were chosen by a company under pressure to reduce manufacturing costs. The impacts follow the classification presented in table B-1 .

As table B-6 indicates, the labor-intensive domestic *manufacturing* alternative would keep production and employment in the United States, and therefore have *initially* positive effects, but these would become negative in later years, the result of a gradual decline in the ability to compete with low-wage foreign countries. This was the situation Systek anticipated. Employment would drop, profits deteriorate, and tax payments fall. Positive effects on the trade balance (the result of lower imports in early years because of the absence of offshore production] would soon be offset by shipments from foreign competitors.

On the other hand, the domestic manufacturing alternative(s) would probably slow the migration of U.S. technology overseas. Developing countries get both tangible and intangible benefits from offshore plants, including learning and experience that strengthens local industries, Over the longer term, the result could be a relative weakening of the position of U. S. firms. How serious is this possibility?

For offshore plants that ship most of their production hack to the United States, labor-intensive operations, mostly assembly, are performed overseas. Although the general skills learned by production workers and supervisors are relevant, assembly technology itself is of little significance competitively. The situation is rather different for point-of-sale semiconductor plants, but most of these are in Europe, where local firms already possess much of the technology associated with wafer fabrication and related processing steps.

Automating domestic manufacture might have somewhat similar results, but evaluation of this alternative is more problematic because the technology of automated production has been advancing rapidly, Electronics firms have guessed wrong at various times in their own evaluations, and the second column in table B-6 should be viewed tentatively. Employment would probably decline, but the competitive positions of U.S. firms that chose to automate might or might not improve, depending on circumstances. Purchases of automated manufacturing equipment would stimulate the U.S. capital goods industry to the extent that this equipment was purchased domestically.

This is a difficult alternative for smaller companies with limited capital for investment, In consumer electronics, RCA has been perhaps the most active U.S. firm in automating; it is no accident that this company is one of the largest and most diversified in the industry.

Most of the effects of the *foreign subcontracting* option would be similar to those of offshore manufacturing, as table B-6 outlines. This choice would harm domestic suppliers, who would have difficulty selling to overseas subcontractors.

Discontinuing production, the last alternative, has negative consequences for the U.S. economy, although the capital released could be invested in other industries.

Summary and Conclusions

American manufacturers in many industries are moving some of their production overseas. At the same time, foreign firms—for various reasons--have begun to invest more heavily in the United States. In general, the advantages and disadvantages of either type of investment—from the standpoint of impacts on U.S. employment, and the U.S. economy in general—can only be evaluated on a case-by-case basis. In most instances, the net impacts of offshore manufacturing by U.S. electronics firms seem to be relatively small. But even if the net effects are small, the consequences for the individuals and firms affected can be serious—for workers who lose their jobs, for suppliers who lose sales, for communities and regions where industrial activity has diminished. To call these short run adjustment problems does nothing to mitigate them.

Moreover, the shift of unskilled and semiskilled jobs overseas seems in the end detrimental to U.S. interests. This country already has a large number of unemployed job-seekers, many of whom are realistic candidates for unskilled or semiskilled manufacturing jobs but not for work demanding high skill levels. That overseas investment may sometimes help maintain the competitiveness of American firms and industries seems small recompense for those who lose jobs or job opportunities. Onshore investments by Japanese and other foreign electronics companies may provide something of a counterweight, but thus far many more jobs have been lost than gained. On the other hand, policies that would restrict overseas investments by U.S. firms seem generally counterproductive. As discussed at some length i n chapter 8, the alternative of choice would appear to be a strong commitment to upgrading the U.S. labor force so that transfers of unskilled work overseas will be less damaging.

APPENDIX C

Case Studies in the Development and Marketing of Electronics Products*

Consumer Electronics: The 700-Watt Power Amplifier

The Product

In early 1970, Robert Carver, an engineer turned entrepreneur with a passion for music and high fidelity sound reproduction founded a small company—Phase Linear—in Seattle to manufacture high-power, state-of-the-art stereo amplifiers. The firm began as a limited partnership but was incorporated later that year. Carver became the majority stockholder, while his partner and an SBIC (Small Business Investment Corp. see ch. 7) were minority shareholders. During the early years of the company Carver made all the major decisions, Phase Linear Corp. 's first product was a 700-watt power amplifier for use as a component in home audio systems. Carver tried to bring out one new product each year, and by 1974 Phase Linear had three amplifiers on the market.[1]

Stereo amplifiers range in power output from a few watts per channel on up to 350 watts per channel—the Phase Linear 700's capability—or more. The main feature differentiating the Phase Linear 700 from others on the market was its great power; one of the first advertisements touted it as "the most powerful, most advanced high-fidelity solid state amplifier in the world. " In a February 1972 article in the magazine *Audio*, Carver described several of the design problems overcome in achieving this power level. The main obstacle had been transistor voltage breakdown, While 350 watts at 8 ohms for each of two channels requires a power supply capability of more than 200 volts, the best existing audio transistors had sustaining voltages of only 120 volts. Carver solved the problem by working with a major semiconductor manufacturer to modify a 600-volt television horizontal sweep transistor so that it would be suitable for use in audio amplifiers.[2]

Crossover distortion created another barrier. In small, low-power amplifiers, this form of distortion can be avoided by allowing an "idling current" to flow continuously from the output transistors. At lower powers, the idling current does not generate much heat, but in a 700-watt amplifier with 24 output transistors this approach is impractical. A novel biasing circuit, eliminating crossover distortion while operating without idling current, solved the problem.

The Industry

Market Growth.–During its early years, the high-fidelity industry catered to a small market consisting mostly of the wealthy. The cost of early high-fidelity equipment made it a sign of status. In the 1930's, few could afford the $3,000 to $10,000 price of a Capehart record changer. As the price of audio components fell during the 1940's and 1950's, a new market for high-fidelity equipment grew, centered on hobbyists—audiophiles and music enthusiasts willing to spend several thousand dollars to assemble systems built around separate tuners, amplifiers, turntables, and speakers. Sales levels remained modest, but continuing technological improvements led eventually to the present mass market. Factors contributing to the expansion of high-fidelity equipment sales in the United States since 1960 include:

- rising levels of disposable income;
- the introduction of stereophonic sound recordings in 1959;
- approval by the Federal Communications Commission of FM stereo-multiplex broadcasting in 1962;
- solid-state equipment designs beginning in the mid-1960's, which sharply reduced manufacturing costs as well as improving reliability; and
- progressively lower tariffs on imports, leading to more intense price competition (duties on speakers and amplifiers were cut from 15 to 7,5 percent, and on tuners and receivers from 12.5 to 10.4 percent, between 1968 and 1972).[3]

Demographic trends helped catalyze demand during the 1960's and 1970's. Fifteen to thirty-five year olds buy most high-fidelity equipment; at the time this was the most rapidly growing segment of

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*These case studies are based on reports prepared for OTA by J. J. Wheatley, D. M McKee, S. R. Barnes, L. E. Hartmann, and D. J. Keith under contract No. 033-1190.

[1] Interview with Robert Carver.

[2] R. Carver, "A 700 Watt Amplifier Design, " *Audio*, February 1972

[3] E. Ashkenazi, "The Executives' Corner, " *Wall Street Transcript*, June 11, 1973.

the U.S. population. The flowering of the music-oriented youth culture in the 1960's also boosted sales. In the latter part of that decade, audio products became the fastest growing portion of the consumer electronics industry, with demand especially strong in the 15 to 24 age bracket. Few American manufacturers were able to capitalize on this growth, as imports made major inroads into the U.S. market. Japanese equipment often surpassed the products of U.S. companies in performance, while selling for less. Continued technological improvements, creative new product developments, and lower foreign labor costs helped imports eat away at the market shares of American firms.

Amplifier Technology.—The evolution of the power amplifier is marked by a long series of incremental design improvements aimed at reducing distortion in the reproduction of music. Amplifiers create two kinds of distortion. Clipping is the most serious; it occurs when the music being reproduced demands a higher instantaneous power level than the system can deliver. Normally, these extraordinary power demands are fleeting: the high C in an aria, the climax of a thundering crescendo in a baroque score. On an oscilloscope display, clipping appears as a flattening of the peaks and valleys of the waveforms.

The second type, crossover distortion, occurs at low instead of high volume levels. Crossover distortion gets its name from the small notches in waveforms seen on an oscilloscope as the polarity crosses from plus to minus or vice versa. Resulting from nonlinearities in transistor characteristics at low current values, this form of distortion produces harmonics that are approximately constant in level regardless of output power, hence only audible during quiet passages.

Consumer Behavior.—Buyer psychology was one of the keys to the market for the Phase Linear 700, as illustrated by the opening paragraph of an article in a 1976 issue of Saturday Review:[4]

> When I first got into hi-fi nearly 20 years ago, everyone knew that you needed a minimum of 10 watts of amplifier power for good high fidelity. And so I swapped my table radio, with the serviceman installed phono input (one watt of power, if I was very lucky), for a fashionable 10 watt amplifier. After that came a 25 watter, then my first stereo amplifier (35 watts in each of its two channels), then a 60 watt per channel amplifier. Today I have one with two 200-watt channels. At each step of the way, I've been perfectly in fashion. But what else, if anything, have I gained from my power hunger?

The author goes on to point out that sound quality did in fact improve, but in small increments and at high cost.

The Phase Linear 700.—When" introduced, the Phase Linear amplifier was not only more powerful than others on the market, but offered more power for the money. In 1971, the Crown DC 300 (150 watts per channel) listed at $685, compared to the Phase Linear's $749. s The Phase Linear stood out as a bargain, offering more than twice as many watts per dollar, and helping establish a new market category. In the early 1970's, a "super-power" amplifier was considered to be anything delivering more than 50 watts per channel. The entrants in this class included, in addition to the Crown DC 300: the Pioneer SA-1000 (60 watts per channel, $230); the Harman-Kardon Citation 12 (60 watts per channel, $298); the SAE Mark 111 (120 watts per channel, $700); Sony's TA-3200F (130 watts per channel, $359); and the C/M 911 (120 watts per channel, $540,[6] The Phase Linear 700 surpassed all these by a large margin. So successful was Phase Linear in opening up a new market niche that it faced no direct competition—from either American or foreign firms—during its first 3 years.

The Competition.—To the extent that it provided more power at a lower price, the Phase Linear 700 was able to capture buyers from other companies. These competitors were mostly large or medium-large, and well-established. Crown—maker of the DC 300—was a division of International Radio and Electronics. The privately held firm sold most of its products to professional musicians and institutional purchasers such as churches. Marantz, producer of another powerful amplifier, was a wholly owned subsidiary of the Superscope Corp. Superscope had been incorporated in California in 1954, and in 1966 purchased the Marantz Co., Inc., adding 50-percent interest in Marantz Japan, Inc. in 1971. Marantz products were manufactured in the company's Tokyo plant. Superscope had also served as exclusive U.S. distributor of Sony products since 1957. A third maker of high-power amplifiers was the McIntosh Corp., also privately held. A small company compared to Crown or Superscope, McIntosh produced high-end stereo equipment almost exclusively,

From an international perspective, that the Japanese presence in the super-power category was small may seem remarkable; Japanese producers had by 1970 captured an overwhelming share of the U.S. audio market. The explanation appears to be

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[4] I Berger, " Power Plays,' *Saturday Review*, Jan, 6, 1976, p. 4(I

[5] " 1972 HI-F' I Preview Direc tory, " *Audio*, September 1971.

‘[bid.

simple: the market for separate amplifiers of all sizes was not very large, and within it, the market for the very largest amplifiers, with their high price tags, was even smaller—less than 10 percent.[7] The Japanese approach had been to concentrate their product development and marketing efforts on the largest selling stereo components, such as integrated tuner-receivers. Japanese firms like Akai, Hitachi, Kenwood, Nikko, Pioneer, Panasonic, and Sansui also offered separate amplifiers in the more popular power ranges. Many of these companies were large and diversified. Panasonic, for example, is a brand name of the Matsushita conglomerate, whose export sales to the United States in 1971 totaled $358 million. Pioneer had 1970 U.S. sales of $126 million, and was already one of the largest high-fidelity equipment producers in the world.

These firms relied on their ability to sell equipment perceived to be of good quality at low prices. Their strategy had been to concentrate almost exclusively on mass-market products, leaving the expensive, high-end components to smaller American firms. Phase Linear thus faced little competition from the major Japanese electronics firms in its early years—primarily because of the relative smallness of the market for super-power amplifiers. But even though Phase Linear achieved its initial success by appealing to audiophiles—and while doing so acquired a reputation for high quality—the company soon began selling to a wider range of buyers, largely because of its modest prices.

Distribution.—Most audio equipment manufacturers sell through networks of franchised dealers served by regional sales representatives. Dealers generally take delivery from the factory, although Pioneer and some of the other large firms maintain regional warehouses. The greatest portion of retail sales are made through audio specialty stores—high-volume, low-margin outlets emphasizing the heavily advertised, low-priced Japanese brands. A second type of retailer, the "audio salon, " tends to be individually owned, and to specialize in more expensive products. In addition to the prestige lines of the mass-market firms, these stores sell high-end equipment made by smaller and less well-known companies. Other major outlets include: mail order houses; discount and department stores; appliance, radio, and TV dealers; and catalog showrooms. Generally, these limit themselves to the more moderately priced and popular components.

Product Development

The super-power amplifier for home stereo systems was largely the brainchild of Phase Linear's founder, Robert Carver. Very high power as a route to better sound quality at all listening levels was a novel idea when Carver began experimenting in his home workshop, He built a series of amplifiers whose power capability surpassed anything on the market. The tests he ran backed up his insights; music sounded better to him played through the prototypes. Measurements of audio distortion supported his subjective judgments.

Convinced of the virtues of a stereo amplifier with a wattage rating more than double anything then available, Carver set out to create a design suited for commercial production. Most of this work he did himself, While Carver enlisted the aid of several Motorola engineers to solve the transistor voltage breakdown problem, the ideas were basically his.[8]

Phase Linear placed a premium on technology in those early days. Carver, highly regarded in the audio industry as a gifted designer, wanted to build an amplifier of unprecedented power, but he also wanted to build one that was affordable, This second objective, more than anything else, called for the creative use of technology in order to reduce production costs—the simplest possible design that would deliver very high power levels,

Carver did not have the financial resources to do much marketing research, but his experience told him that a low-priced, high-power amplifier would sell. After showing prototypes built in his home workshop to dealers, and being assured that they would carry the product, he decided to go into limited production. Manufacturing began in an old Safeway store leased for the purpose.

Marketing

At first, Phase Linear took a rather ad hoc approach to distribution and marketing. As word of the Phase Linear 700 spread, the company accepted direct orders from anyone—individuals, as well as dealers large and small. In 1971, phase Linear hired a marketing manager who set up a system of company sales representatives, but the firm still found itself with a growing backlog of orders from an unwieldy assortment of some 600 buyers.[9] Two years later, a new marketing manager took over—Don Prewett, a recent MBA graduate. Prewett began setting up a new distribution system,

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[7] Interview with Don Prewett, Phase Linear Corp

[8] "A 700 Watt Amplifer Design, " op. cit

[9] Prewett, op. cit.

It took 2 years to reorganize Phase Linear's system of dealers and sales representatives. Prewett found representatives with overlapping territories and Phase Linear products stocked by competing stores. The firm's managers decided that Phase Linear products should be sold primarily through large chains and retailers of stereo equipment, which at that time were growing at a phenomenal rate, while avoiding small, specialized outlets. Two of the highest volume stereo chains in the country became major outlets for Phase Linear. With the demand for stereo equipment exploding in the early 1970's, these retailers were opening many new stores, By 1980, the company was selling its products through 16 sales representatives to 275 dealers operating about twice that number of retail outlets. Dealers and designated repair shops handled service in the field.

Phase Linear's strategy was to dominate its chosen market niche and expand from there, The 700 faced no real competition for more than 3 years, As it became apparent that the first part of this strategy would be successful, the company quickly began to extend its product line, In January 1972, it came out with the Phase Linear 400, which offered 200 watts per channel, This amplifier proved even more popular than the 700. By 1974, two to three times as many 400s were being sold as 700s, and the company's annual sales had reached $3.5 million.

Thanks to imaginatively simple design, production costs were low; because of the lack of competition, the Phase Linear 700 could be priced to yield a healthy profit. As a result, the firm was able to generate virtually all the funds needed for expansion from internal sources.

The Industry Reaction

Phase Linear's entry into the high-fidelity industry was inconspicuous. At the time of its incorporation in early 1971, the company counted only a few employees. Most of the industry regarded its product as an oddity with limited appeal.

Japanese firms, which constituted the dominant force in the audio industry worldwide, had overlooked the potential of extremely high-power amplifiers, which did not seem to fit their export-oriented approach. Efficient production technology and effective advertising, sales, and distribution enabled them to drive their American competitors out of the market for mainstream products like stereo tuner-receivers. But the Japanese manufacturers did not regard the stereo separates market as big enough to deserve much attention. Firms such as Kenwood, Sansui, and Pioneer maintained separate stereo component lines, but mostly for the sake of product mix and the lustre that high-end components added to their image.

As a result, competitive response to Phase Linear's products was slow in taking shape. Only in 1975, after the company had already secured the largest market share of any entrant in the market for separate amplifiers—15 to 17 percent—did several firms, both American and foreign, introduce super-power amplifiers of their own. For the most part, Phase Linear's U.S. competition came from small and relatively new companies. One of these, the Great American Sound Co., came out with a model called the Ampzilla aimed at the heart of Phase Linear's market—the 20- to 35-year-old male hi-fi hobbyist. Bose Co., which had been primarily a manufacturer of speakers, also introduced a super-power amplifier. One of the largest firms to enter at this time was Marantz, mentioned earlier. These companies constituted the first wave of competition. A second wave came as the huge Japanese manufacturers, including Mitsubishi and Yamaha, finally began making super-power amplifiers.

The response of Pioneer Corp., the sales leader in the industry, was the most belated—but most significant by far for Phase Linear. In 1978, U.S. Pioneer, a wholly owned subsidiary of Pioneer-Japan, bought Phase Linear. Just prior to the acquisition, Carver had sold his stock interest back to the corporation. At this point, U.S. Pioneer purchased the company from the remaining stockholders—Carver's ex-wife, the SBIC, and his former partner—for a price reported to be in the middle seven-figure range,

How did this change of ownership affect Phase Linear? While leaving the company's management team intact, Pioneer placed at Phase Linear's disposal a wide range of new resources. The company now had ample financing for product development efforts, and new sources of technology. Phase Linear's marketing capability was strengthened because it could use the parent company's extensive U.S. retail network. Pioneer also became a supplier of component parts for Phase Linear's products.

What was Pioneer's motive in purchasing Phase Linear? The major reason was probably a desire to strengthen its position in a rapidly growing market segment. Partly because of their successful strategy of dominating the mass market, many of the Japanese brands lacked the quality image necessary for success at the upper end. The best evidence for the thesis that Pioneer acquired Phase Linear primarily for its prestige value is the succession of new stereo components introduced under the Phase Linear name. Within 2 years of the acquisition, "Phase Linear" turntables and tuners were being exported from Japan to the United States. These products were developed by Pioneer design engineers and manufactured at Pioneer facilities. Except for their high price tags, they did not differ greatly from comparable Pioneer products.[10] Rather than any significant transfers of technology to or from the United States, the effects of the takeover seem to have been restricted to marketing and financial matters.

In recent years, Phase Linear has fared well internationally, with 30 percent of its 1979 sales coming from exports, two-thirds of these to Europe. But Japan is one major market that Phase Linear, along with almost all other U.S.-based audio manufacturers, has not been able to crack. Only two American companies—McIntosh and JBL, the latter a manufacturer of speakers—have established distribution channels in Japan. Their entries took place shortly after the end of the war. Since then, no major American manufacturers of consumer electronics have been able to sell their products within Japan in any volume. This inability stems at least in part from distribution problems. The task is not impossible, but costs for deciphering and meeting the many product regulations, as well as establishing marketing channels, are great. Even so, the distribution of electronic products and household appliances in Japan is less complex than for goods such as food or kitchenware. A major reason is the emergence of a few large manufacturers of consumer products and household appliances—e.g., Matsushita—which have taken the initiative in organizing simpler marketing channels, Still, over 80,000 retailers, more than three-quarters quite small, handle consumer electronic products.

Phase Linear executives had their eye on the Japanese market for some time prior to the 1978 acquisition by Pioneer, but report that Pioneer's policy has been to refrain from encouraging efforts by Phase Linear to export back to Japan. In particular, Pioneer apparently has no intention of making its domestic marketing channels available to its American subsidiary. This might reflect: 1) simple exclusion; 2) a decision that it would be too costly to undertake a marketing program in Japan; or 3) a market-dividing strategy whereby Pioneer decided to promote Phase Linear only in the United States and Europe.

Conclusion

Within the high-fidelity industry, qualitative differences between products of similar price tend to be small. Industry executives generally believe that the successful firms are those that market most effectively. Phase Linear was typical; its rapid rise to a position of leadership in one sector of the industry was largely due to effective marketing—designing and building a product that others had overlooked but that consumers were ready to purchase. Robert Carver began to pursue his ideas based on intuition about the market. At the time, the notion that real demand could exist for a super-power amplifier would probably not have gotten much of a hearing in a large, established company.

Technology played a crucial role in the second stage, the actual development of the product, where Carver's sense of design led to a simple, low-cost amplifier. Phase Linear's critics sometimes remarked that they were "designed to the bone, " meaning that they gave maximum power while offering little in the way of backup or protective circuitry. But it was apparently just this quality of brute power that younger buyers of stereo equipment wanted. Nonetheless, the company also recognized that demand for a 700-watt amplifier would be limited, and quickly moved to broaden their offerings.

Robert Carver later started another company; in 1982, Carver Corp. began advertising a power amplifier featuring "750 Watts/chan. Dynamic Headroom for just $799."

Semiconductors: The 4K Dynamic MOS RAM

The Product

Electronic data processing, at one time solely a matter of computers, has spread to a wide range of products: industrial controllers, automated machine tools, "smart" terminals, calculators, even household appliances. These systems need memory—the ability to store and retrieve information (see ch. 3). Random access memories (RAMs] can retrieve or rewrite digital data stored in an arbitrary location on command. Most integrated circuit memory is of the random access type. Both major transistor technologies are used in semiconductor memories—bipolar and MOS (metal oxide semiconductor, ch. 3), with MOS now the largest seller by far.

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[10] Interviews with stereo dealers.

MOS RAMs can either be static or dynamic. Static RAMs hold their contents indefinitely, provided they are supplied with power. Dynamic RAMs rely on capacitance for storage; they must be "refreshed" every few milliseconds. Static RAMs require more complex memory cells than dynamic RAMs, and are thus not as dense, taking up more area on the chip and costing more.

In 1974, when the 4K dynamic RAM—which can store 4,096 bits of information—was introduced, a new generation of memory circuits was appearing about every 30 months. Each design generation had been four times larger than the previous one, the sequence being 256 bits, 1K, 4K, then 16K, and—in the early 1980's—64K. By 1983, 256K RAMS were in pilot production. One explanation for the fourfold density increment is that, while technological *capability* in terms of circuit density roughly doubled each year, design costs were high enough so that, if new designs came out every 12 to 15 months, they would not generate enough cumulative sales to be profitable. By the end of the 1970's, the intervals between RAM generations had lengthened to several years.

The newly introduced 4K dynamic RAMs were hailed in mid-1974 as far outdoing 1K types as the cheapest way to satisfy user needs, Despite spotty availability during that year, they were quickly designed into microcomputers, minicomputers, and peripherals; manufacturers of mainframes waited for price decreases and assurances of product reliability before switching from 1 K to 4K chips.

The Industry Setting

While some captive semiconductor manufacturers—notably IBM—have designed and built their own RAMs for internal use, this case study treats the competition for sales in the merchant market. Development of 4K chips for merchant sales began in the early 1970's, with samples available by late 1973. As the 4K RAM moved into volume production, the semiconductor industry entered the most severe downturn in its history, the result of a general recession in the U.S. economy beginning in 1974. Semiconductor firms furloughed 50,000 employees, and idled $750 million in production capacity.[11]

As the 4K chip emerged and economic recovery began, 1K RAM sales declined, The 4K RAMs accounted for only $14 million in sales during 1974, but $45 million the next year. By 1976 1K sales had fallen to $42 million, while 4K sales soared to $161 million.[12]

Intel Corp. 's 4K RAM design was first onto the market—via a licensee—but the competition quickly became intense, complicated by production problems at several firms, including the industry's largest manufacturer, Texas Instruments (TI). Only at the end of 1975 had firms such as Intel, TI, and Mostek ironed out most of their processing difficulties; while earlier projections had been for shipments of 10 million chips during the year, actual output was perhaps half this, The 4K RAM posed the greatest difficulties the industry had faced up to that time in moving a product into volume production; indeed, before the 4K RAM reached high volumes, 16K RAMs had been announced.

It took several years for an industry standard 4K RAM configuration to emerge. Three chip designs were vying for dominance, with the situation in considerable flux:[13]

> Intel/TI's 22-pin package, announced by Intel and then modified by TI, uses TTL voltage levels for all address, data-in, and data-out lines; it requires only one high-voltage clock level but needs three power supplies.
>
> Motorola/AMI's [American Microsystems, Inc.] 22-pin package differs in having an extra reset pin, which must be energized when power is first applied.
>
> Mostek's 16-pin package takes up less board space than the other two, at the cost of some added system complexity in clocking and interface logic, since the device must be multiplexed; it is also TTL-compatible at all inputs, including the clock input.

By the end of 1976, sales of 16-pin designs were increasing at the expense of 22-pin devices. The 22-pin part was larger; the extra pins also led to greater assembly cost. A second focus of technological competition was access time—the time, on average, to retrieve a bit of information from the memory. Access time for memory chips is normally measured in nanoseconds, 1 nanosecond (ns) being 10^{-9} seconds. For RAMs, an access time of 100 ns is considered fast; 500 ns is slow.

The Competitors

Capital requirements for manufacturing 4K RAMs were not, in the mid-1970's, a significant barrier to entry. Many of the competing firms had

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[11] "New Leaders in Semiconductors," *Business Week*, Mar 1, 197b, p 40

[12] *Dataquest*, Oct. 7, 1977, pp. 18.6-9.

[13] L. Altman, "Semiconductor Random-Access Memories," *Electronics*, June 13, 1974, p. 109.

begun operations only a few years earlier, and were still relatively small.

Microsystems International Ltd.—The first company to bring a 4,096-bit RAM to market—in late 1972—was Microsystems International of Ottawa, Canada, a licensee of Intel. The 22-pin, 3-transistor memory cell chip was based on proprietary process technology, with the company benefiting from earlier experience as a licensee for Intel's 1K RAMs. Although first with a working part, Microsystems International never became a major factor in 4K RAM sales.

Intel.—Intel's 4K chip followed an immensely successful 1 K product—with the possible exception of IBM's proprietary 1K design, the most widely used semiconductor memory circuit up to that time. Judging that the product lifetime for a 2K RAM in volume production would probably be no more than 6 or 8 months, Intel jumped to a 4K chip, introducing-in the summer of 1973—a slow (600 ns access time) 4K device designed for small systems. The company planned to introduce a high-speed version later in the year; both were to have a 22-pin, single-transistor memory cell design. The higher speed chip, with maximum access time of 150 ns, would be better suited for large computers and was projected to take over most of Intel's 4K production during the first half of 1975. Intel hoped to capture as much as half the potential market,

Meanwhile, customer desire for greater circuit board density was prompting movement away from the 22-pin package, At the end of 1974, Intel announced plans to introduce its own 16-pin device. The company thereafter continued to build both 22- and 16-pin RAMs,

Mostek.—In September 1973, Mostek was sampling an innovative 16-pin RAM, one in which some of the pins served two functions (called multiplexing). The chip enjoyed a two-to-one density advantage over the competition. Eventually, after a redesign reduced the size even further, it became the de facto industry standard. However, Mostek, along with other chipmakers, suffered through yield and quality problems which cut into its ability to capture early market share.

Despite the pioneering features of its 16-pin design, the firm—in common with the rest of the industry–did not rely on patents to protect its technology. Mostek's 1977 Common Stock Prospectus stated ". . . the Company believes that success in the semiconductor industry is not dependent upon patent protection but is dependent upon engineering and production skills and marketing ability. It does not anticipate that the grant of any patent application will significantly improve its competitive position. "

National Semiconductor.—National developed both one- and three-transistor cell designs of its own. By mid-1975 it was marketing 22- and 18-pin chips—the 22-pin part faster than, but compatible with, that of TI. National's strategy of seeking faster access times is part of the explanation for its decision not to build a 16-pin device; National's engineers felt, incorrectly as it turned out, that the Mostek approach did not lend itself to speed improvements that would prove great enough. The 18-pin choice allowed good board density and high speed without requiring the multiplexing circuitry of 16-pin packages. Two other firms quickly lined up as alternate sources for National's 18-pin part.

Texas Instruments.—TI was the first to drop its 4K RAM price below the cost to purchase four 1K chips. By September 1974, TI was producing more 4Ks than anyone else, having solved its earlier yield problems. At the close of the year, TI added an 18-pin package to its existing 22-pin 4K catalog; both the 18-pin and the new 22-pin part offered access times of 200 ns. TIs' second source for its 4K RAMs was Advanced Micro Devices (see below).

Other U.S. Entrants.—Fairchild became Mostek's second source, offering a pin-compatible version of Mostek's unit while also producing another design, with faster access times, based on the proprietary Fairchild Isoplanar processing technology. Meanwhile, American Microsystems, Inc. (AMI) and Motorola developed their 4K RAMs jointly, sharing masks and processing technology. AMI was particularly confident of its product—' 'even for the chronically confident semiconductor industry''—and expected its entry to become the industry standard; its speed and power characteristics, single clock design, pin configuration, and second-source at Motorola all seemed to the company to justify this belief.[14] AMI's partner, Motorola, was relying on this new 4K RAM to bring volume MOS sales to its semiconductor division, "after a couple of false starts with, early memory products."[15] Still, Motorola also sought other alternate sourcing arrangements.

Japanese Firms.–-Semiconductor manufacturers in Japan were developing their own 4K RAMs over the same time period. Nippon Electric Co. designed a 4K RAM described as an improved and enlarged version of the company's three-transistor cell, 1K part.[16] Hitachi hoped to have a 300 ns chip on the

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[14] H Wolff, ''4 ,096-Bit RA MS Are on the Doorstep,'' *Electronics*, A pr 12, 1973, p. 76.

[15] H Wolff "Customers Sweat out 4,096-Bit RA MS," *Electronics*, Mar 21, 1974, p. 70

[16] ''4,096-Bit RAMs Are on the Doorstep,'' op cit

market by the end of 1973. Fujitsu's 4K RAMs used three-transistor cells, but one-transistor production versions were anticipated. Toshiba was also developing a 4K design.

These development efforts attracted little attention in the United States. Shipments of 4K RAMs from Japan did not begin to enter the U.S. market until 1977, and then only in small quantities. If Japanese competition appeared to be no more than a minor threat, European firms posed even less of one-in part because most had neglected MOS technology, continuing to concentrate on bipolar. In 1976, U. S. firms had 90 percent of the world market for MOS devices of all types, with the Japanese holding most of the rest-largely as a result of sales at home.

Initial Japanese entry into the U. S. market was based on a combination of low prices and high quality, with special emphasis given the latter (Chs. 5 and 6). Although the Japanese were a minor factor in the case of the 4K RAM, they persisted in this strategy with the 16K RAM and other semiconductor products.

The Market

Demand.—As table C-1 shows, fewer than a million 4K RAMs--at $15 to $20 each--were sold in 1974. Volume increased as prices broke the $10 barrier-dropping to $6 late in 1975—and mainframe computer manufacturers began to buy in large quantities. Sales peaked in 1978, before 16K RAMs took over.

The companies involved grew rapidly as 4K RAM volumes jumped, Intel's sales in 1970 totaled only $4,2 million; by 1974 they were $134.5 million, and by 1979 had reached $663 million, This was not all due to the 4K RAM, but that device played a major role.

Distribution.—Within the United States, most semiconductor firms sell directly to large customers as well as through independent distributors. During the mid-1970's, many of the firms producing 4K RAMs were rather small, with little marketing experience. However, a well-developed network of industrial distributors such as Arrow Electronics and Hamilton / Avnet served the many smaller customers for memory products.

Table C-1 .—Worldwide Sales of 4K Dynamic MOS RAMs

Year	Sales (millions of units)
1974	0.7
1975	5.0
1976.	28,0
1977	57,1
1978,	76,5
1979.	69.2
1980	31.2
1981	13.0

SOURCE Dataquest

Product Development

Top managers in semiconductor firms devote a great deal of attention to product and process development—the two go together—because of the rapidly evolving technology, Many industry executives have technical backgrounds,

Planning.—At Intel, product planning committees are organized for each of the firm's "strategic business segments. " The committees—e.g., that for RAMs—operate with a 5-year time frame. Planning responsibilities may take a third of a committee member's working hours. Intel's approach has been to look for high-growth products where the company's technology can provide an advantage. proposals emerging from the planning process are presented to an executive group that includes the chairman and vice-chairman of the board, the president, and the vice presidents.

Texas Instruments—another technology leader--emphasizes project-oriented teams for planning future activities, while a more conventional operating hierarchy looks after current operations.

Not all firms in the industry try to be innovators. Instead, managements may opt to become alternate sources for products introduced by others. This strategy is sometimes dictated by costs—since the extensive research and development (R& D) necessary to come up with a proprietary design may seem too risky, particularly for a company without a position of technical leadership. It does require the ability to duplicate (and perhaps improve on) the device in question, and get into production quickly.

In the case of the 4K RAM, American entrants followed one of two approaches to R&D. In the first group were firms such as Intel and Mostek, which attempted to take the lead, hoping that their designs would become de facto industry standards. In the second were companies like Advanced Micro Devices, that aimed at becoming alternate suppliers with a competitive advantage in attributes such as quality or performance. Technical leadership in the semiconductor industry requires two kinds of scarce resources: money and skilled engineers. The choice of strategies depended on these, but even a second-source supplier needs clever designers —

and still more, competent process engineers. During the 1960's and 1970's, successful U.S. merchant firms were sometimes built around the abilities of three or four inventive circuit designers. Even so, the R&D emphasis in many firms during development of the 4K RAM was heavily on process technology. The case of Advanced Micro Devices (AMD) illustrates the point.

The Example of Advanced Micro Devices.—AMD was founded in 1969 with an initial capital investment of $1.5 million, Research, design, and development activities began immediately; by the end of the first year half a million dollars had been spent, although sales had not begun. R&D played only a limited role in the strategy adopted by the company. The president and chairman of the board—W. J. Sanders, III—while an engineer, had resigned a position in marketing at Fairchild to start AMD. Sanders chose to emphasize second-sourcing of chips developed by larger firms, Not only did AMD have limited funds for developing new products, but initially the company had no proprietary technology.

Product design and development throughout the industry was almost exclusively a technical activity during these years, Marketing research was insignificant by comparison. Neither Intel nor AMD had internal marketing research staffs. One reason was a pervasive feeling that production capacity would limit total sales over the foreseeable future.

During its first few years of operation, AMD followed a strategy of introducing devices that could be put into production quickly to serve existing markets; R&D spending remained low until 1974, when it reached about $1.5 million. The company tried to concentrate on high-volume chips—for example, targeting customers who might be able to grow rapidly in their own industries, which in turn would permit AMD to expand more rapidly than its competitors, At first, the firm concentrated its sales efforts on 25 to 30 customers worldwide. In the late 1970's, AMD began to modify its approach, pursuing new products of its own,

The choice of integrated circuits to second-source was critical for AMD. To fit the company's product development strategy, a proposed new integrated circuit would: 1) be marketable in high volume at a price attractive to AMD's customers, implying; 2) that it would be complex enough to be a cost-effective substitute for existing devices, but not; 3) so complex that it became, on the one hand, difficult to make, or, on the other, so specialized as to limit its market. The essential links are between design engineers—those at the semiconductor firm and those at the customer—rather than between sales staff and purchasing department.

The three fundamental steps in producing integrated circuits—wafer fabrication, assembly, and testing—are now all essentially mass production processes. During the peak period of 4K RAM production, however, assembly and testing were both quite labor-intensive. Because of this, AMD—like its counterparts in the U.S. industry—had established offshore plants in low-wage countries. AMD's offshore facilities were in Manila and in Penang, Malaysia.

AMD's approach to the 4K RAM market typifies its strategy during the mid-1970's. The firm produced two 4K chips—one an 18-pin design with two power supply voltages, the other a 22-pin part requiring three voltages. Both were interchangeable with 4K RAMs manufactured by TI, but AMD made a number of design changes aimed at reducing power consumption, improving noise immunity, and meeting military standards. The last has been a centerpiece of AMD's marketing approach; by advertising that all its chips met military specifications, the firm sought to establish an image of high quality and high reliability, AMD's emphasis on making modest improvements in the products they chose to manufacture, adhering to high quality standards, and concentrating on standard devices foreshadowed the Japanese strategy of a few years later.

Demand for AMD's 4K RAMs came mostly from computer companies—about 10 in number—along with another 150 firms manufacturing systems and equipment ranging from typesetters to computer peripherals, and including a half-dozen telecommunications accounts as well as 10 or 12 military contractors. Each customer was, potentially, a high-volume purchaser. A mainframe computer with 8 megabytes of memory, for instance, needed 18,000 to 20,000 4K RAMs,

Pricing and Profits

As part of its overall strategy, AMD attempted to hold its prices somewhat above those of the competition by stressing quality. Prices for semiconductor products tend to be high at first, declining rapidly as production volumes and the number of entrants grow. Manufacturers sometimes set prices in anticipation of future cost reductions. Eventually, product obsolescence puts still more downward pressure on prices. At the time the 4K RAM was coming onto the market, the semiconductor industry was in a deep recession, leading to even more price cutting than normal.

Intel—one of the acknowledged technical leaders —also charged premium prices, but on the basis of offering the most up-to-date products; the company continues to pursue a strategy of building unique circuits when possible, thus maintaining healthy profit margins. Intel has, in many years, been among the most profitable companies in the industry—table C-2. The table lists profit levels for a number of U.S. merchant firms in 1978, the peak sales year for 4K RAMs and a generally good one for the industry; profitability ran somewhat ahead of that for U.S. industry as a whole, represented by the Fortune 500 average.

The 4K RAM Lifecycle

Before Intel's pioneering 1K RAM entered the market, semiconductor firms often simply copied each other's products. Customer demands for alternate sourcing-more than one supplier for a given part—provided an easy avenue into the market for a new company. Mostek's Executive Vice President, Berry Cash, remarked: "Everyone used to copy everyone else. About the only thing you could do when you got something good was run like hell and work on new products to obsolete it."[17]

This pattern changed, partly as a result of experience with the 1 K RAM. A number of firms tried but failed to duplicate Intel's chip; after 3 years only two or three other companies had learned to build it. As a consequence, companies began to negotiate formal alternate sourcing agreements for the next generation 4K RAM. Through these agreements, firms could acquire design rights—and sometimes lithographic masks. Thus, as pointed out earlier, Fairchild negotiated a second-source agreement with Mostek, while Motorola and American Microsystems worked jointly on 4K RAM development.

Table C-2.—Profit Levels for U.S. Semiconductor Firms, 1978

	After-tax earnings	
	As percent of sales	As percent of equity
Advanced Micro Devices	7.1 0/0	17.60/o
Fairchild Camera and Instrument	4.6	12.0
Intel	11.0	21.6
Mostek	7.1	15.8
Motorola	5.6	16.6
National Semiconductor . .	4.6	17.1
Texas Instruments	5.5	17.6
Unweighed average	6.50/o	16.50/o
Average for Fortune 500 industrial firms . .	4,80/o	14.3"/0

SOURCE Annual reports

During the early years of the 4K RAM product cycle—1973-76—Intel enjoyed a major share of sales, but in the end, most observers rated Mostek the overall "winner" of the 4K RAM competition. Many other entrants benefited in terms of profits and demonstrated viability in the rapidly growing memory market. Mostek's success was due not only to customer acceptance of its 16-pin design, but also to the head start it got when TIs' 22-pin device encountered production problems.

The situation in 1977, the year before output peaked, is illustrated in table C-3. While Mostek sold the most of any one design, TIs' total 4K RAM sales—spread over three designs—were slightly greater. There were really no losers, especially since manufacturing capacity constrained sales. Nonetheless, Mostek's 16-pin RAM found the greatest eventual acceptance in the marketplace; 1977—the year covered by the table—marked the sales peak for 22-pin units, while the 16-pin alternative did not peak until 1979. The world market share of 4K RAMs for Japanese firms was 18 percent in 1977, with NEC the clear leader. The Japanese were splitting their efforts between 16- and 22-pin designs.

Table C-4 gives market shares from 1977 to 1981. For the first years, AMD's second-source strategy led to an increasing proportion of a declining market, while Intel's share declined in part because it began moving into new products. The market share of Japanese firms actually fell over this period. By 1980, several manufacturers had begun to abandon the 4K RAM market.

Conclusion

The 4K RAM reached its unit sales peak in 1978 (table C-l). Dollar volume had been greater the year before—a common phenomenon in the industry. While volumes have since tapered off, 4K RAMs will continue to be widely marketed at least through the mid-1980's. Where a dozen companies made the devices in 1980, the number has since been cut perhaps in half—those who can still make a reasonable margin on sales remaining. The lifecycle of the 4K RAM proved somewhat longer than that for 1K chips, illustrating a trend toward lengthening product cycles for RAMs that is expected to continue. One factor in the longer lifecycle was strong price competition; as 4K prices fell, mass acceptance of the next-generation 16K RAM was delayed. Only when 16K prices came down to the point where one

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[17] "Bourn Times Again for Semiconductors," *Business Week*, Apr 20, 1974, p 66

Table C-3.—Estimated Worldwide Sales of 4K Dynamic MOS RAMs, 1977

	Shipments (millions of units)			
	16-pin	18-pin	22-pin	Total
United States:				
Advanced Micro Devices	—	0.55	1.84	2.39
Fairchild	2.08	—	—	2.08
Intel	2.0	—	8.4	10.4
Intersil	0.5	—	0.4	0.9
Mostek	11.8	—	—	11.8
Motorola	1.55	—	1.19	2.74
National	0.38	—	3.3	3.68
Signetics	0.54	—	0.33	0.87
Texas Instruments	0.9	5.9	5.6	12.4
U.S. total	19.8 (820/o)	6.45 (96%)	21.1 (80°/0)	47.2 (830/o)
Japan:				
Fujitsu	1.8		1.1	2.9
Hitachi	0.45		0,46	0.91
Nippon Electric Co, (N EC).	2.15	0.25	3.7	6.1
Japan total	4.4 (18%)	0.25 (4°/0)	5.26 (20°/0)	9.91 (17%)
World total	24.2	6.7	26.4	57.1

SOURCE Dataquest

Table C-4.—World Market Shares of 4K Dynamic MOS RAMs

	Share of unit sales				
	1977	1978	1979	1980	1981
United States:					
Advanced Micro Devices	4.1 %	8.6 "/0	14.60/o	9.40/0	12.7 o/o
Fairchild	3.6	1.2	—	—	–
Intel	18.2	14.4	8.7	3.2	—
Intersil	1.6	0.5	1.4	3.9	1.1
Mostek	20.7	22.2	20.1	22.8	17.3
Motorola	4.8	7.4	9.2	16.2	24.9
National	6.4	7.3	11.3	14.6	16.1
Signetics	1.5	1,5	0.7	—	—
Texas Instruments	21.7	21.8	15.3	2.6	—
U. S. total	82.6°/0	84.90/,	81.3%	72.70/,	72.1%
Japan:					
Fujitsu .,	5.1%	2.50/,	1.1 %	2.1%	1.5%
Hitachi	1.6	2.3	1.2	0.6	–
Nippon Electric Co.	10.7	8.0	7.9	4,7	2.5
Japan total	17.4°/0	12,80/0	10.2 "/0	7.4 "/0	4.0 "/0
Europe:					
ITT.	–	2.0%	7.4%	16.0%	18.9%
SGS-Ates	—	0.4	1.1	3.9	5.1
		2.4"/,	8.5%	19.9%	24.0°A

SOURCES **1977**—table C-3.
1978-1981—Dataquest

chip cost about the same as four 4K devices did the new generation parts begin to take over. Similar forces were at work during the early 1980's as 64K RAMs entered the marketplace.

Computers: A Machine for Smaller Businesses

The Product

Before 1970, the computer industry was dominated by a few relatively large manufacturers—with IBM holding by far the greatest market share. As the decade progressed, advances in hardware created numerous opportunities for newer firms to sell small computers in markets as yet untapped by established mainframe-oriented companies. The new entrants at first aimed their minicomputers at original equipment manufacturers (OEMs) and at sophisticated customers who could put small processors to work in science and engineering. Between the minicomputer market and that for large, general purpose mainframes lay a vast pool of potential customers—many of them small businesses—largely unfamiliar with the esoterica of computer hardware and software, and without the capability to plan their own data processing installations. Companies from both the mainframe and minicomputer portions of the industry began to design small business computers (SBCs) to attract such customers.

Small business systems range in price from about $5,000 to perhaps $100,000. Typical installations include a central processing unit, one or more terminals for input, disk storage, and a serial or line printer for hard copy output. By the late 1970's, 80 to 90 suppliers were marketing nearly 300 different SBC systems.[18] Among these, the IBM System / 32—the focus of this case—fell near the middle in cost and features. When first introduced, the System / 32 could be leased for $770 to $1,085 per month, or purchased for $33,100 to $40,800. It had been designed for businesses with sales in the range of $1 million to $10 million, and as many as 200 or 300 employees. The complete system—consisting of the central processing unit, up to 32 kilobytes of main memory, a keyboard, display, printer, a single floppy disk drive, and a nonremovable hard disk for mass storage—was housed in a desk-sized enclosure. Software was unbundled, with everything but the operating system sold separately. In 1978, the software available included three programing languages and a series of industry-specific applications packages.

Hardware.—Thirty-two models of the System / 3a were available, differing mostly in the capacity of the hard disk—3.2 to 13.75 megabytes—and printer configuration.[19] Printer options included a serial printer with speeds ranging from 40 to 80 characters per second, and line printers of 50 to 155 lines per minute, The basic machine came with 16 kilobytes of memory; model changes could be made in the field.

The System / 32 could be operated in batch or interactive modes and also function as a smart terminal or a satellite processor linked to other computers. For example, a System / 32 can easily be set up to communicate with: another System / 32; an ink-jet document printer; an IBM Office System 6/430, 6/440, or 6/450; an IBM Mag Card II typewriter; IBM Systems /3, /7, /360, or /370; some of the equipment in a 3740 Data Entry System; or a 5230 Model 2 Data Collection System.

Software.—IBM supported the System/32 by regularly offering new software. The three programming languages available were: Report Program Generator II (RPG II), a commercially oriented language; COBOL; and FORTRAN IV. A utility program aided in file preparation and management; other software supported the communicant ions features mentioned above—e.g., use of the System / 32 as a remote work station for a 370 series mainframe. Other miscellaneous software included: word processing; form letters; a library of mathematics subroutines; statistics; critical path analysis; and a manufacturing management package for scheduling purchases, fabrication, and shipments.

Much more software was made available through the 14 Industry Application Programs (IAPs) supplied on IBM-owned floppy disks and written in RPG II; these could be customized still further if necessary. The 1+1 IAPs handled tasks associated with: accounting firms; medical groups; bulk mailing; construction; hospitals; manufacturing; distribution; law firms; lumber dealers; food distributors; student administration; motor freight; financial institutions; and retailing. Typical IAP functions are accounting, analysis or control of cost / time / i riven - tory / sales, management of files and records, and planning and scheduling.

Upward comparability was one of IBM's design goals. System / 32 purchasers had two possible growth paths: into a System / 3 Model 8, 12, or 15;

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[18] *Datapro Feature Report: All About Small Business -; omputers* [Delran, N J Datapro Research Corp , September 1978), p 70C-010-30a

[19] *Datapro Reportson Min ıcomputers IBM System/32* (Delran, N.]. Datapro Researc h Corp , January 1978), pM 11-491-601

or into a System / 34. With minor modifications RPG II programs from a System / 32 could be run on a System / 3 or vice versa; this also meant that System / 3 users could move into 32s or add 32s to their networks. For those wanting to move into a System / 34, the System / 32 RPG programs were source-compatible with the System / 34, allowing IAPs to run without change.

Support by the manufacturer—not only new software packages, but also hardware updates and servicing—are important to most SBC customers. Those who rented the System / 32 could get service 24 hours a day, 7 days a week. Purchasers had service available 9 hours per day, 5 days per week under the Minimum Monthly Maintenance Charge, or could buy 24-hour service for an additional fee. IBM also emphasized ease of use—the minimal training needed to run IAPs, indeed to operate the entire system.

The Market

That the SBC market offered enormous growth potential was a truism of the early 1970's. The pool of prospective customers for an SBC costing less than $1,000 per month included as many as half a million small organizations—virtually none of which had prior electronic data processing experience. Besides the sheer numbers involved, this market was important for another reason, Computer customers exhibit high loyalty to the firm from whom they buy their initial system. By capturing first-time purchasers, a supplier gains a big future advantage. Computer manufacturers who chose not to compete vigorously in the SBC market ran a real risk of seeing their future market share and competitive position eroded. Adding to the potential market were expanding applications in distributed data processing, where many SBC models could be used as remote job entry stations.

These markets brought a pair of requirements for a competitive SBC. First, it would have to be simple—user-friendly—so that a customer with little or no data processing background could learn to operate it quickly. The second requirement was compatibility with other machines in a networking or distributed processing environment. Upward—and for larger SBCs, downward—compatibility was an important selling point, so that customers could expand or upgrade their installations.

The established mainframe computer manufacturers had, at least initially, advantages in all these areas. Their nationwide sales and service staffs were accustomed to dealing with customers having business applications, rather than the OEMs and technically trained users who bought minicomputers. They also had considerable software experience; mainframes were ordinarily marketed with extensive software support compared to the minicomputers of that era. Moreover, a mainframe manufacturer could design an SBC compatible with other parts of its product line; existing customers then comprised a readymade market base. As a final—and very important—weapon, the large, established firms had brand recognition. Not only IBM, but companies like Burroughs, NCR, and Univac were familiar names. Many new purchasers, bewildered by competing claims and fearful of the pitfalls involved in purchasing a computer, automatically turned to one of these companies. A decade later, IBM reaped similar benefits when it entered the personal computer market. Despite these putative advantages, most of the established mainframe manufacturers had a good deal of trouble adjusting to the competition for SBC sales.

Minicomputer firms—for many of whom SBCs were upward rather than downward extensions of their product lines—faced serious handicaps in comparison. Unlike the mainframe companies, minicomputer suppliers such as Digital Equipment Corp. (DEC) had little experience selling to end-users. OEMs or engineering organizations did not need extensive support; minicomputer firms had neither large service networks nor large marketing staffs. They competed most heavily on hardware features and price. Software was less critical; most users could write their own. Minicomputer customers who needed software or other support frequently bought from "systems houses" or other middlemen, Systems houses purchased hardware in bulk, supplying customized software and assembling a system to meet customer requirements. Not restricted to any one manufacturer, they could put together processors, terminals, storage units, and other peripherals from a variety of sources to customize a given installation. By taking advantage of the lower hardware prices it could command, a systems house might be able to supply an entire installation, including software, for less than the hardware cost to a single-unit purchaser. Qantel and Basic Four both had considerable success as systems houses before entering the SBC market with equipment of their own designs.

Minicomputer makers also experimented with other marketing channels aimed at small end-users. An example is the "software representative" created by Datapoint to locate potential customers. The sale was between Datapoint and the end-user, with the representative getting a commission and afterwards supplying software and other services independently.

Development of the System/32

IBM had been slow compared to Burroughs and NCR in exploiting the SBC market. Prior to the introduction of the System/32 in January 1975, IBM’s only offering was the System/3. Originally priced at the very top of the SBC range—although later models cost much less—the System/3, which reached the market in 1970, had gone on to sell more units than any other computer in IBM’s history; by 1975, over 30,000 had been purchased worldwide. The success of the System/3 was a major reason for IBM's decision to expand its line of SBC machines into the lower price ranges.

In many respects, the System/32 was a direct descendent of the System/3 Model 6. The central processing units of the two were quite similar, and many of the software products offered for the System/32 were adaptations of those developed for the System/3 Model 6. Changes included faster printers, simplified operation, and improved applications programs. With the System/3 Model 6, only limited applications software had been available, and those wishing to write their own programs had to master a complicated operating system.

Development of the System/32—hardware, software, and the market studies leading up to these—was the job of IBM’s General Systems Division (GSD). The GSD emerged from a major corporate reorganization in 1972 that split the former Data Processing Group into three divisions. With this reorganization, the GSD was given development and manufacturing responsibility for the System/3 and related peripherals. Responsibility for all small business applications within IBM followed in 1974, at which time the GSD was given its own marketing arm.

By the next year, the GSD marketing and sales force had grown to some 4,500 sales representatives working out of 67 sales offices, plus nearly 3,000 field engineers. The System/32 entered the market accompanied by an extensive advertising campaign, along with exhibits at trade shows, direct mail, and in-person sales calls. These promotional efforts were tailored to potential customers with little or no computing experience, Initial sales of the System/32, which was made in Rochester, Minnesota and Virmercate, Italy—with components and subassemblies coming from other IBM facilities—exceeded the company’s projections.

The System/32 offered a price-performance combination not available in other IBM systems. Heavy demand during the first year led to extended delivery dates. The reason for this success was not any technological advantage with respect to the competition, but IBM’s accurate perception of the needs and concerns of the SBC market. Indeed, from a hardware perspective the System/32 was a rather limited machine. Instead of being designed for multiprogramming, it was restricted to executing one program at a time. It had less disk storage than a number of other SBC systems. Furthermore, because the disks were hard and nonremovable, only on-line storage was available. The technology utilized in the System/32 did reflect the state of the art in using MOS integrated circuits in both memory and processor.

Probably the most innovative aspect of the System/32 was its software. While IBM had been accustomed to writing customized software for mainframe purchasers, such an approach was not practical given the large number of SBC customers. Hence the Industry Application Programs, aimed at meeting perhaps three-quarters of user needs. The remainder could be supplied by IBM or an independent vendor at extra cost. The IAP concept was not unique, but the design, distribution, and support for these programs was a major undertaking, Unbundling the software was another new departure; IBM had traditionally supplied hardware and software together at a single package price. IAPs, in contrast, were sold for an initial one-time payment plus a monthly support fee. The Wholesale Food Distribution IAP, for example, carried an initial charge of $3,120, plus $147 per month for support. By emphasizing reliable hardware, minimal maintenance, and off-the-shelf software, IBM was able to continue its “hand-holding” approach to marketing while supplying large numbers of machines.

The Competitive Response

Burroughs and NCR were the two companies most affected by IBM’s entrance into the SBC market. While both offered broad product lines, SBCs had come to represent a significant share of their total revenues. Both had seen the importance of SBCs early, and sought to utilize their sales and marketing organizations—which were much more extensive than those of the minicomputer suppliers—to establish themselves in this part of the market.

Burroughs, then the dominant force in SBCs, had formed two special marketing groups–the “general accounts force, ” and the “selected accounts force’’—to handle smaller machines. The general accounts force sold exclusively to small firms, while the selected accounts force devoted its efforts to large organizations with requirements that could be served by small computers. Thus Burroughs explicitly recognized the dual nature of the SBC: stand-alone for the small enterprise, distributed processing for larger customers.

Burroughs had originally entered the lower end of the SBC market in 1973 with the first of its B700 series, selling more than 2,000 in the first 3½ years. When the System/32 was introduced, Burroughs responded immediately—doubling the main memory of the B700 and bringing out six new models. In April 1976, Burroughs announced the B80, which was—unlike IBM's System/32—capable of multiprograming and multiple terminal support. This machine was well received initially, but suffered from severe software problems; it was soon replaced by the B90. Burroughs' share of the SBC market began to slip, a considerable concern to a company that, as early as 1973, got 30 percent of its revenues from the low end of its product line.[20]

NCR also made an early entry into the SBC market, In 1972 it had introduced the NCR 322, a minicomputer priced in the $15,000 range, followed by the Century 8200, the first of a series of SBCs. These two models represented the first results of a thoroughgoing and painful reorganization at NCR, a company that few observers at the time believed could survive. NCR was seen as tradition-bound, still producing electromechanical products that could not compete with electronic equipment. Then, under a new president in the early 1970's, NCR invested nearly $300 million in product development, one thrust being interactive systems designed specifically for business applications.[21] A turnaround followed, as the company went from a loss of $60 million in 1972 to earnings of $72 million in 1975.

The new commitment to electronic products also brought changes to NCR's marketing organization. The old system of branch offices was dismantled, to be replaced by a "vocational sales" organization. Under the earlier system, each salesperson had been responsible for a group of products: sometimes two NCR representatives found themselves competing for the same sale, Under the new arrangement, salesmen were responsible for selling to one of four vocational groups: retail stores; financial organizations; commercial-industrial enterprises; and a residual group consisting of medical, educational, and government organizations. In addition, the entire field engineering force—some 7,000 people—was retrained to service the new electronically based product line.[22]

Sperry Univac was the last of the major mainframe manufacturers to move into the SBC market, introducing the BC/7 in 1977—a machine featuring multiple terminal concurrent data entry capability, a great deal of available storage, and removable disks–none of which were available on the System/32. Sperry Univac had created fully staffed marketing organizations in 18 cities, with plans for further expansion, just for the BC/7.[23] A further indication of their commitment to the SBC market was the acquisition of Varian Data Machines, a major manufacturer of minicomputer products. Nonetheless, the BC/7 family suffered from applications software that did not compare favorably with the competition, and could capture but 2 percent of the SBC market.

Among the minicomputer firms, DEC was and still is the largest and most successful. The company, which had developed the first commercially successful mini—the PDP-8—probably had the most to lose in competing for SBC sales. DEC had established itself by mass-producing "black boxes" sold primarily to OEMs. In the 1970's, this market was coming under increasing pressure from other companies, including those making microcomputers, and DEC realized its greatest growth prospects lay in small business and other end-user markets.

When the System/32 was introduced, DEC was the first to respond, countering—only 10 days after IBM's announcement—with the Datasystem 310, which played to DEC's own strengths. It was slower, with less memory than the System/32, but cost a third less. DEC retained its established marketing practices, selling networked systems directly while relying on independent distributors for simple turnkey sales. These distributors bought hardware at a discount, added software, and then sold the systems at approximately the same price DEC would have charged for the hardware alone. After purchase, DEC provided hardware maintenance, with the distributors responsible for software.

Another minicomputer manufacturer, Wang Laboratories, also responded quickly, releasing a series of computers—the WCS series—that proved quite successful.[24] Like other minicomputer manufacturers, Wang stressed its low prices and proven

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[20] "The Burroughs Syndrome," *Business Week*, Nov. 12, 1979, p. 80.

[21] "NCR Transition Nearly Complete: Company Targets Three Markets, " *Computerworld*, May 24, 1976, p. 35.

[22] "NCR's New Strategy Puts It in Computers to Stay, " *Business Week*, Sept. 26, 1977, p. 104.

[23] "Sperry Sets Computer for Small Business, " *Advertising Age*, Apr. *25, 1977*, p. *46*.

[24] *Auerbach Computer Technology Reports: Wang Laboratories*, Auerbach Publishers No. 140.6856.150, 1977, p. 2.

hardware. However, the company realized that price competitiveness alone would not assure success, and moved to establish a dealership and service network to provide the services that SBC customers expected. One function of Wang's new distribution system was to provide applications software, including customized programs.

Conclusion

When IBM moved into the SBC market, other firms rapidly cut prices on existing models and sought to upgrade and expand their product lines. More companies entered the fray, perhaps feeling that IBM's entry had legitimatized the SBC. Buyers could choose from more sophisticated systems at lower prices. *Business Week* estimated that, by 1975, IBM had captured about 28 percent of SBC sales, with Burroughs around 12 percent and NCR just under 5 percent. IBM's share of this market continued to climb; by 1978 it was put at 37 percent, with Burroughs and NCR together still accounting for less than 20 percent.[25]

By 1980, the System/32 in its basic configuration sold for $23,490—a reduction of $10,000 compared to the original price 5 years earlier. While the System/32 was more successful at the outset than anticipated, sales declined rapidly once its successor, the System/34 was introduced. The System/34 could handle multiple work-stations; it offered more processing power, multiple programing capabilities, and more storage. Selling in the same price range, the System/34 continued the trend toward greater performance/cost ratios.

Beyond its brand recognition and "safe" image, IBM's immediate success with the System/32 came from its decision to stress applications—an obvious strategy, but one that IBM executed better than the competition. The technology in the System/32 was not much different from its predecessor. In the SBC market, technical wizardry counted for little compared to cost and convenience.

[25] "The Burroughs Syndrome," op cit

Index

Index