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# EXPLORATORY AND NORMATIVE TECHNOLOGICAL FORECASTING: A CRITICAL APPRAISAL

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## Abstract

Comparison of the still evolving approaches to "exploratory" and "normative" technological forecasting yields marked contrasts. In particular the simple schemes used by those trying to predict the technology of the future look pallid when matched against the sophisticated techniques designed by those who are allocating the resources that will create the future. Exploratory technological forecasts are largely based either on aggregates of "genius" forecasts (e.g., the Delphi technique) or on the use of leading indicators and other simple trend-line approaches. The practitioners of economic forecasting, in contrast, long ago recognized the need for multi-variate systems analysis and cause-effect models to develop reliable predictions.

Normative forecasting is at the opposite extreme on the sophistication scale, fully utilizing Bayesian statistics, linear and dynamic programming, and other operations research tools. Here, despite the uniqueness, uncertainty, and lack of uniformity of research and development activities, each of the designers of normative techniques has proposed a single-format wholly quantitative method for resource allocation. Along the dimensions of unjustified standardization and needless complexity, for example, the proposed R&D allocation methods far exceed the general cost-effectiveness approach used by the Department of Defense in its program and system reviews.

For both exploratory and normative purposes, dynamic models of broad technological areas seem worthy of further pursuit. In attempting to develop "pure predictions" the explicit recognition of causal mechanisms offered by this modeling approach seems highly desirable. This feature also has normative utility, provided that the dynamic models are limited in their application to the level of aggregate technological resource allocation and are not carried down to the level of detailed R&D project funding.

1. On Technological Forecasting.

Increased recognition during the present decade of the importance of science and technology to corporate and national existence has produced an intensive search for new methods for managing research and development. The attention being devoted to so-called "technological forecasting" is one manifestation of this concern.

"Technological forecasting", as defined by those claiming to be its practitioners, is actually two fields, joined more by a vision than a reality. On the one hand is "exploratory forecasting", the attempt to predict the technological state-of-the-art that will or might be in the future, or as Cetron puts it, "... a prediction with a level of confidence of a technical achievement in a given time frame with a specified level of support."[1] Most laymen assume that all of "forecasting" is this kind of forecasting. The second aspect has been called "normative forecasting"[2] and includes the organized attempts to allocate on a rational basis the money, manpower, and other resources that might effect the creation of tomorrow's technological state-of-the-art. Normative forecasting presumably provides aids to budgetary decisions in the technological area. Still more broadly defined by some of its leading exponents, "normative forecasting" applies to a wide variety of attempts to determine policies and decisions that will influence

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[1] Cetron, M.J., et al., A Proposal for a Navy Technological Forecast (Washington, D.C.: Naval Material Command, May 1966, AD 659-199 and 560-200).

[2] Gabor, D., Inventing the Future (London: Seckery Warburg, 1963).

the effective growth of science and technology, in the corporation, the government agency, or the nation as a whole.

There is no doubt that both kinds of "forecasting" are necessary contributors to the technical planning process. And for the military as well as for most corporations this technical input is a critical ingredient of an overall business plan. Yet only in theory but not in fact have these two components , the exploratory and the normative, been integrated adequately. In his milestone book on the subject, Erich Jantsch expresses the logic of and the need for this integration: "Exploratory technological forecasting starts from today's assured basis of knowledge and is oriented towards the future, while normative technological forecasting first assesses future goals, needs, desires, missions, etc., and works backward to the present ... The full potential of technological forecasting is realized only where exploratory and normative components are joined in an iterative or, ultimately, in a feedback cycle."[3]

This paper presents a critical appraisal of the field of technological forecasting. The central theme is that the two phases of exploratory and normative approaches are out of step with each other. Exploratory techniques are too naive and do not take advantage of what has been learned about forecasting in non-technical areas. Nor do the exploratory techniques reflect what is known about the influences upon the generation of future technology.

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[3] Jantsch, E., Technological Forecasting in Perspective (Paris: Organisation for Economic Co-operation and Development, 1967), pp. 15, 17.

Normative techniques in contrast are too complex and mathematically sophisticated and cannot justify their elegance on substantive grounds.

If "the full potential of technological forecasting" is to be realized, a more harmonious relationship must be established between the exploratory and normative parts. Dynamic systems models of broad technological areas, stressing the feedback relations that affect the growth of science and technology, demonstrate promise of providing a basis for that harmony. Such models have already been developed in prototype form, addressed to a number of problems of interest to technological forecasters. Their further development is dependent upon the availability of skilled manpower and necessary funding.

## 2. An Appraisal of Exploratory Technological Forecasting.

Exploratory technological forecasting includes a variety of techniques for predicting the future state of science and technology. Unfortunately most of the methods are really only variants on simple trend extrapolation procedures, broadly defined, that have limited utility in today's rapidly shifting technological environment. The principal exploratory methods are:

(1) so-called "genius" forecasting, based either on individual wisdom or on a group "genius" forecasting process known as the Delphi technique; and

(2) formal trend extrapolation to either a straight-line fit or an S-shaped expectation.

The formal trend methods include single-curve projections as well as estimations based on the envelope encompassed by the projection of a family of

related curves. They also include both the extrapolation of a single time series as well as the projection of lead-lag relationships between two time series, the latter known as "precursive event" forecasting.

## 2.1 Intuitive Trend Forecasts.

In theory technological forecasting is not supposed to be able to foretell the "major breakthrough". In fact this is one of few ways in which intuitive hunches or guesses might provide service. Occasionally, but unpredictably, the brilliant scientist (or the perceptive marketeer, or the starry-eyed science fiction writer) may predict the future as different from a mere extension of the past. But more usually individual wisdom-based forecasting works on the rule that "past is prologue". Trend extrapolation thus becomes the simple kind of model that the unaided mind can manipulate intuitively.

With the promotional boost of The RAND Corporation's sponsorship, the hunches of individual "experts" have been coaxed and guided in an iterative group forecasting procedure known as the "Delphi method".[4] This Delphic oracle procedure assumes that collective (and normalized) wisdom is better than individual "guesstimates", although recent behavioral research plus the mythology regarding Delphi itself question this assumption. In using the Delphi approach a panel of experts is solicited for their opinions on the future technology in a specified area. Assembled opinions thus gathered are redistributed to the panel for a series of reassessments during which criticisms

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[4] Gordon, T.J. and Helmar, O., "Report on a Long-Range Forecasting Study" (Santa Monica, California: The RAND Corporation, September 1964, Paper P-2982).

and defenses of extreme forecasts are also obtained and communicated. The end result tends to be a more polarized and justified range of future estimates than were originally gathered. Thus the collective "ballpark guesses" of the experts are refined and legitimized. It is interesting to speculate whether a Delphic sampling of the appropriate whiz kids would have predicted an effective intercontinental ballistic missile when Vannevar Bush failed in his prophecy! Would Delphi have done better than Lindemann in his lack of foreseeing the German V-2 rockets? Is there sufficient evidence to believe that the Delphic search for concensus produces more "truthful" forecasts than a comparable assemblage of individual genius forecasts?

## 2.2 Formal Trend Forecasts.

Those who lack the wisdom demanded by genius forecasting (perhaps in reality they possess the wisdom needed to appreciate the weaknesses of the intuitive methods!) have adopted formal procedures for translating the events of the past into the predictions of the future. Data on the time-history of some parameter of technological progress (e.g., tensile strength of materials, engine thrust per lb. of fuel) are plotted against time on linear or logarithmic scales. Using "eyeball" extrapolation, or statistical "best fit" procedures, a growth-of-technology line is drawn through the data points and extended into the future. An assumption of technology saturation effects produces the biological growth pattern with its S-shaped curves; an assumption of no saturation leads merely to longer straight lines. Poor fit of the data to a single line suggests the need for alternative technological projections, and often leads to a forecast of an envelope of possible technological states. When two sets of these progress parameter curves appear to be correlated,

with one curve consistently leading the other in time (e.g., the speed of bombers versus commercial transports), similar trend extrapolations are applied. In this case, the process is referred to as forecasting by the analysis of precursive events.

The trend extrapolations, both intuitive and formal, fail to state explicitly their underlying assumptions. As Jantsch points out, "... the simple extrapolation of secular trends does contain one analytical element -- the intuitive expectation that the combined effect of internal and external factors which produced a trend over a past period will remain the same during a future period, or that it will undergo an estimated gradual change".[5] Yet the changes occurring in numerous areas of technology deny the validity of these stability-oriented assumptions.

## 2.3 The Experiences of Economic Forecasting.

Rather than continue to berate the undeveloped state of exploratory forecasting it appears wiser to apply the forecasters' own tools. The development of exploratory forecasting techniques seems to be following the path previously taken by economic forecasting (in a precursive event relationship). A review of the parallels involved indicates that exploratory forecasting can advance more rapidly by skipping some of the development that occurred in economic forecasting.

Economic forecasting is now beginning its fifth stage of development, with an obvious sixth stage just over the horizon. These stages of evolution are:

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[5] Jantsch, ibid., p. 156.

(1) wisdom, expert or genius forecasting;

(2) "naive" models;

(3) simple correlative forecasting models;

(4) complex multi-variate econometric forecasts;

(5) dynamic causally-oriented models; and

(6) learning models.

2.3.1 Expert forecasts. The first stage of development of economic forecasting was the intuitive judgmental expert forecast. Perceptive economists, applying their mental models to analyses of economic factors, predicted future economic performance, often with excellent foresight. This nonquantitative "genius" stage has been (and still is being) paralleled in the technological field.

2.3.2 "Naive" forecasting models. As economists began applying quantitative techniques to economic forecasting, so-called "naive" models came to the front. The most naive forecasts are the "same level" and the "same trend" predictions. The "same level" model assumes that next year will be the same, economically, as this year. The "same trend" forecast says that the economic trend from this year to next will be the same as from last year to this one. Economists themselves have labelled these approaches as "naive", yet technological forecasters are using them almost exclusively. (The use of S-shaped curves and log scales by technical forecasters merely reflects their higher mathematical training relative to their earlier economic counterparts.)

2.3.3 Simple correlative models. In the third stage of development of economic forecasting two or three variables were interrelated by statistical

correlation (or just by charts) to forecast economic behavior. The use of "leading" economic indicators is the simplest representation of this phase of forecasting and is replicated in technological forecasting by precursive event forecasts. Recent work by Mansfield in predicting the rate of diffusion of technological innovations indicates that exploratory technological forecasting is now in this third stage.[6]

2.3.4 Complex multi-variate econometric forecasting. The great growth of quantitative economics accompanied its movement into large-scale multivariate statistical models for explaining and predicting economic performance. No longer were the models simple or naive, and the computer quickly found an important role in implementing the needed calculations. (Input-output models of the economy can be associated with this fourth stage of evolution.) But the models were not usually causally-oriented; rather the "best fit" criterion, applied to tests on past data, was the primary measure of acceptability. It is not surprising, therefore, that these complex but non-causal forecasting models usually performed no more accurately than did simpler models and naive forecasts. Nor even have they consistently outperformed the "expert" forecasts of the business economists. Although technological forecasting has not yet moved openly into this fourth phase, it is likely to do so soon unless effectively urged in other directions.

2.3.5 Dynamic causally-oriented forecasting. Recently a change has begun to show up in the style and structure of economic forecasting models. The

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[6] Mansfield, E., "Technical Change and the Rate of Imitation", Econometrica, October 1961.

model-builders have attempted to include more a priori causal structuring, mixed linear and nonlinear relationships are being represented, feedback phenomena are included in the models, and dynamic computer simulation is being used to project economic forecasts.[7]

Moreover, this new type of economic forecasting model has the unique feature of coupling exploratory and normative purposes in a consistent manner. Not only can the models be initialized with present and historical inputs to project the future economy, but simulated tests can be run using proposed normative changes in policies and parameters. Contemplated resource allocations, for example, are thus fed into the "exploratory" model to project anticipated consequences, and these in turn suggest alternatives to the proposed allocations. This type of iteration between exploratory forecasts and normative recommendations has been proposed as the ultimate for technological forecasting.[8]

As shall be pointed out in the last section of this paper, much work has already been done along similar lines in technology-related areas. But the review literature recognizes only the contributions of Lenz to the dynamic modelling phase of exploratory forecasting and viewshis work, unfortunately, as "hardly useful for any practical purpose".[9] Until this work

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[7]Examples of this "new" type of economic forecasting model are: Duesenberry, J.S., et al. (editors), The Brookings Quarterly Econometric Model of the United States (New York: Rand McNally, 1965); Fromm, G. and Taubman, P., Policy Simulations with an Econometric Model (Washington, D.C.: The Brookings Institute, 1968); Hamilton, H.R., et al., Systems Simulation for Regional Analysis (Cambridge: The M.I.T. Press, 1968); Weymar, F.H., The Dynamics of the World Cocoa Market (Cambridge: The M.I.T. Press, 1968).

[8]Jantsch, ibid., p. 17.

[9]Lenz, R.C., Jr., Technological Forecasting, Second Edition (Wright-Patterson Air Force Base: U.S. Air Force Aeronautical Systems Division, June 1962, Report ASD-TDR-62-414), as cited Jantsch, ibid., p. 241.

and related dynamic models are indeed recognized for their potential, exploratory forecasting will stall in its third stage of development or waste itself needlessly in the unproductive fourth stage it is about to enter.

2.3.6 Learning models. The next logical stage of development for economic forecasting is the creation of learning models. These would be structured similar to those used in stage five, but they would be paired with real-time data collection and data interpretation systems. The combination, monitored by computer routines for analyzing model adequacy, would permit parameter and possibly even structural changes in the forecasting model based upon experienced model and economy performance. But no serious activity is yet underway in this stage in either the economic or the technological forecasting area.

This review of exploratory forecasting has concluded that pathetically simple methods are being used to predict what technology will be in the future. The techniques parallel an earlier stage of growth of economic forecasting, and as yet have not recognized the importance of causal dynamic models. Jantsch seems to agree with this condemnation of exploratory forecasting's underdevelopment: "... no model has so far succeeded in taking into account more than a limited number of influencing factors by assuming relationships that are generally unproved or not known in detail, and mathematical formulations do not yet include even all of these recognized factors".[10]

The empirical "research on research" of the past decade has now produced an impressive basis of understandings of the influences on scientific and

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[10] Jantsch, ibid., p. 155.

technological progress.[11] Surely it is important to begin embodying these findings into the development of improved exploratory models.

3. An Appraisal of Normative Technological Forecasting.

Normative technological forecasting activities attempt to provide a basis for allocating technology-generating resources so as to maximize attainment of organizational goals. The effectiveness of any normative method depends upon:

(1) the meaningfulness of its treatment of goals;

(2) the correctness of its assumed relationships between allocated resources and generated technology;

(3) the adequacy of its balancing of the resources-to-technology considerations against the worth of goal fulfillment; and

(4) the implementability of the method, including the ability to acquire reasonable inputs at reasonable costs as well as the ability to persuade organizational decision-makers to use the generated outputs.

Most of the effort in the development of normative forecasting techniques has gone into items 1 and 3 above. The expression of goals, the

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[11] Among the recent summaries of aspects of this research are: D.G. Marquis (editor), Second Report of the M.I.T. Research Program on the Management of Science and Technology (Cambridge: M.I.T. Sloan School of Management, October 1967); and Isenson, R.D., "Factors Affecting the Growtn of Technology - As Seen through Hindsight", unpublished paper presented at the NATO Defense Research Group Seminar, Teddington, England, November 1968.

establishment of values for them, the accounting for the conflicting interests of various groups, are primary questions debated by the designers of normative forecasting methods. The techniques for manipulating the resources being allocated against these assumed values are also many and varied, ranging from simple linear and dynamic programming to elaborate embodiments of Bayesian analyses and Monte Carlo techniques. And these techniques are under continuing refinement, with accompanying developments of the computer software needed for the desired calculations. These areas can be left to others to criticize.

Yet items 2 and 4 above have been largely ignored. Little effort has been devoted to making the forecasting techniques practicable or believable by the manager. The most sophisticated, perhaps even the best, normative approach requires thousands of estimate inputs for every use. Moreover, the assumed relationships between allocated resources and generated technological outputs are seldom even explicity identified in the normative techniques. Usually, the forecasts receive as inputs the estimates of the technical outputs that would be produced by various funding levels. In other words, in most cases no exploratory forecasting technique is used to generate the basis for normative manipulations! The assumed technical outputs are guesses only.

## 3.1 Technical Output Generation.

Let me treat first the question of how technical outputs are handled in normative forecasting. If resources are to be deployed wisely by a company, a government agency, or a nation, that deployment should be based upon the best understandings available of the likely results of the use of

those resources. The area of exploratory forecasting is devoted to a search for and an expression of these understandings. But the exploratory forecasters have made little impact on their normative brethren. An examination of the leading normative forecasting techniques demonstrates this failing.

3.1.1 PROFILE. PROFILE (Programmed Functional Indices for Laboratory Evaluation), developed by Marvin J. Cetron for the U.S. Navy, is among the better known methods for resource allocation in R&D.[12] PROFILE uses three basic criteria -- Military Utility, Technical Feasibility, and Application of Resources -- plus a fourth criterion, Intrinsic Value to the Laboratory, which acts as a "fudge factor" to influence the final weighted index that is developed.

In his PROFILE paper Cetron asserts, "Research and development tasks become more technically feasible if they are being executed by personnel who have the necessary expertise, have confidence in the successful completion of the task and recognize the benefits to other applications".[13] This is an interesting albeit empirically unsubstantiated theory of the technology generation process. The theory is interpreted in PROFILE by criteria for Applicability to Long Range Plan and Mission, Probability for Achieving Task Objective, and Technological Transfer. Of the three only the "probability of achievement" estimate is related to a forecast of anticipated technological output, and that is a single-valued "genius"

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[12] Cetron, M.J., "Programmed Functional Indices for Laboratory Evaluation (PROFILE)," presented at the 16th Military Operations Research Symposium; Seattle, Washington; October 1966.

[13] Ibid., p. 5.

forecast, produced generally by a "non-genius". The fact that the man who must do the work is usually the estimator as well raises further questions as to the meaningfulness of the input. The "applicability" measure assesses value of the output's contribution to lab objectives generally, while "technological transfer" identifies output value in terms of possible contributions to other technical tasks. These estimates are hardly related to the likelihood of future technology being generated, yet PROFILE misuses them in this fashion.

PROFILE's Application of Resources sector treats availability of manpower, facilities, and funding for the R&D project being contemplated. Yet this treatment mixes considerations of factors that might be included in a model of technology generation with project cost considerations. And, of course, all of these are weighted in PROFILE as if they are measures of value, and added in a linear combination of factors. The failure to appreciate the difference between worth of an outcome, the influences upon the attainment of that outcome, and the cost of the outcome thus characterizes the PROFILE approach. Most critical is that the explicit "exploratory" forecast is limited to a "hunch" probability estimate by the staff members filling out the PROFILE forms.

3.1.2 QUEST. What PROFILE is designed to do for an individual laboratory, the QUEST system (Quantitative Utility Estimates for Science and Technology), developed by Cetron, is supposed to do for the entire Navy R&D program.[14] The complexity of QUEST's matrices of Value of Technology to Missions and Relevance of Science to Technology illustrates the heavy emphasis placed

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[14] Cetron, M.J., "QUEST Status Report", IEEE Transactions on Engineering Management, vol. EM-14, no. 1, March 1967.

upon the valuing procedure. The technology generation procedure, however, is largely ignored by QUEST. In its examination of the contribution of a technical effort to a given mission, "the assumption is that the objective of the technical effort will be accomplished".[15] In its evaluation of the relevance of each science area to each technology area, a subjective single-valued estimate is assigned by the forms-filling engineer and researcher to describe the essentiality of the science to the technology. These estimates range from 0, "the technology does not draw on this science at all", to 10, "no progress is possible in this technology without vigorously pursuing this acience". This estimate is hardly what would be described as an elaborate exploratory forecasting method.

3.1.3 PATTERN. PATTERN (Planning AssistanceThrough Technical Evaluation of Relevance Numbers), developed by Honeywell's Military and Space Sciences Department, is perhaps the most extensive and expensive normative forecasting technique in use.[16] Yet PATTERN's sophistication is largely concentrated in its allocation methodology, as opposed to its generation of exploratory forecasts. Primarily "genius" forecasting, trend extrapolation and envelope curves are employed to predict the possible technical state of the art, and resource allocations are not fed back to affect technological developments. In particular, the key exploratory forecast embodied in PATTERN is someone's estimate of the number of years that a system in question will remain in each of several sequential stages of advancement. The stages considered are: research, exploratory development, advanced development, product design,

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[15] Ibid., p. 62.

[16] Jestice, A.L., Project PATTERN - Planning Assistance Through Technical Evaluation of Relevance Numbers (Washington, D.C.: Honeywell, Inc., 1964).

and availability. This series of timing estimates is a rather modest recognition of exploratory forecasting capabilities.

3.1.4 PROBE. Finally, an examination of TRW's Probe II approach further indicates the conflict between simple exploratory forecasting and elaborate normative procedures.[17] Based on a modified Delphi technique, TRW determines Desirability, Feasibility, and Timing of each forecast event. Then to determine appropriate corporate response, SOON (Sequence of Opportunities and Negatives) charts, similar to PERT networks, are prepared to demonstrate the details of specific accomplishments that will be needed to realize the forecast event. Apparently no one is concerned (at least, not in print) that collective wisdom alone produces the exploratory forecasts whereas detailed R&D planning is the basis of the normative reaction.

Investigation of other well-known and highly regarded normative forecasting techniques (e.g., TORQUE) provides further evidences to support the point already established. Very sophisticated methods of valuing technology and allocating resources are being combined with very trivial methods of forecasting technical outputs. The methods appear to be aimed at producing five decimal-place accuracy outputs from one decimal-place accuracy inputs, a task comparable to acquiring silk purses from sow's ears. The inconsistency of this practive, and the obvious notion that a chain is only as strong as its weakest link, have not yet shifted enough attention to the needed improvement of exploratory forecasting methodology.

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[17] North, H.A., "Technological Forecasting in Industry", presented to NATO Defense Research Group Seminar; Teddington, England; November 12, 1968.

### 3.2 Implementability of Normative Forecasts.

If the problem just cited were corrected, if the normative allocations were indeed based on legitimate and respectable efforts at exploratory forecasting, a number of problems would still exist in gaining effective implementation of the normative techniques. Some of the observed problem areas are:

(1) the costliness of the inputs;

(2) the dubious accuracy of the estimates;

(3) the inflexibility of the methods; and

(4) the probable limited impact upon managerial decisions.

3.2.1 Costliness. Each of the primary normative methods described above is a heavy user of resources. Jantsch estimates the original setup cost for a PATTERN scheme at $250,000 to $300,000 with annual "maintenance" costs of roughly $50,000.[18] QUEST requires estimates for a "value of technology to missions" matrix that may be of the order of 30 by 50 and for a "relevance of science to technology" matrix of approximately 50 by 130 size. Each of these QUEST inputs may have to be provided for the three time frames of now, five years from now, and ten years from now, as well as for several sets of assumed funding levels.[19] Probe II required inputs from 140 experts.[20] Many organizations, including those already cited, may find the expenditure of these resources to be an awesome consideration, especially as the techniques require resubmittal of all the inputs on a reasonably regular basis.

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[18] Jantsch, ibid., p. 226.

[19] Cetron, ibid.

[20] North, ibid., p. 9.

To be sure, learning must take place which reduces these input acquisition costs, but each estimator is still needed to regenerate on a regular basis his inputs to the forecasting systems.

3.2.2 Dubious Accuracy. A second problem is the questionable believability of the inputs submitted. The scientific-technological expert is a doer who understands the state of knowledge in his field and the process employed for advancing that state. Instead of asking the expert to assess that state or to describe that process, the normative methods principally call upon him to become a crystal-ball gazer and to leap inferentially to a conclusion (usually probabilistic) as to what will occur in the future. Little objective evidence exists to defend this kind of expert testimony.

This problem of input accuracy is worsened by the likelihood that the estimator providing the inputs will be affected by the conclusions derived from his inputs. The scientist entering data into a normative forecast has to guard against "signing his own death warrant". This participative role in what are likely to be self-fulfilling or self-defeating forecasts almost assures that the inputs will be biased consciously or unconsciously, and surely not in any systematic manner.

3.2.3 Inflexibility. In many areas of critical decision-making resource allocators evaluate their alternatives using quantitative techniques such as, for example, the cost-effectiveness analyses used by the DOD in selecting weapon systems. These cost-effectiveness evaluations permit wide latitude in the mode of costing adopted, as well as in the method for value assessment. Top level Defense management reviews each analysis for its

soundness in order to qualify the adequacy and acceptability of the derived recommendations. Following these formal reviews the overall resource allocation is still subject to a balancing against other usually nonquantified social, economic and political considerations.

Of the managerial areas being subjected to quantitative resource allocation techniques, research and development consists of more unique programs, with more uncertain outcomes, and less uniformity of types of results than any other area. Yet the normative forecasting techniques proposed and somewhat adopted for selecting and funding R&D programs are supposed to be applied uniformly to all programs, regardless of scope, phase, duration, criticality, technology, or what-have-you. This degree of unjustified standardization is not matched by the flexible view taken for DOD weapon system trandeoffs. Moreover, the complexity and mathematical sophistication of the normative technological forecasting methods again exceeds by far the relatively simple formats and seldom-more-than-arithmetic computation procedures used in DOD cost-effectiveness determinations. Is it possible that the current style of normative technological forecasting is an overreaction to the difficulties of managing research and development?

3.2.4 Limited impact. The characteristics of normative forecasting just described, as well as the characteristics of the decison-making process, combine to suggest that the present generation of techniques is likely to have only limited impact on specific managerial decisions. The costliness, dubious accuracy, and inflexibility of approach will naturally tend to limit the use of these methods. But more important is that experience in other related areas has shown that comparable techniques are seldom truly responsible for selection decisions.

In their excellent review of formal project selection methods, Baker and Pound found that few organizations of the 50 studied were employing the formal selection processes that were described in published papers by their employees.[21] Perhaps this is indicative only of the low state of managerial decision-making generally, but other evidences suggest that the problem is more fundamental.

In a study by the author of about 100 R&D contractor selection decisions, informal person-to-person factors were found to influence the awards far more than did formal evaluation procedures.[22] In fact, six to eight months prior to formal award announcements, long before the formal proposal evaluations, all but ten percent of the awards of R&D contracts up to several millions of dollars in magnitude were predictable from the available data.

When major decisions are to be made it appears that management needs to consider factors other than those generally included in formal complex evaluation procedures. Investigation of 51 of the largest contract awards by the National Aeronautics and Space Administration revealed that NASA headquarters did not follow the suggestions of its Source Evaluation Boards in 25 percent of the cases.[23] But these 25 percent accounted for 67 percent of the total funds contracted on the 51 awards. It is possible that formal evaluation methods are followed only when the outcome is not regarded as vital to the organization.

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[21] Baker, M.R. and Pound, W.H., "R and D Project Selection: Where We Stand", IEEE Transactions on Engineering Management, vol. EM-11, no. 4, December 1964.

[22] Roberts, E.B., "Questioning the Cost/Effectiveness of the R&D Procurement Process", in Yovits, M.C., et al. (editors), Research Program Effectiveness (New York: Gordon and Breach, Publishers, 1966).

[23] Bergsteinsson, P., The Evaluation and Selection of Sources for Major NASA Contracts (unpublished Master of Science thesis, M.I.T. Sloan School of Management, 1967).

Previously this paper pointed out that the PROFILE technique contains a "fudge factor" criterion, Intrinsic Value to the Laboratory, that permits managerial "overrides" of otherwise elaborate evaluations. More recently Cetron has indicated that consideration of so-called "sacred cows" in another technique under investigation by the Navy also permits the rest of a complex evaluation procedure to be scrapped in favor of explicit management preferences.[24] Is it not reasonable that in the important cases such "sacred cow" factors would limit the impact of formal evaluations oriented against a top manager's desires?

Evidence gathered in a series of other studies also argues that real decisions are not made in the manner suggested by the formal, complex decision-aiding systems in R&D.[25] These data do not suggest that the formal evaluation systems are without value. Indeed these methods seem to stimulate a more thoughtful and more orderly planning process that enhances management effectiveness. But the data do indicate that the present type of normative forecasting techniques is likely to have only limited impact on managerial resource allocation for R&D.

## 4. Integrating Exploratory and Normative Forecasting with Dynamic System Models.

Throughout this paper the inconsistencies between the developments of exploratory and normative forecasting techniques have been highlighted. In mathematical sophistication and level of detail the simple schemes used by

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[24] Cetron, M.J., "Prescription for the Military R&D Manager", presented at the NATO Defense Research Group Seminar; Teddington, England; November 12, 1966, pp. 19, 21-22.

[25] Roberts, E.B., "Facts and Folklore in Research and Development Management", Industrial Management Review, vol. 8, no. 2, Spring 1967.

those trying to predict the technology of the future look pallid when matched against the techniques employed by those who are allocating the resources that will create the future. The examination of exploratory forecasting methods indicates that what is known about the process that generates future technology is not presently included in the forecasting models. This lack shows up further as a critical weakness of the normative techniques, which are attempting to select and budget R&D projects based on meager schemes for forecasting future technological pssibilities.

An earlier section of the paper pointed out the potential of dynamic models which are oriented toward the inclusion of those cause-and-effect relationships that are likely to alter future technological developments. These models are being utilized in economic analysis, forecasting and policy design, i.e., in both exploratory and normative modes. Jantsch has realised how much these dynamic system models might contribute to technological forecasting. However, he has seriously underestimated the degree of their present development.

> Rigid computer models are on the threshold of becoming useful for technological forecasting. In particular, "dynamic forecasting" is serving as a guideline in a number of serious attempts; this term, introduced by Lenz to denote the modelling of all significant cause-effect relationships which influence the growth of technology in general or a functional capability, may be extended here so as to include technology transfer in general. The hope, of course, is to achieve adequate results with a limited dynamic model. The "Industrial Dynamics" concept of Forrester for complex business decision-making provides the background to many attempts in this area.[26]

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[26]Jantsch, ibid., p. 202.

The "Industrial Dynamics" concept that Jantsch references emphasizes the importance of feedback relationships in influencing the dynamic evolution of a situation.[27] For example, the connections between exploratory and normative forecasting form the kind of feedback loops that significantly affect future behavior. An exploratory forecast generates a prediction that a desired outcome is highly feasible within a reasonable time period; this leads to a high value index established for the related R&D project in the normalized forecast, which in turn influences increased funding for the project. The resultant strengthened research support enhances the likelihood of timely completion of the project, and this status improvement is reflected in the exploratory forecast. This type of feedback relationship is critical to the technological growth process and it demands the integration of the exploratory and normative phases. Dynamic feedback system models are the most likely candidates for accomplishing this integration.

4.1 Dynamic System Models in Technology-Related Areas.

Though generally unrecognized by Jantsch and other reviewers of the technological forecasting field, dynamic models of technology-related feedback systems have been under development for ten years. A brief review of these models will demonstrate their present availability for broader exploitation in technological forecasting and their traditional integration of exploratory and normative considerations.

4.1.1 R&D projects. As the primary present use of technological forecasting is in the area of R&D project selection and budget allocation, it seems appropriate to mention the dynamic systems models oriented toward examining

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[27] Forrester, J.W., Industrial Dynamics (Cambridge: The M.I.T. Press, 1961).

these projects. The major effort here is the author's book on the factors affecting R&D project life cycles.[28] The mathematical model of the project process follows the scheme illustrated in Figure 1. Indeed the model treats

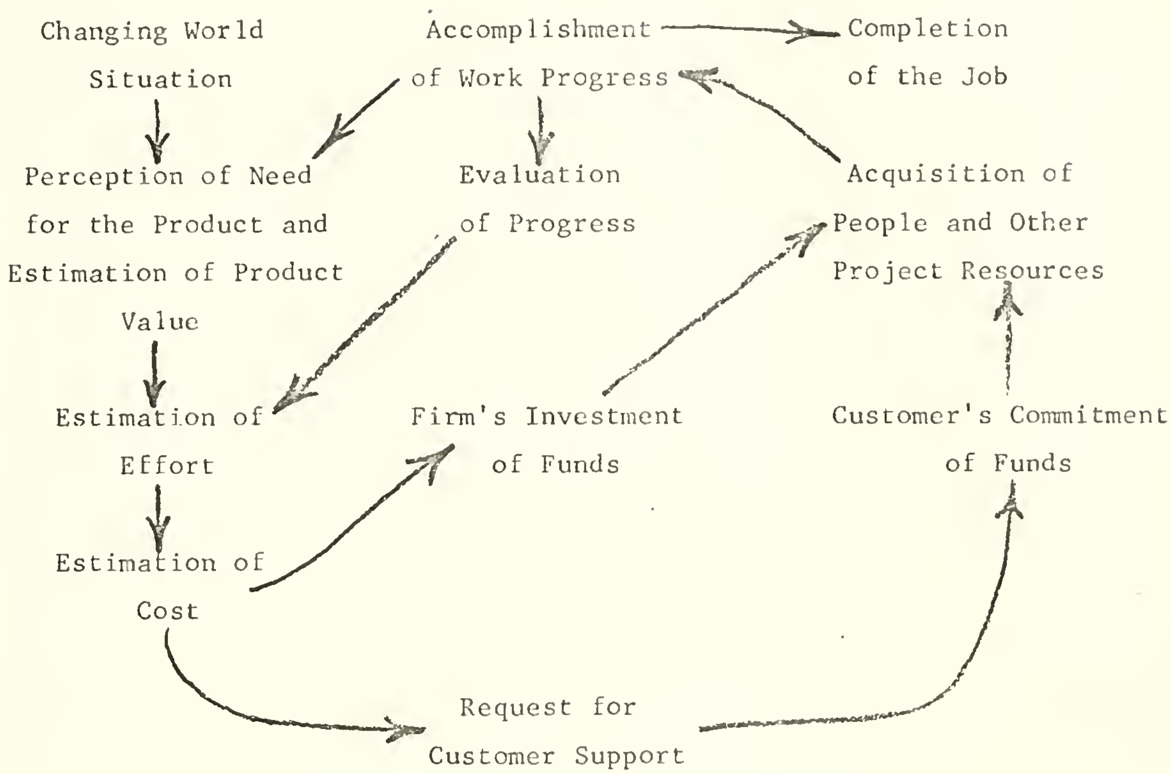


Figure 1. Dynamic system underlying project life cycles.

both the exploratory and normative sides of the project process and contains a detailed sector that represents the technology-generating process. Initially this model was intended as a conceptual tool only, but it has already been applied to specific technological forecasting in the United States and Japan, resulting in publications in both countries.[29]

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[28] Roberts, E.B., The Dynamics of Research and Development (New York: Harper & Row, Publishers, 1964).

[29] Schlager, K.J., "How Managers Use Industrial Dynamics", Industrial Management Review, vol. 6, no. 1, 1964. Reference to the Japanese application is contained in a private communication to the author from S. Sakakura.

4.1.2 Multi-project and multi-phase allocations. Beyond looking at projects singly, technological forecasters are concerned with the problems of beneficial and conflicting "cross support" between multiple projects. This problem has been treated in dynamic feedback system models aimed at two subtopics -- the cross-support between projects and the cross-support between various phases of R&D activity in a technical organization. The former area has been the subject of one excellent graduate thesis, while the latter has been covered by a variety of high quality thesis efforts.[30]

4.1.3 Technical organization forecasting. Several dynamic system models have been developed as attempts at analyzing and causally predicting the growth (or decline) of a technical organization (exploratory style) and the effect of various policies on that growth (normative style). Two papers and an array of good quality graduate theses document this area of activity.[31] The paper listed by Robert Spencer describes ventures undertaken at the Dow Chemical Company to better plan and allocate resources for one of its major divisions.

4.1.4 Technological growth forecasts. A number of dynamic system models emphasizing feedback effects have tackled the question of the growth of a

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[30] Nay, J.N., Choice and Allocation in Multiple Markets: A Research and Development Systems Analysis (unpublished Master of Science thesis, M.I.T. Department of Electrical Engineering, 1966); D.C. Beaumariage (1961), P.W. Lett (1961), G.R. Wachold (1963), and G. Welles III (1963) produced thesis studies at the M.I.T. Sloan School of Management on the allocation of funds and effort among several series-related phases of work.

[31] Roberts, E.B., "Problems of Aging Organizations", Business Horizons, vol. 10, no. 4, Winter 1967; Spencer, R.W., "Modelling Strategies for Corporate Growth", presented at the Society for General Systems Research Conference, Washington, D.C., 1966; and M.I.T. Management theses by L. Salba (1967), C.H. Perrine (1968), and J. Troutner (1968).

new technology. Lenz and Reisman have concerned themselves with the training and employment of the professional people who cause a new technological area to develop.[32] Nord has focused on the growth process for a new product, while Forrester has written on the growth of a new technology-based firm.[33]

Many other papers, theses, and unpublished studies have also dealt with exploratory and normative aspects of scientific and technological developments. The wide variety of models identified here does indicate that "rigid computer models", as Jantsch refers to them, or, preferably, "dynamic feedback system models" are part of the presently available state-of-the-art of technological forecasting.

4.2 Toward Effective Use of Dynamic System Models.

It is clear that the large-scale dynamic simulation models described above have the capacity to include realistically the cause-and-effect relationships believed to generate technological advances. What is not clear is how to use these models most effectively.

A focus on the previously asserted need for consistency between exploratory and normative forecasting seems to provide a clue toward effective use. Although many of the general factors influencing growth of a technological area are understood, this understanding does not extend down to rather minute details or up to any high degree of accuracy. The uncertainties of research and development, the uniqueness of the programs, the intangibility of the progress, and the long time delays in the feedback of results constrain the possible accuracy of understanding to a marked extent. Thus, exploratory forecasting models are similarly limited in the accuracy and detail that can be demanded of them. And, consistently, attempted normative

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[32] Lenz, ibid.; Reisman, A., "Higher Education: A Population Flow Feedback Model", Science, vol. 153, July 1, 1966.

[33] Nord, O.C., Growth of a New Product (Cambridge: The M.I.T. Press, 1963); Forrester, J.W., "Modelling the Dynamic Processes of Corporate Growth", presented at the IBM Scientific Computing Symposium; Yorktown Heights, New York; December 1964.

forecasts must be confined to the same range of uses. To attempt to use normative technological forecasting to select and allocate funds to hundreds or thousands of individual projects is obviously beyond the effective capacity of the models that can be built. Much more knowledge is needed, not about allocation techniques but rather about the technological development process, before such a high degree of disaggregation becomes meaningful.

It seems reasonable that dynamic feedback system models can be developed to help answer a number of fundamental resource allocation questions. Should more money in total be expended on research and development activities? How should the R&D budget be split between its research and its developmental components? How should the budget treat new potentially important areas of science and technology as opposed to the older on-going activities? How should funds be allocated in support of various broad missions or goals? These and other key questions are now largely being ignored in the mistaken rush to decide quantitatively but unjustifiedly the selection and funding of each and every R&D project. But it is in the realm of these policy issues that integrated exploratory and normative technological forecasting, enriched by the use of dynamic feedback systems models, will make its most potent contribution.

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