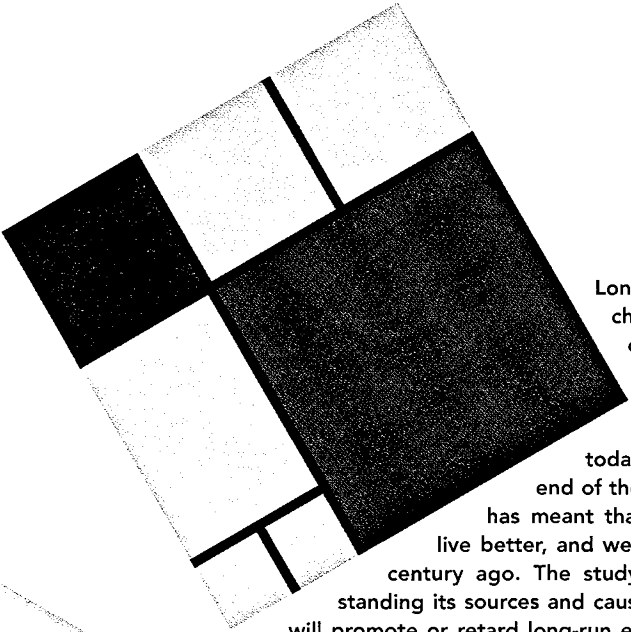
Long-Run Economic Growth

PART 2



Long-run economic growth is the subject of this two-chapter part of the book. Chapter 4 covers the theory of growth, and Chapter 5 covers the worldwide pattern of economic growth. Long-run economic growth is the most important topic in macroeconomics. Standards of living in the United States today are at least seven times what they were at the end of the nineteenth century. Successful economic growth has meant that almost all citizens of the United States today live better, and we hope happier, lives than even the rich elite of a century ago. The study of long-run economic growth aims at understanding its sources and causes and at determining what government policies will promote or retard long-run economic growth.

Long-run growth is a module that is not very closely connected to the study of business cycles, recessions, unemployment, inflation, and stabilization policy that makes up the bulk of this book. The models used and the conclusions reached in Part 2 will by and large not be central to subsequent parts, for starting in Chapter 6 we turn to business cycles.

Why, then, include this two-chapter part? The principal reason is that long-run economic growth is such an important topic.

CHAPTER 4

The Theory of Economic Growth

QUESTIONS

What are the causes of long-run economic growth — that is, of sustained and significant growth in an economy's level of output per worker?

What is the "efficiency of labor"?

What is an economy's "capital intensity"?

What is an economy's "balanced-growth path"?

How important is faster labor-force growth as a drag on economic growth?

How important is a high saving rate as a cause of economic growth?

How important is technological and organizational progress for economic growth?

4.1 SOURCES OF LONG-RUN GROWTH

economic growth

The process by which productivity, living standards, and output increase.

Step back and take a broad, sweeping view of the economy. Look at it, but do not focus on the "short run" of calendar-year quarters or even of a year or two in which shifts in investment spending and other shocks push the unemployment rate up or down — that's what we will do in Chapters 9 through 12. Look at it, but do not focus on the "long run" period of 3 to 10 years or so, in which prices have time to adjust to return the economy to a full-employment equilibrium but in which the economy's productive resources do not change much — that's what we will look at in Chapters 6 through 8. What do we do here in Chapters 4 and 5? We take that step back and focus on the very long run of decades and generations — a period over which everything else dwindles into insignificance except the sustained and significant increases in standards of living that we call long-run **economic growth.**

When we take this broad, sweeping view, it is clear that what we are calling economic growth is the only truly important factor. As Table 4.1 shows, material

TABLE 4.1

Current GDP per Capita Levels for Countries with More than 50 Million People

The World Bank's latest estimates of GDP per capita levels, measured at purchasing power parities. (That is, currencies are converted into dollars at a rate that gives approximately the same purchasing power both before conversion in the other country and after conversion in the United States.) The final column shows how far the country's GDP per capita is "behind" the United States — when the United States's level of GDP per capita was last below that of the country's current value.

Country	GDP per Capita	Matches U.S. Level in . . .
United States	$35,060	2004
Germany	26,220	1988
France	26,180	1988
Japan	26,070	1988
United Kingdom	25,870	1987
Italy	25,320	1987
Mexico	8,540	1940
Russia	7,820	1940
Brazil	7,250	1939
Thailand	6,680	1928
Iran	6,340	1925
Turkey	6,120	1924
China	4,390	1900
Philippines	4,380	1900
Egypt	3,710	1897
Indonesia	2,990	1879
India	2,570	1874
Vietnam	2,240	1854
Pakistan	1,940	1849
Bangladesh	1,720	1836
Nigeria	780	—
Ethiopia	720	—
Congo	580	—

Source: World Bank.

standards of living and levels of economic productivity today in the United States are more than four times what they are in, say, Mexico (and more than nine times those of Egypt, and more than 40 times those of Nigeria). Only a trivial part of these differences is due to whether unemployment in a country is currently above or below its average level or whether various bad macroeconomic policies are currently disrupting the functioning of the price system. The overwhelming bulk of these differences is the result of differences in economies' productive potentials and in the factors that determine productive potential — the skills of the **labor force**, the value of the **capital stock**, and the level of technology and organization currently used in production.

These enormous gaps between the productive potentials of different nations spring from favorable initial conditions and successful growth-promoting economic policies in the United States — and from less favorable initial conditions and less successful policies in Mexico and downright unsuccessful policies in Egypt and Nigeria. As Figure 4.1 shows, material standards of living and levels of economic productivity in the United States today are at least seven times what they were at the end of the nineteenth century (and more than 30 times what they were at the founding of the republic). The bulk of today's gap between living standards and productivity levels in the United States and Mexico (and Egypt

labor force

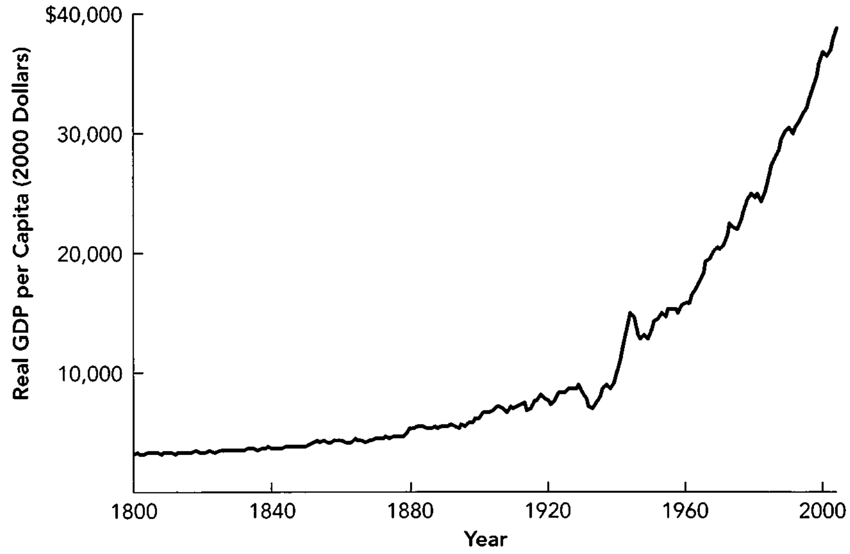
The sum of those who are employed and those who are actively looking for work.

capital stock

The economy's total accumulated stock of buildings, roads, other infrastructure, machines, and inventories.

FIGURE 4.1

American Real GDP per Capita, 1800–2004 (in 2000 Dollars) The pace of modern economic growth in the United States has been astonishing. Economic historians estimate — and if anything, their estimates are underestimates — economic product per person in the United States measured in 2000 prices has grown from $1,200 at the time of the writing of the Constitution to over $36,000 in 2004.



Source: Louis Johnston and Samuel H. Williamson (2004), "The Annual Real and Nominal GDP for the United States, 1789–Present." Economic History Services, March 2004, http://www.eh.net/hmit/gdp/.

and Nigeria) opened up in the past century; the bulk of success (or failure) at boosting an economy's productive potential is thus — to a historian at least — of relatively recent origin.

Successful economic growth means that nearly all citizens of the United States today live better — along almost every dimension of material life — than did even the rich elites of preindustrial times. If good policies and good circumstances accelerate economic growth, bad policies and bad circumstances cripple long-run economic growth. Argentineans were richer than Swedes before World War I, but Swedes today have four times the standard of living and the productivity level of Argentineans.

We classify the factors that generate differences in economies' productive potentials into two broad groups:

- First, differences in the economy's *efficiency of labor* — how technology is deployed and organization is used to increase the amount of output a worker can produce, even with the same amount of capital.
- Second, differences in the economy's *capital intensity* — how large a multiple of current production has been set aside in the form of useful machines, buildings, and infrastructure to boost the productivity of workers, even with the same technology or organization.

Economists have spent much time over the past two generations dividing economic growth into that part due to improvements in technology and in social and business organization that boost the efficiency of labor, on the one hand, and into that part generated by investment in capital to boost the economy's capital intensity — the ratio of the capital stock to output — on the other. A very important finding is that investment that boosts capital intensity plays a substantial role in generating growth. But an even more important finding is that the lion's share of economic growth comes from factors that affect the efficiency of labor.

In this two-chapter section on economic growth, this first chapter, Chapter 4, sets out economists' basic theory of economic growth. It presents the concepts and models economists use to organize their thinking about the causes of long-run economic growth and stagnation. Chapter 5 then sketches the facts of economic growth over time and across the world. Chapter 4 is a tour of how economists think about economic growth. Chapter 5 is a tour of how economic growth is progressing or not progressing around the world.

Now let's begin our tour of how economists think by looking in more detail at the two broad groups into which economists divide factors affecting long-run economic growth: the efficiency of labor, on the one hand, and capital intensity, on the other.

The Efficiency of Labor

The biggest reason that Americans today are vastly richer and more productive than their predecessors of a century ago is that they have enjoyed an extraordinary amplification of the **efficiency of labor**. Efficiency has risen for two reasons: advances in technology and in organization. We now know how to make electric motors, dope semiconductors, transmit signals over fiber optics, fly jet airplanes, machine internal combustion engines, build tall and durable structures out of concrete and steel, record entertainment programs on DVDs, make hybrid seeds, fertilize crops with nutrients, organize assembly lines, and do a host of other things our predecessors did not know how to do. These technological advances allow American workers

efficiency of labor

The skills and education of the labor force, the ability of the labor force to handle modern technologies, and the efficiency with which the economy's businesses and markets function.

to easily perform value-generating tasks that were unimaginable, or at least extremely difficult to accomplish, a century ago.

Moreover, the American economy is equipped to make use of all these technological capabilities. It has the forms of business organization, it has the stability and honesty of government, it has the schools to educate its population, and it has the other socioeconomic institutions needed to successfully utilize modern technology. So it is both better technology and advances in organization that have led to vast increases in the efficiency of labor and thus to American standards of living.

We have to admit that we economists know less than we should about the processes by which this better technology and these advances in organization come to be. Economists are good at analyzing the consequences of advances in technology and improvements in organization and other factors that make for a high efficiency of labor, but they have less to say about their sources.

Capital Intensity

A secondary but still large part of America's very long run economic growth — and a secondary but still large component of differences in material standards of living across countries today — has been generated by the second source of growth: **capital intensity**. Does the economy have a low ratio of capital per unit of output, that is, relatively little in the way of machines, buildings, roads, bridges, and so on? Then it is likely to be poor. The higher is the economy's capital intensity, the more prosperous the economy will be: A more capital-intensive economy will be a richer and a more productive economy.

capital intensity

The ratio of the capital stock to total potential output, K/Y, which describes the extent to which capital, as opposed to labor, is used to produce goods and services.

Fitting the Two Together

The task of the rest of Chapter 4 is to build economists' standard model of long-run economic growth, a model into which we can fit these two broad groups of factors. This standard model is called the *Solow growth model*, after Nobel Prize–winning MIT economist Robert Solow. The Solow growth model is a dynamic model of the economy: It describes how the economy changes and grows over time as saving and investment, labor-force growth, and progress in advancing technology and improving social organization raise the economy's level of output per worker and thus its material standard of living. Saving and investment are the drivers leading to increases in capital intensity. Progress in technology and organization are the drivers leading to increases in the efficiency of labor.

RECAP SOURCES OF LONG-RUN GROWTH

In the very long run, economic growth is the most important aspect of economic performance. Two major factors determine economic growth: growth in the efficiency of labor — a product of advances in technology on the one hand and improvements in economic and social organization on the other — and the economy's capital intensity. Policies that accelerate innovation or improve institutions and so boost the efficiency of labor accelerate economic growth and create prosperity, as do policies that boost investment and raise the economy's capital intensity to a higher level.

4.2 THE SOLOW GROWTH MODEL

As is the case for all economic models, the Solow growth model consists of

- *Variables:* economic quantities of interest that we can measure.
- *Behavioral relationships:* relationships that (1) describe how humans, making economic decisions given their opportunities and opportunity costs, decide what to do and (2) determine the values of the variables.
- *Equilibrium conditions:* conditions that tell us when the economy is in a position of balance, when the variables we are focusing on are "stable" — that is, when the variables are changing in simple and predictable ways.

Almost every economic model has a single key economic variable at its heart. We will be most interested in that one variable — the one the model is organized around.

In the case of the Solow growth model, the key variable is *labor productivity:* output per worker, how much the average worker in the economy is able to produce. We calculate output per worker by simply taking the economy's level of real GDP or output Y, and dividing it by the economy's labor force L. This quantity, output per worker, Y/L, is our best simple proxy for the standard of living and level of prosperity of the economy.

In every economic model — and the Solow growth model is no exception — economists analyze the model by looking for an *equilibrium:* a point of balance, a condition of rest, a state of the system toward which the model will converge over time. Economists look for equilibrium for a simple reason: either an economy is at its (or one of its) equilibrium position(s), or it is moving — and probably moving rapidly — to an equilibrium position.

Once you have found the equilibrium position toward which the economy tends to move, you can use it to understand how the model will behave. If you have built the right model, it will tell you in broad strokes how the economy will behave. *In economic growth, the equilibrium economists look for is an equilibrium in which the economy's capital stock per worker, its level of real GDP per worker, and its efficiency of labor are all three growing at exactly the same proportional rate.*

The equilibrium economists look for in the case of the Solow growth model is thus a *balanced-growth equilibrium.* In this growth equilibrium the capital intensity of the economy — its capital stock divided by its total output, K/Y — remains constant as the rest of the variables in the economy grow. The amount of capital that the economy uses to produce each unit of output remains constant over time, as both the capital stock and output grow at the same proportional rate, and thus capital intensity does not change.

balanced-growth path

The path toward which total output per worker tends to converge as the capital-output ratio converges to its equilibrium value.

For each balanced-growth equilibrium, there is a **balanced-growth path**: this is a growing economy and so the economy's variables of interest change over time. We need to know how fast it is growing: at what rate output per worker, Y/L, is increasing. So, after finding the balanced-growth equilibrium, we calculate this balanced-growth path. Forecasting then becomes straightforward. If the economy is on its balanced-growth path, the present value of output per worker is on and future values of output per worker will continue to follow the balanced-growth path. If the economy is not yet on its balanced-growth path, it will head toward it: Over time, the economy will converge to its balanced-growth path.

We will see how this works later on. First we need to set out the pieces of the Solow growth model.

The Production Function

Let's start with the average worker, a worker whose productivity is simply Y/L, the economywide average. This average worker uses the economy's current level of technology and organization. These are captured by the current value of the efficiency of labor E. This average worker also uses an average share of the economy's capital stock: He or she has K/L worth of capital to amplify his or her productivity. We want to analyze how these two — efficiency of labor E and the capital-to-labor ratio K/L — affect the average worker's productivity Y/L.

To do this, we write down a behavioral relationship that tells us how the average worker's productivity Y/L is related to the efficiency of labor E and the amount of capital K/L at the average worker's disposal. We give this behavioral relationship a name: the **production function.** Tell the production function what resources the economy's average worker has available, and it will tell you how much output the typical worker can produce. In an abstract form we write the production function as

$$\frac{Y}{L} = F\left(\frac{K}{L}, E\right)$$

This says just that there is a systematic relationship between **output per worker** Y/L — real GDP divided by the number of workers — and the economy's available resources: the capital stock per worker K/L and the efficiency of labor E. The pattern of this relationship is prescribed by the form of the function $F(\ )$.

production function

The relationship between the national product per worker and the resources used to produce it: the quantity of capital per worker, and the efficiency of labor. Equivalently, the relationship between the national product and capital, labor, and the efficiency of labor.

output per worker

The average amount of output produced in a year per worker, Y/L. Equal to the average labor productivity. Used as a proxy for the material standard of living.

As long as all we know about the production function is that we write it with the symbols $F(\ )$ — one capital letter and one set of parentheses — it is not of much use. We know that there is a relationship between resources and production, but we don't know what that relationship is. We cannot calculate much of anything; we cannot give quantitative answers to any questions we are asked about the effects of changes in economic policy and the economic environment on economic growth.

To make our model more useful, we will give a simple algebraic form to our production function: the Cobb-Douglas form, which we choose primarily because using it makes lots of formulas later in the chapter simpler than they would otherwise be. We write the Cobb-Douglas production function as

$$\frac{Y}{L} = \left(\frac{K}{L}\right)^{\alpha}(E)^{1-\alpha}$$

where α is a parameter between zero and 1. The economy's level of output per worker Y/L is equal to the capital stock per worker K/L raised to the power of a parameter α, and then multiplied by the current efficiency of labor E itself raised to the power $(1 - \alpha)$.[1]

The value of α in the Cobb-Douglas production function tells us how rapidly the economic usefulness of additional *investment* in buildings and machines declines as the economy accumulates more and more of them. That is, α measures how fast diminishing returns to investment set in, in the economy. A value of α near zero means that the extra amount of output made possible by an additional unit of capital declines very quickly as the capital stock rises. A value of α near 1

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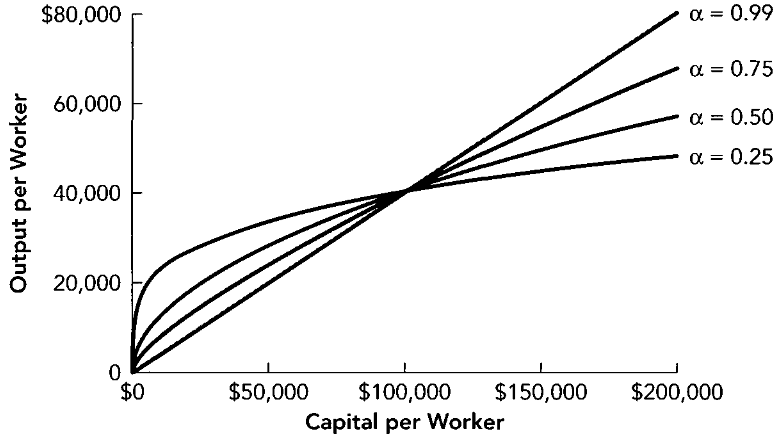
[1] When we are interested not in the level of output per worker but in the total level of output Y in the economy, we simply multiply both the left- and right-hand sides of the equation above by the labor force L to get the total output form of the production function $Y = (K)^{\alpha}(LE)^{1-\alpha}$.

FIGURE 4.2

The Cobb-Douglas Production Function for Different Values of α As the exponent α in the Cobb-Douglas production function changes, the speed with which diminishing returns to investment set in — and thus the curvature of the production function — changes. With a high value of α near 1, output per worker Y/L increases nearly one-for-one with the capital stock per worker K/L. With a low value of α near zero, the economy quickly reaches the point where additional capital accumulation raises output by only a little. For each of the values of α plotted in this figure, the value of the efficiency of labor E has been adjusted so that output per worker Y/L is equal to $40,000 a year when the capital stock per worker K/L is equal to $100,000.



means that each additional unit of capital makes possible almost as large an increase in output as the last additional unit. As α varies from a high number near 1 to a low number near 0, the force of diminishing returns to investment gets stronger, as Figure 4.2 shows.[2]

The value of α determines how quickly the Cobb-Douglas production function flattens out when output per worker is plotted on the vertical axis and capital per worker is plotted on the horizontal axis. The value of the efficiency of labor E tells us how high the production function rises: A higher level of E means that more output per worker is produced for each possible value of the capital stock per worker, as Figure 4.3 shows.

The Cobb-Douglas production function is flexible. It can be "tuned" to fit any of a wide variety of different economic situations. Are we studying an economy in which productivity is high? Use the Cobb-Douglas production function with a high value of the efficiency of labor E. Does the economy rapidly hit the wall as investment proceeds, with little increase in the level of production? Use the Cobb-Douglas function with a low value — near zero — of α. Is the speed

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[2] One way of illustrating this point in algebra is to use a little calculus to calculate the *marginal product of capital*, the MPK — how much total output increases as a result of a one-unit increase in the capital stock. For the Cobb-Douglas production function, MPK = $\alpha/(K/Y)$. The higher the current capital-to-output ratio, the lower is the marginal product of capital. And the lower the parameter α, the lower is the marginal product of capital.

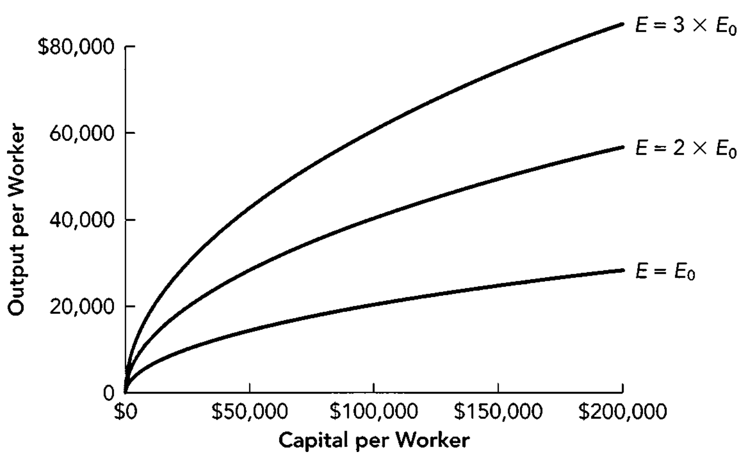

FIGURE 4.3

The Cobb-Douglas Production Function for Different Values of E

As the parameter E in the Cobb-Douglas production function increases, the curve representing the function moves upward. With a higher value of E, each possible value of capital per worker produces a larger value for output per worker.

with which diminishing returns to investment set in moderate? Pick a middle value of α. The Cobb-Douglas function will once again fit.

Given values for the diminishing-returns-to-investment parameter α, the efficiency of labor E, the economy's capital stock K, and the labor force L, we can calculate the level of output per worker Y/L in the economy. Box 4.1 shows how to use the production function.

BOX 4.1

USING THE PRODUCTION FUNCTION: AN EXAMPLE

Suppose we know that the current value of the efficiency of labor E is $10,000 a year and that the diminishing-returns-to-investment parameter α is 0.3. Then determining how the level of output per worker Y/L depends on the capital stock per worker K/L is straightforward.

Let's start with the case in which the capital stock per worker is $125,000. The Cobb-Douglas production function is

$$\frac{Y}{L} = \left(\frac{K}{L}\right)^{\alpha}(E)^{1-\alpha}$$

Substitute in the known values of K/L, E, and α to get

$$\frac{Y}{L} = (125{,}000)^{0.3}(10{,}000)^{0.7}$$

Use your calculator to evaluate the effect of raising numbers to these exponents to get

$$\frac{Y}{L} = (33.812)(630.957)$$

And then multiply to get

$$\frac{Y}{L} = \$21{,}334 \text{ per year}$$

If we are interested in a capital stock per worker level of \$250,000, the calculations are

$$\frac{Y}{L} = (250{,}000)^{0.3}(10{,}000)^{0.7}$$

And, using your calculator,

$$\frac{Y}{L} = (41.628)(630.957)$$

$$\frac{Y}{L} = \$26{,}265 \text{ per year}$$

Note that the first \$125,000 of capital per worker boosted output per worker from \$0 to \$21,334, while the second \$125,000 of capital per worker boosted output per worker only from \$21,334 to \$26,265 — by less than one-quarter as much. These substantial diminishing returns to investment should come as no surprise: The value of α is quite low at 0.3, and low values of α produce rapidly diminishing returns to capital accumulation.

This example offers another important lesson: Keep your calculator or computer's spreadsheet handy! Nobody expects anyone to raise \$250,000 to the 0.3 power in her or his head and come up with 41.628. The Cobb-Douglas form of the production function, with its fractional exponents, carries the drawback that students (or professors) can do problems in their heads or with just pencil and paper only if the problems have been carefully rigged beforehand.

Nevertheless, we use the Cobb-Douglas production function because of its extraordinary convenience: By varying just two parameters we can fit the model to an enormous variety of potential economic situations.

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Saving, Investment, and Capital Accumulation

In Chapter 6 we will talk in detail about the circular-flow relationship you learned in your Principles of Economics class: The amount of output an economy produces (real GDP, or Y) equals total spending, with total spending divided into four parts, consumption spending C, investment spending I, government purchases G, and net exports NX, which equal gross exports minus imports, $NX = GX - IM$.

Here we want to use this relationship to understand how investment spending is equal to *total saving*. The answer is that they are very closely related: The net flow of saving — household saving, plus *foreign saving* invested in our country, minus the *government's budget deficit* — is equal to the amount of investment. In the end, there is no place that net saving can go but to finance investment. If you save it, and it gets into the hands of a bank, then unless some other household borrows it (and so offsets your positive saving with its negative saving) the bank will lend it out, and it will be spent on business investment.

To see this more formally, a little bit of easy algebra is all we need. Start from the national income identity: Consumption C plus investment I plus government purchases G plus net exports $GX - IM$ equals real GDP Y:

$$C + I + G + GX - IM = Y$$

First subtract *net taxes* T from both sides:

$$C + I + (G - T) + GX - IM = Y - T$$

Next subtract consumption spending C, the government budget deficit $G - T$, and net exports $GX - IM$, from both sides:

$$I = (Y - T - C) + (T - G) + (IM - GX)$$

The right-hand side is the three pieces of total saving: household saving, government saving, and foreign saving. $Y - T - C$, real GDP minus net taxes minus consumption spending, is household saving. Call it S^H, S for saving and H for household.

When government purchases are less than net taxes, $T - G$ is positive, the government is running a *surplus* and is saving. Call this S^G, S for saving and G for government. But with the exception of a few years at the end of the 1990s, the U.S. government has run *deficits*. Then the government is "dissaving" — borrowing by running a deficit. $G - T$, government purchases minus net taxes, is the government's deficit. When the government runs a deficit, its saving S^G is negative.

$IM - GX$ is simply the excess of imports over exports, which equals the net flow of saving that foreigners invest here. Call it S^F, S for saving and F for foreign. With these new symbols, our equation above tells us that investment is equal to saving:

$$I = S^H + S^G + S^F$$

The right-hand term, $S^H + S^G + S^F$, is the total saving flowing into the economy. The equation says that businesses take all this saving and use it to invest — to buy and install the machines and build the buildings that make up our capital stock.[3]

Now, let's assume that total saving $S^H + S^G + S^F$ is a constant fraction s of real GDP Y:

$$s = \frac{S^H + S^G + S^F}{Y}$$

Multiply both sides by Y and you get $sY = S^H + S^G + S^F$. Thus investment spending I is equal to saving sY:

$$I = S^H + S^G + S^F = sY$$

In this chapter we will assume that s is almost always constant. We may think about the consequences of its taking an upward or downward jump or two at some particular moment of time, but the background assumption (made because it makes formulas much simpler) will be that s will remain at its current value as far as we look into the future. We call s the economy's saving rate or, more completely, its *saving-investment rate* to remind us that s is measuring both the flow of saving into the economy's financial markets and also the share of total production that is invested and used to build up and increase the economy's capital stock.

saving rate

The share of total GDP that an economy saves, s, equal to the sum of household, government, and foreign saving divided by total output.

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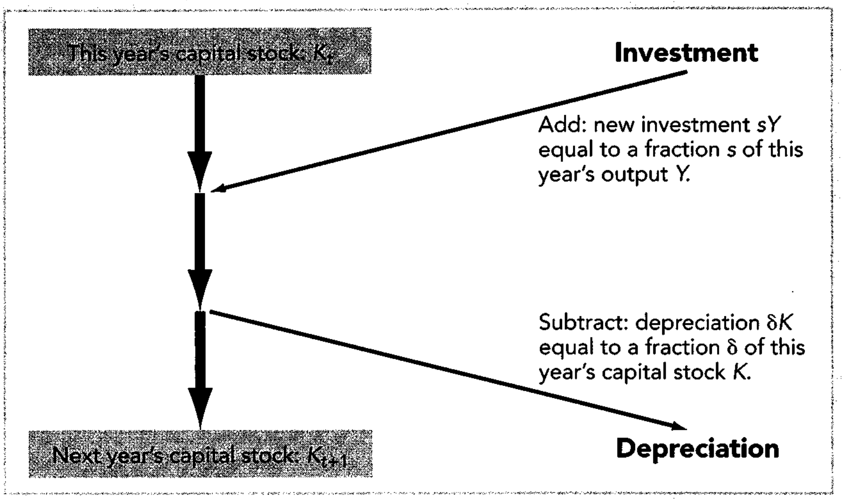
[3] With more time, pages, and patience, we would develop this relationship further, by taking into account the differences between the government's investment that builds up publicly owned capital such as roads and bridges, and the remainder of government purchases. But here we will follow economists' custom of ruthless simplification, and say that all investment is captured in I.

FIGURE 4.4
Investment and Depreciation
Gross investment adds to and depreciation subtracts from the capital stock.



We assume the saving-investment rate s is constant, but we can't make the same assumption about the capital stock. The economy's capital stock K is not constant. It changes from year to year. Let's adopt the convention of using a subscript when we need to identify the year to which we are referring. K_0 denotes the capital stock at some initial year, usually the year at which we begin the analysis; K_{2003} means the capital stock in 2003; K_t denotes the capital stock in the current year; K_{t+1} means the capital stock next year; and K_{t-1} means the capital stock last year.

depreciation

The difference between gross and net investment in capital; the amount by which capital stock wears out, becomes obsolete, or is scrapped over a year.

Over time investment makes the capital stock tend to grow. But over time **depreciation** makes the capital stock tend to shrink — old capital becomes obsolete, or breaks, or simply wears out. We make a simple assumption for depreciation: The amount of capital that wears out, breaks, and becomes obsolete in any year is simply a constant parameter δ (lowercase Greek delta, the depreciation rate) times the current capital stock. Thus we can write that next year's capital stock will be[4]

$$K_{t+1} = K_t + \text{Investment} - \text{Depreciation}$$

$$K_{t+1} = K_t + sY_t - \delta K_t$$

as illustrated in Figure 4.4. From these definitions, we can see that the capital stock is constant — that this year's capital stock K_t is equal to next year's K_{t+1} — when

$$sY_t = \delta K_t$$

capital-output ratio

The economy's capital stock divided by potential output, K/Y.

And this is true when the **capital-output ratio** is

$$\frac{K_t}{Y_t} = \frac{s}{\delta}$$

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[4] Sometimes you will hear people refer to the change in the capital stock as *net investment* — investment net of depreciation — and refer to the amount of plant and equipment purchased and installed as *gross investment*. In this book "investment" will mean *gross investment*, and we will use "investment minus depreciation" in place of *net investment*.

Now suppose for a page or two that our economy has no labor-force growth and no growth in the efficiency of labor. (We will immediately drop this assumption when we leave this subsection, and we include it here only because understanding a more complex case later will be easier if we understand the simpler case now.) The labor force is constant at its initial value L_0. The efficiency of labor is constant at its value E_0.

If the capital-output ratio K/Y is lower than s/δ, then depreciation (δK) is less than investment (sY) so the capital stock and the capital-output ratio will grow. They will keep growing until K/Y reaches s/δ. If the capital-output ratio K/Y is greater than s/δ, then depreciation (δK) is more than investment (sY), so the capital stock and the capital-output ratio will shrink. They will keep shrinking until K/Y falls to s/δ. In the very long run, the capital-output ratio will be s/δ. The requirement

$$\frac{K_t}{Y_t} = \frac{s}{\delta}$$

is the equilibrium condition in this particular simple case of the Solow growth model — the case in which there is neither growth in the labor force nor growth in the efficiency of labor.

What is that equilibrium value of output per worker? A little algebra detailed in Box 4.2 shows us that we can move back and forth between the capital-per-worker

BOX 4.2

THE TWO FORMS OF THE PRODUCTION FUNCTION: SOME DETAILS

How do we transform our production function from one that focuses on the capital-labor ratio to one that focuses on the capital-output ratio? Through a little bit of simple algebra. Begin with our capital-per-worker form of the Cobb-Douglas production function:

$$\frac{Y}{L} = \left(\frac{K}{L}\right)^{\alpha}(E)^{1-\alpha}$$

Rewrite K/L as (K/Y) times (Y/L):

$$\frac{Y}{L} = \left(\frac{K}{Y}\frac{Y}{L}\right)^{\alpha}(E)^{1-\alpha}$$

Regroup:

$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\alpha}\left(\frac{Y}{L}\right)^{\alpha}(E)^{1-\alpha}$$

Divide both sides by $(Y/L)^{\alpha}$:

$$\left(\frac{Y}{L}\right)^{1-\alpha} = \left(\frac{K}{Y}\right)^{\alpha}(E)^{1-\alpha}$$

Finally, raise both sides to the $1/(1-\alpha)$ power in order to get Y/L by itself on the left-hand side:

$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\frac{\alpha}{1-\alpha}}(E)$$

This is the capital-output ratio form of the production function.

◆

form of the production function that we have already seen,

$$\frac{Y}{L} = \left(\frac{K}{L}\right)^{\alpha} (E)^{1-\alpha}$$

and a different (but more convenient) form, the capital-output ratio form of the production function:

$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\frac{\alpha}{1-\alpha}} (E)$$

Both forms of the production function contain the same information. But for our purposes the capital-output ratio form is more convenient to work with, so work with it we shall.

What, then, is the equilibrium value of output per worker? We know the value of the diminishing-returns-to-investment parameter α. We know the value of the efficiency of labor E. And we know that in equilibrium K/Y will be equal to s/δ. So just substitute s/δ in for K/Y where it appears, and calculate. Box 4.3 shows how.

4.3
BOX

CALCULATING OUTPUT PER WORKER: AN EXAMPLE

Suppose we know that the current value of the efficiency of labor E is \$10,000 a year, and that the diminishing-returns-to-investment parameter α is 0.5. Then — in this special case in which both the labor force and the efficiency of labor are constant — we can calculate what the long-run value of output per worker will be once we know the saving-investment rate s and the depreciation rate δ.

Suppose the economy's saving-investment rate s is 16 percent, and the depreciation rate δ is 4 percent. Then substituting the parameters into the capital-output ratio form of the production function is straightforward:

$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\frac{\alpha}{1-\alpha}} (E)$$

$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\frac{0.5}{1-0.5}} (10{,}000)$$

And we know that in the very long run the capital-output ratio K/Y will be $s/\delta = .16/.04 = 4$. Thus

$$\frac{Y}{L} = (4)^{\frac{0.5}{1-0.5}} (10{,}000)$$

Output per worker will be \$40,000 per year.

◆

We can reach the same conclusion by a different, graphical, approach — an approach that is more friendly to those who prefer lines and curves on graphs to Greek variables and exponents in equations. Recall Figure 4.2, which showed how to draw the production function at any one moment in time (for a fixed and known level of the efficiency of labor E). Plot output per worker Y/L on the

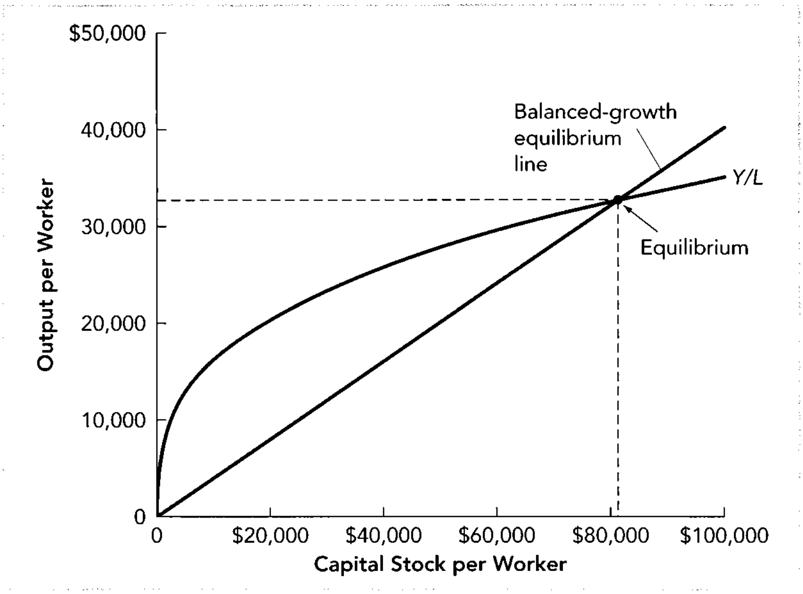

FIGURE 4.5

Equilibrium with Just Investment and Depreciation

The blue line shows output per worker as a function of the capital stock per worker for the known, constant values of the diminishing returns to investment parameter α and the efficiency of labor E. The red line shows the reciprocal of the equilibrium capital-output ratio, δ/s. If the economy is to the left of where the lines cross, the capital stock is growing. If the economy is to the right, the capital stock is shrinking. Where the lines cross is the equilibrium value of output per worker and capital per worker.

vertical axis, and capital per worker K/L on the horizontal axis. This curve tells you the relationship between levels of capital per worker and what the economy can produce.

Which of the many points on this production function curve is the economy's equilibrium? Recall our equilibrium condition: In equilibrium the economy's capital intensity, its capital-output ratio K/Y, is equal to s/δ. We can think of this equilibrium condition $K/Y = s/\delta$ as another line on the figure. It is a straight line starting at the bottom left (0,0) origin point and climbing to the upper right, with its slope Y/K equal to δ/s. Figure 4.5 shows that only one point satisfies both (1) this equilibrium condition for the economy's capital intensity and (2) the behavioral relationship relating output per worker to capital per worker, that is, the production function. This point is where the curves in Figure 4.5 cross.

We can use either the algebra or the graphical method to think about the long-run consequences of, say, changes in a government's fiscal policy. Before the 2000 presidential election the U.S. federal budget was in surplus and was expected to remain in surplus for decades. In the following few years, however, the George W. Bush administration pushed hard for significant increases in spending (which drove conservative small-government Republicans up the wall) and significant decreases in taxes (which drove liberal pro–government-program Democrats around the bend), with the result being a large downward shift in government saving S^G and thus in the economy's saving-investment rate s. Such a shift is going to mean that the equilibrium line rotates counterclockwise, and so the intersection point moves to a lower equilibrium value of output per worker. The economy's equilibrium condition $K/Y = s/\delta$ will be satisfied at a lower capital intensity, and so the economy will be poorer.

This depressing effect of rising government deficits on the standard of living is one important reason that international agencies like the International Monetary Fund (IMF) and the World Bank and almost all economists advise governments to avoid large and prolonged deficits.

Note that in this particular, restricted case the economy's labor force is constant. Its capital stock is constant. There are no changes in the efficiency of labor. Thus equilibrium output per worker is constant. There is — in this particular, restricted case — no growth of output per worker when the economy is in equilibrium. If we are to have a model in which economic growth continues, then we need to have growth in the labor force and, more important, growth in the efficiency of labor — which is why we have to move on to the next subsection, and think about a more complicated model.

Adding in Labor-Force and Labor-Efficiency Growth

If labor forces were constant and technological and organizational progress nonexistent, we could stop the chapter here. But the economy's labor force continues to grow as more people turn 16 and join the labor force than retire and as immigrants continue to arrive. And the efficiency of labor rises as science and technology progress and people keep thinking of new and more efficient forms of business organization.

We assume — once again making a simplifying leap — that the economy's *labor force* L is growing at a constant proportional rate n every year. (Note that n is not the same across countries and can shift over time in any one country, but our background assumption will be that n is constant as far as we can see into the future.) Thus between this year and the next the labor force grows according to the formula

$$L_{t+1} = (1 + n)L_t$$

Next year's labor force will be n percent higher than this year's labor force, as Figure 4.6 shows. If this year's labor force is 10 million and its growth rate n is 2 percent per year, then next year's labor force will be

$$\begin{aligned} L_{t+1} &= (1 + n)L_t \\ L_{t+1} &= (1 + 2\%)(10{,}000{,}000) \\ L_{t+1} &= (1.02)(10{,}000{,}000) \\ L_{t+1} &= 10{,}200{,}000 \end{aligned}$$

We assume that the rate of growth of the labor force is constant not because we believe that labor-force growth is unchanging, but because the assumption makes the analysis of the model simpler. The trade-off between realism in the model's description of the world and simplicity as a way to make the model easier to analyze is one that economists always face, and economists have a strong bias toward resolving this trade-off in favor of simplicity.

We also assume that the efficiency of labor E grows at a constant proportional rate g:

$$E_{t+1} = (1 + g)\,E_t$$

Next year's level of the efficiency of labor will be g percent higher than this year's level, as Figure 4.7 shows. If this year the efficiency of labor is \$10,000 per worker,

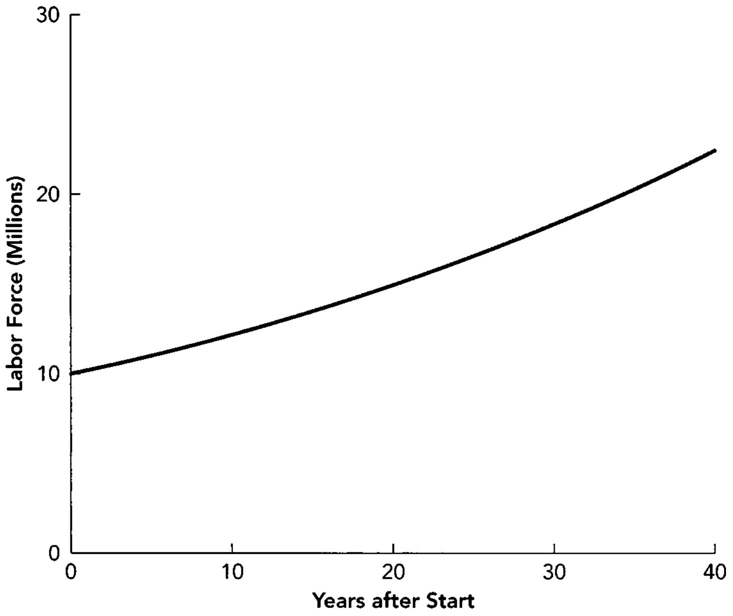

FIGURE 4.6

Constant Labor-Force Growth at $n = 2$ Percent per Year

The labor force growing at 2 percent per year. A labor force increasing at 2 percent per year will double roughly every 35 years.

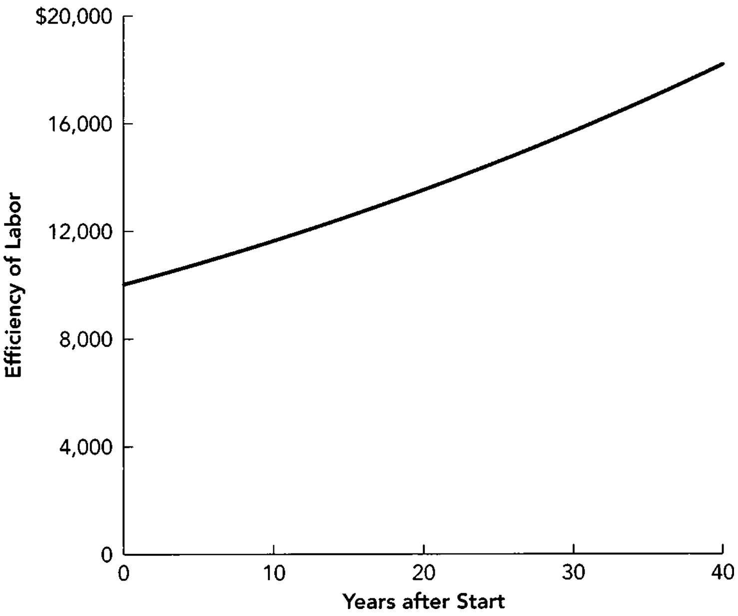

FIGURE 4.7

Efficiency-of-Labor Growth at $g = 1.5$ Percent per Year

Labor efficiency growing at 1.5 percent per year. If the efficiency of labor grows at 1.5 percent per year, it will take roughly 47 years for it to double.

and if g is 1.5 percent per year, then next year the efficiency of labor will be

$$E_{t+1} = (1 + g)E_t$$
$$E_{t+1} = (1 + 0.015)(\$10{,}000)$$
$$E_{t+1} = \$10{,}150$$

The Balanced-Growth Capital-Output Ratio

Earlier, when we had assumed that labor force and efficiency were both constant, and thus that n and g were both equal to 0, our equilibrium condition was $K/Y = s/\delta$. Since the saving-investment rate s and the depreciation rate δ are both constant, our equilibrium condition required that the capital-output ratio K/Y be constant. Now we've added realism to our model by allowing the labor force and efficiency to both increase over time at constant rates n and g. What effect does this added realism — allowing n and g to take on values other than 0 — have on our equilibrium condition?

In an important sense, none! Once again, our equilibrium condition is that the capital-output ratio be constant. When the capital-output ratio is constant, we say that the economy is in **balanced growth:** Output per worker is then growing at the same rate as the capital stock per worker. The two variables are in balance, and they are also both growing at the same rate as the efficiency of labor.

balanced growth

When output per worker Y/L and capital per worker K/L are growing at the same rate.

But at what *value* will the economy's capital-output ratio be constant? Here is where allowing n and g to take on values other than 0 matters. The capital-output ratio will be constant — and therefore we'll be in balanced-growth equilibrium — when $K/Y = s/(n + g + \delta)$. Add up the economy's labor-force growth rate, efficiency-of-labor growth rate, and depreciation rate; divide the saving-investment rate by that sum; and that is your **balanced-growth equilibrium capital-output ratio.**

balanced-growth equilibrium capital-output ratio

The value of the capital-output ratio to which an economy with constant saving rate, depreciation rate, labor-force growth rate, and efficiency growth rate converges over time. Equal to $s/(n + g + \delta)$.

Why is $s/(n + g + \delta)$ the capital-output ratio in equilibrium? Think of it this way: Suppose the economy is in balanced growth. How much is it investing? There must be investment equal to δK to replace depreciated capital. There must be investment equal to nK to provide the labor force which is expanding at rate n with the capital it will need. And since the efficiency of labor is growing at rate g, there must be investment equal to gK in order for the capital stock to keep up with increasing efficiency of labor. Adding these three parts of required investment together and setting the sum equal to the investment sY actually going on,

$$(n + g + \delta)K = sY$$

shows clearly that the economy's *investment requirements* for balanced growth equal the actual flow of investment when

$$\frac{K}{Y} = \frac{s}{(n + g + \delta)}$$

This is the balanced-growth equilibrium condition. It is constant because s, n, g, and δ are all constant. So when there is balanced growth — when output per worker Y/L and capital per worker K/L are growing at the same rate — the capital-output ratio K/Y will be constant.

To see more formally that $K/Y = s/(n + g + \delta)$ is the balanced-growth equilibrium condition requires a short march through simple algebra. Take a look again at the capital-output ratio form of the production function:

$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\frac{\alpha}{1-\alpha}}(E)$$

Recall that the efficiency of labor E is growing at the constant proportional rate g. With the capital-output ratio K/Y constant, output per worker must be growing at the rate g as well. Recall also that the labor force is growing at a constant proportional rate n. With output per worker growing at rate g and the number of workers growing at rate n, total output is growing at the constant rate $n + g$.[5] For the capital-output ratio K/Y to be constant, the capital stock also has to be growing at rate $n + g$. This means that the year-over-year change ΔK_{t+1} in the capital stock must be

$$\Delta K_{t+1} = (n + g)K_t$$

BOX 4.4

SOME MATHEMATICAL RULES OF THUMB: TOOLS

This is a good place to introduce four mathematical rules of thumb to make life easier throughout this book. They are all only *approximations*. But they are good enough for our purposes. They are:

1. *The growth-of-a-product rule:* The growth rate of a *product* is equal to the *sum* of the growth rates of its components. Since total output Y is equal to output per worker Y/L times the number of workers L, the growth rate of total output Y will be equal to the growth rate of Y/L plus the growth rate of L.
2. *The growth-of-a-quotient rule:* The proportional change of a *quotient* is equal to the *difference* between the proportional changes of its components. Since output per worker Y/L is equal to the quotient of output Y and the number of workers L, its growth rate will be the difference between their growth rates.
3. *The growth-of-a-power rule:* The proportional change of a *quantity raised to a power* is equal to the *proportional change in the quantity times the power* to which it is raised. For example, suppose that we have a situation in which output Y is equal to the capital stock K raised to the power α: $Y = K^{\alpha}$. Then the growth rate of Y will be equal to α times the growth rate of K.
4. *The rule of 72:* A quantity growing at k percent per year doubles in $72/k$ years. A quantity shrinking at k percent per year halves itself in $72/k$ years.

You may hear people say that a background in calculus is needed to understand intermediate macroeconomics. That is not true. These four mathematical rules of thumb contain 95 percent of what calculus is used for in intermediate macroeconomics. (Of course, you do need calculus if you want to do more than just take them on faith, and instead have a deep understanding of just *why* these rules of thumb work.)

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[5] The fact that the growth rate of a product, Y/L times L, is equal to the sum of the growth rates, growth rate of Y/L plus the growth rate of L, is one of the handy mathematical rules of thumb contained in Box 4.4.

Since next year's capital stock equals this year's plus investment minus depreciation, the year-over-year change in the capital stock is also equal to

$$\Delta K_{t+1} = sY_t - \delta K_t$$

Setting our two expressions for the change in the capital stock equal to each other,

$$(n + g)K_t = sY_t - \delta K_t$$

collecting the terms with the capital stock on the left-hand side,

$$(n + g + \delta)K_t = sY_t$$

and then dividing,

$$\frac{K_t}{Y_t} = \frac{s}{n + g + \delta}$$

gives us the Solow growth model's equilibrium condition: $K/Y = s/(n + g + \delta)$. The balanced-growth equilibrium capital-output ratio is equal to the share of production that is saved and invested for the future — the economy's saving-investment rate s — divided by the sum of three things:

- The growth rate of the labor force n.
- The growth rate of the efficiency of labor g.
- The depreciation rate δ at which capital breaks down and wears out.

We'll sometimes call $s/(n + g + \delta)$ the *"equilibrium" capital-output ratio,* and we'll sometimes call it the "balanced-growth" capital-output ratio. To be always saying "balanced-growth equilibrium" is too much of a mouthful.

How do we know $K/Y = s/(n + g + \delta)$ gives us balanced growth, where capital per worker K/L and output per worker Y/L grow at the same rate? Suppose the current capital-output ratio is lower than $s/(n + g + \delta)$. Then $(n + g + \delta)\ K$ will be less than the economy's total investment which is equal to sY, the saving rate s times the level of output Y. Thus saving and investment will more than provide new workers with the capital they need to be fully productive, more than cover the increase in output due to the increase in labor efficiency, and more than compensate for the wearing out of capital through depreciation. The capital stock will grow faster than $n + g$. Since $n + g$ is the rate at which output grows, the capital-output ratio will rise.

Suppose instead the current capital-output ratio is above $s/(n + g + \delta)$. Then sY will be less than $(n + g + \delta)\ K$ — the economy's total investment sY will be insufficient to keep the capital stock growing at rate $n + g$. And since $n + g$ is the rate at which output grows, the capital-output ratio will fall.

Thus a capital-output ratio greater than $s/(n + g + \delta)$ makes the capital-output ratio fall. And a capital-output ratio less than $s/(n + g + \delta)$ makes the capital-output ratio rise. So a capital-output ratio equal to $s/(n + g + \delta)$ is indeed the balanced-growth equilibrium condition.

We now have our Solow growth model. It consists of one equilibrium condition telling us that the stable capital-output ratio will be $K/Y = s/(n + g + \delta)$. It consists of a production function. And it consists of four assumptions:

- The rate of labor-force growth equals n.
- The rate of increase in the efficiency of labor equals g.
- The rate of depreciation equals δ.
- The saving-investment rate equals s.

"Robert Solow got the Nobel Prize for that?!" you may ask. Ah, but what he got the Nobel Prize for was taking a complicated subject and making a useful model of it that was very simple indeed. The model is simple to write down. But it is powerful. As we unfold its implications and use it to understand very long run economic growth, we will see that it generates many insights.

RECAP THE SOLOW GROWTH MODEL

When the economy's capital stock and its level of real GDP are growing at the same proportional rate, its capital-output ratio — the ratio of the economy's capital stock K to annual real GDP Y — is constant, and the economy is in balanced-growth equilibrium. In equilibrium, the capital-output ratio K/Y will equal the constant ratio $s/(n + g + \delta)$. The standard growth model analyzes how this balanced-growth equilibrium is determined by four factors: the economy's saving-investment rate s, the economy's labor-force growth rate n, the growth rate of the efficiency of labor g, and the capital stock depreciation rate δ.

4.3 UNDERSTANDING THE GROWTH MODEL

Balanced-Growth Output per Worker

Suppose that the capital-output ratio is equal to its balanced-growth equilibrium value: The economy is on its *balanced-growth path.* What does an economy on its balanced-growth path look like? The first and most important thing to look at is output per worker Y/L — what it is now, and how it grows. Y/L is, after all, our best simple proxy for the economy's overall level of prosperity: for material standards of living and for the possession by the economy of the resources needed to diminish poverty. Let's calculate the level of output per worker Y/L along the balanced-growth path (paying close attention to the time subscripts, for we are interested in where the economy is, where it was, and where it will be).

Begin with the capital-output ratio version of the production function:

$$\frac{Y_t}{L_t} = \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}}(E_t)$$

Since the economy is on its balanced-growth path, it satisfies the equilibrium condition $K/Y = s/(n + g + \delta)$. Substitute that in:

$$\frac{Y_t}{L_t} = \left(\frac{s}{n + g + \delta}\right)^{\frac{\alpha}{1-\alpha}}(E_t)$$

But s, n, g, δ, and α are all constants, and so $[s/(n + g + \delta)]^{\alpha/1-\alpha}$ is a constant. This tells us that along the balanced-growth path, output per worker is simply a constant multiple of the efficiency of labor, with the multiple equal to

$$\left(\frac{s}{n + g + \delta}\right)^{\frac{\alpha}{1-\alpha}}$$

Over time, the efficiency of labor grows. Each year it is g percent higher than the last year. Since along the balanced-growth path output per worker Y/L is just a

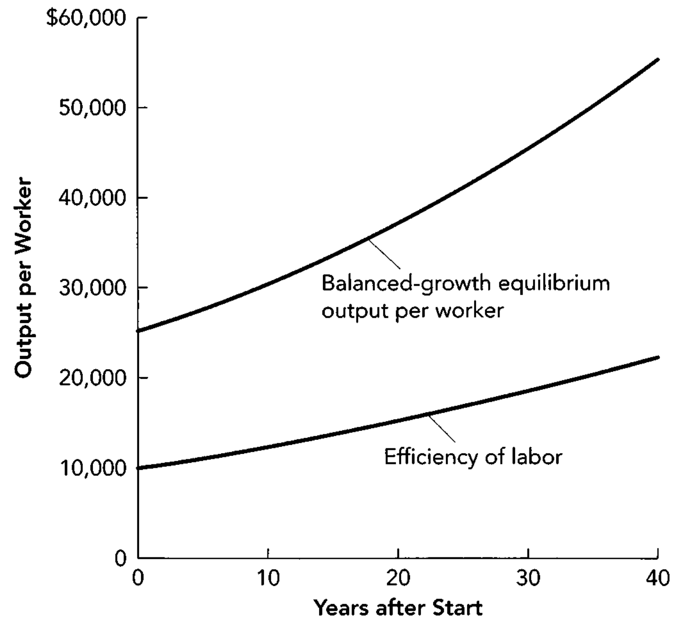

FIGURE 4.8
Balanced Growth: Output per Worker and the Efficiency of Labor
Along its balanced-growth path, the level of output per worker is a constant multiple of the efficiency of labor. What that multiple is depends on all the parameters of the growth model: the saving rate *s*, the labor-force growth rate *n*, the efficiency-of-labor growth rate *g*, the depreciation rate δ, and the diminishing-returns-to-investment parameter α.

constant multiple of the efficiency of labor, it too must be growing at the same proportional rate g. Figure 4.8 shows the pattern of balanced-growth output per worker and the efficiency of labor.

We now see how capital intensity and technological and organizational progress drive economic growth. Capital intensity — the economy's capital-output ratio — determines what multiple output per worker Y/L is of the current efficiency of labor E. Things that increase capital intensity — raise the capital-output ratio — make balanced-growth output per worker a higher multiple of the efficiency of labor, and so make the economy richer. Things that reduce capital intensity make balanced-growth output per worker a lower multiple of the efficiency of labor, and so make the economy poorer.

Suppose that α is 1/2, so that $\alpha/(1 - \alpha)$ is 1, and that $s = n + g + \delta$, so that the balanced-growth capital-output ratio is 1. Then balanced-growth output per worker is simply equal to the efficiency of labor. But if we consider another economy with twice the saving rate s, its balanced-growth capital-output ratio is 2, and its balanced-growth level of output per worker is twice the level of the efficiency of labor.

The higher is the parameter α — that is, the slower diminishing returns to investment set in — the stronger is the effect of changes in the economy's balanced-growth capital intensity on the level of output per worker.

- Suppose that the balanced-growth capital-output ratio is 4. Then if α is 1/3, $\alpha/(1 - \alpha)$ is 1/2, and the level of output per worker is twice the level of the efficiency of labor. Economists think that 1/3 is a reasonable parameter value for the United States today.

- By contrast, if α is 1/2, $\alpha/(1-\alpha)$ is equal to 1, and again with a balanced-growth capital-output ratio of 4, the level of output per worker is fully four times the level of the efficiency of labor. Economists think that 1/2 is a reasonable parameter value for the United States a century ago or for relatively poor countries today.

Note — this is important — that changes in the economy's capital intensity shift the balanced-growth path up or down to a different multiple of the efficiency of labor, but the growth rate of Y/L along the balanced-growth path is simply the rate of growth g of the efficiency of labor E. The material standard of living grows at the same rate as labor efficiency. To change the very long run growth rate of the economy you need to change how fast the efficiency of labor grows. Changes in the economy that merely alter the capital-output ratio will not do it.

This is what tells us that technology, organization, worker skills — all those things that increase the efficiency of labor and keep on increasing it — are ultimately more important to growth in output per worker than saving and investment. The U.S. economy experienced a large increase in its capital-output ratio in the late nineteenth century. It may be experiencing a similar increase now, as we invest more and more in computers. But the Gilded Age industrialization came to an end, and the information technology revolution will run its course. Aside from these episodes, it is growth in the efficiency of labor E that sustains and accounts for the lion's share of long-run economic growth.

We are now finished with our analysis of the economy's balanced-growth path. We see that calculating output per worker when the economy is on its balanced-growth path is a straightforward three-step procedure:

1. Calculate the balanced-growth equilibrium capital-output ratio $s/(n+g+\delta)$, the saving rate divided by the sum of the labor-force growth rate, the efficiency of labor growth rate, and the depreciation rate.
2. Raise the balanced-growth capital-output ratio to the $\alpha/(1-\alpha)$ power, where α is the diminishing-returns-to-investment parameter in the production function.
3. Multiply the result by the current value of the efficiency of labor E.

The result is the value of output per worker:

$$\frac{Y_t}{L_t} = \left(\frac{s}{n+g+\delta}\right)^{\frac{\alpha}{1-\alpha}}(E_t)$$

An example is given in Box 4.5.

CALCULATING EQUILIBRIUM OUTPUT PER WORKER: AN EXAMPLE

4.5

To see how to use the expression for output per worker when the economy is on its balanced-growth path,

$$\frac{Y_t}{L_t} = \left(\frac{s}{n+g+\delta}\right)^{\frac{\alpha}{1-\alpha}}(E_t)$$

let's work through an example. Suppose that the economy's labor-force growth rate n is 1 percent per year, the efficiency-of-labor growth rate g is 2 percent per year, and the depreciation rate δ is 3 percent per year. Suppose further that the diminishing-returns-to-investment parameter α is 1/2, and the economy's saving-investment rate s is 18 percent.

Then the balanced-growth equilibrium capital-output ratio $s/(n + g + \delta)$ equals 3, and $\alpha/(1 - \alpha)$ equals 1. Substituting these values into the equation above,

$$\frac{Y_t}{L_t} = (3)^1 (E_t)$$

$$\frac{Y_t}{L_t} = 3E_t$$

For these parameter values, balanced-growth output per worker is simply three times the efficiency of labor, whatever the value of the efficiency of labor is. When the efficiency of labor is \$10,000 per year, balanced-growth output per worker is \$30,000 per year. When the efficiency of labor rises to \$20,000 per year, balanced-growth output per worker rises to \$60,000 per year.

Over time, because balanced-growth output per worker is a constant multiple of the efficiency of labor, its growth rate is the same as g, the growth rate of the efficiency of labor, 2 percent per year.

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The implications of the balanced-growth capital-output ratio for the balanced-growth level of output per worker, and how that level changes over time, can be seen in an alternative, diagrammatic way. Take a look at Figure 4.9. As in Figure 4.5, draw the production-function curve that shows output per worker Y/L as a function of capital per worker K/L for the current level of the efficiency of labor E_t. In addition, as in Figure 4.5, draw the line that shows where the capital-output ratio

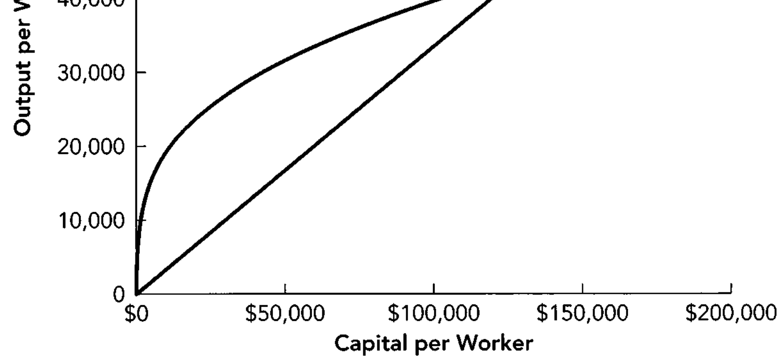


FIGURE 4.9
Calculating Balanced-Growth Output per Worker
The economy is on its balanced-growth path at that level of capital per worker and output per worker at which the capital-output ratio is equal to its equilibrium value.

is equal to its balanced-growth equilibrium value, $K/Y = s/(n + g + \delta)$. This line starts at the bottom left origin point (0, 0) and climbs toward the upper right. Because K/L is on the horizontal axis and Y/L is on the vertical axis, the slope of the line is not K/Y but instead Y/K or $(n + g + \delta)/s$.

Look once again at where the curves cross. That point shows the current level of output per worker along the balanced-growth path. Output per worker is given by the production function for the current levels of capital per worker and the efficiency of labor. And the capital-output ratio is at its balanced-growth path level. Anything that increases the balanced-growth capital-output ratio will lower Y/K so rotate the equilibrium line clockwise raising the balanced-growth path level of output per worker. Anything that decreases the balanced-growth capital output ratio rotates the equilibrium line counterclockwise. It thus lowers the level of output per worker for the given value of the efficiency of labor E.

Over time the efficiency of labor increases. As the efficiency of labor increases, the production-function curve in Figure 4.9 will shift up and out to the right. Over time, therefore, the balanced-growth path equilibrium levels of output per worker and capital per worker levels will rise as the economy climbs up and to the right along the constant balanced-growth equilibrium line.

Off the Balanced-Growth Path

What if the economy is not on its balanced-growth path? How can we use a model which assumes that the economy is on its balanced-growth path to analyze a situation in which the economy is *not* on that path? We still can use the model — and this is an important part of the magic of economics — because being on the balanced-growth path is an *equilibrium condition*. In an economic model, the thing to do if an equilibrium condition is not satisfied is to wait and, after a while, look again. When we look again, it will be satisfied.

Whenever the capital-output ratio K/Y is above its balanced-growth equilibrium value $s/(n + g + \delta)$, K/Y is falling: Investment is insufficient to keep the capital stock growing as fast as output. Whenever K/Y is below its balanced-growth equilibrium value, K/Y is rising: Capital stock growth outruns output. Figure 4.10 on page 106 gives an indication of how this process of **convergence** to the balanced-growth value proceeds. And as the capital-output ratio converges to its balanced-growth value, so does the economy's level of output per worker converge to its balanced-growth path.

convergence

The tendency for a country to approach its balanced-growth path with a constant capital-output ratio.

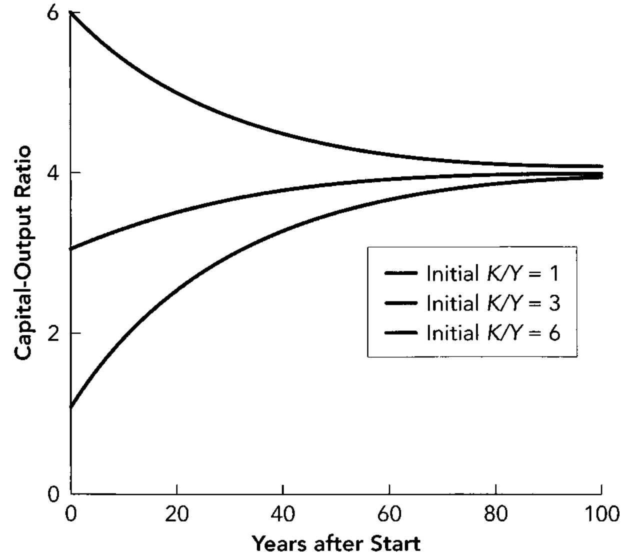
The fact that an economy converges to its balanced-growth path makes analyzing the long-run growth of an economy not on its balanced-growth path relatively easy as well:

1. Calculate the balanced-growth path.
2. From the balanced-growth path, forecast the future of the economy: If the economy is on its balanced-growth path today, it will stay on that path in the future (unless some of the parameters — n, g, δ, s, and α — change). If the economy is not on its balanced-growth path today, it is heading for that path and will get there eventually. But as Figure 4.10 points out, decades may pass before an economy finally gets on that balanced-growth path.

Thus economic forecasting becomes simple. All you have to do is predict that the economy will head for its balanced-growth path, and calculate what the balanced-growth path is.

FIGURE 4.10
Convergence to a Balanced-Growth Capital-Output Ratio of 4

Suppose the balanced-growth equilibrium capital-output ratio is 4. Whether the capital-output ratio starts above or below its balanced-growth equilibrium value, it converges to the level equal to $s/(n + g + \delta)$.



How Fast the Economy Heads for Its Balanced-Growth Path

How fast does an economy head for its balanced-growth path? We assert — but will not derive — that a fraction $(1 - \alpha)(n + g + \delta)$ of the gap between its current position and the balanced-growth path will be closed each year. If $(1 - \alpha)(n + g + \delta)$ turns out to be equal to 0.04, the capital-output ratio will close approximately 4 percent of the gap between its current level and its balanced-growth value in a year. According to the *rule of* 72 (see Box 4.4) an economy closing 4 percent of the gap between its current and its equilibrium value each year will move halfway to equilibrium in 72/4, or 18, years. An example is given in Box 4.6. The convergence of an economy following the Solow growth model to its balanced-growth path does not happen overnight or in a year. It is a matter of decades. The Solow growth model is definitely a long-run model.

4.6

CONVERGING TO THE BALANCED-GROWTH PATH: AN EXAMPLE

Consider an economy in which the rate of labor-force growth n = 1 percent per year, in which the efficiency of labor grows at a rate g = 2 percent per year, in which the depreciation rate δ = 5 percent per year, and in which the diminishing-returns-to-investment parameter α = 1/2.

This economy will, according to the Solow growth model, each year close a fraction of the gap between its current capital-output ratio and its balanced-growth capital-output ratio equal to

$$(1 - \alpha)(n + g + \delta) = (1 - 1/2)(0.01 + 0.02 + 0.05) = 0.04$$

or 4 percent per year. According to the rule of 72, the economy will close half of the gap to its balanced-growth path in 18 years.

◆

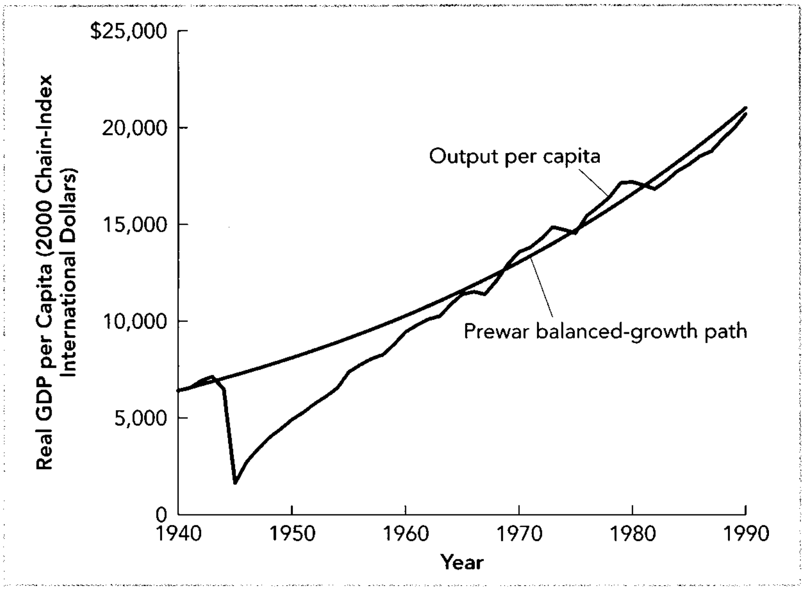


FIGURE 4.11

The Return of the West German Economy to Its Balanced-Growth Path

Economies do converge to and then remain on their balanced-growth paths. The West German economy after World War II is a case in point.

Source: J. Bradford DeLong and Barry Eichengreen, "The Marshall Plan: History's Most Successful Structural Adjustment Programme," in Rüdiger Dornbusch, Willhelm Nolling, and Richard Layard, eds., *Postwar Economic Reconstruction and Lessons for the East Today* (Cambridge, MA: MIT Press, 1993), pp. 189–230.

We can see such convergence in action in many places and times. For example, consider the post–World War II history of West Germany. The defeat of the Nazis left the German economy at the end of World War II in ruins. Output per worker was less than one-third of its prewar level. The economy's capital stock had been wrecked and devastated by three years of American and British bombing and then by the ground campaigns of the last six months of the war. But in the years immediately after the war, the West German economy's capital-output ratio rapidly grew and converged back to its prewar value. As Figure 4.11 shows, within 12 years the West German economy had closed half the gap back to its pre–World War II growth path. And within 30 years the West German economy had effectively closed the entire gap between where it had started at the end of World War II and its balanced-growth path.

RECAP UNDERSTANDING THE GROWTH MODEL

According to the Solow growth model, capital intensity and growth in the efficiency of labor together determine the destiny of an economy. The value of the balanced-growth equilibrium capital-output ratio and the economy's diminishing-returns-to-investment parameter determine the multiple that balanced-growth output per worker is of the current efficiency of labor. The growth rate of output per worker along the economy's balanced-growth path is equal to the growth rate of the efficiency of labor. And if the economy is not on its balanced-growth path, the Solow growth model tells us that it is converging to it — although this convergence takes decades, not years.

4.4 USING THE SOLOW GROWTH MODEL

Up until now we have assumed that all the parameters of the Solow growth model are unchanging. But what if one or more of them were to shift? What if the labor-force growth rate were to rise, or the rate of technological progress to fall? The principal use of the Solow growth model is to analyze questions like these: how changes in the economic environment and in economic policy will affect an economy's long-run levels and growth path of output per worker Y/L.

Let's consider, as examples, several such shifts: an increase in the growth rate of the labor force n, a change in the economy's saving-investment rate s, and a change in the growth rate of labor efficiency g. All of these will have effects on the balanced-growth path level of output per worker. But only one — the change in the growth rate of labor efficiency — will permanently affect the growth rate of the economy.

The Labor-Force Growth Rate

Real-world economies exhibit profound shifts in labor-force growth. The average woman in India today has only half the number of children that the average woman in India had only half a century ago. The U.S. labor force in the early eighteenth century grew at nearly 3 percent per year, doubling every 24 years. Today the U.S. labor force grows at 1 percent per year. Changes in the level of prosperity, changes in the freedom of migration, changes in the status of women that open up new categories of jobs to them (Supreme Court Justice Sandra Day O'Connor could not get a private-sector legal job in San Francisco when she graduated from Stanford Law School even with her amazingly high class rank), changes in the average age of marriage or the availability of birth control that change fertility — all of these have powerful effects on economies' rates of labor-force growth.

What effects do such changes have on output per worker Y/L — on our measure of material prosperity? The faster the growth rate of the labor force n, the lower will be the economy's balanced-growth capital-output ratio $s/(n + g + \delta)$. Why? Because each new worker who joins the labor force must be equipped with enough capital to be productive and to, on average, match the productivity of his or her peers. The faster the rate of growth of the labor force, the larger the share of current investment that must go to equip new members of the labor force with the capital they need to be productive. Thus the lower will be the amount of investment that can be devoted to building up the average ratio of capital to output.

A sudden and permanent increase in the rate of growth of the labor force will lower the level of output per worker on the balanced-growth path. How large will the long-run change in the level of output be, relative to what would have happened had labor-force growth not increased? It is straightforward to calculate if we know the other parameter values, as is shown in Box 4.7.

How important is all this in the real world? Does a high rate of labor-force growth play a role in making countries relatively poor not just in economists' models but in reality? It turns out that it is important, as Figure 4.12 on page 110 shows. Of the 22 countries in the world with output-per-worker levels at least half of the U.S. level, 18 have labor-force growth rates of less than 2 percent per year, and 12 have labor-force growth rates of less than 1 percent per year. The additional investment requirements imposed by rapid labor-force growth are a powerful reducer of capital intensity and a powerful obstacle to rapid economic growth.

AN INCREASE IN THE LABOR-FORCE GROWTH RATE: AN EXAMPLE

4.7

Consider an economy in which the parameter α is 1/2, the efficiency of labor growth rate g is 1.5 percent per year, the depreciation rate δ is 3.5 percent per year, and the saving rate s is 21 percent. Suppose that the labor-force growth rate suddenly and permanently increases from 1 to 2 percent per year.

Before the increase in the labor-force growth rate, the balanced-growth equilibrium capital-output ratio was

$$\frac{s}{n+g+\delta} = \frac{0.21}{0.01 + 0.015 + 0.035} = \frac{0.21}{0.06} = 3.5$$

After the increase in the labor-force growth rate, the new balanced-growth equilibrium capital-output ratio will be

$$\frac{s}{n+g+\delta} = \frac{0.21}{0.02 + 0.015 + 0.035} = \frac{0.21}{0.07} = 3$$

Before the increase in labor-force growth, the level of output per worker along the balanced-growth path was equal to

$$\frac{Y_t}{L_t} = \left(\frac{s}{n+g+\delta}\right)^{\left(\frac{\alpha}{1-\alpha}\right)}(E_t) = (3.5)^{\left(\frac{1/2}{1-1/2}\right)}(E_t) = (3.5)^1(E_t) = 3.5\,E_t$$

After the increase in labor-force growth, the level of output per worker along the balanced-growth path will be equal to

$$\frac{Y_t}{L_t} = \left(\frac{s}{n+g+\delta}\right)^{\left(\frac{\alpha}{1-\alpha}\right)}(E_t) = (3)^{\left(\frac{1/2}{1-1/2}\right)}(E_t) = (3)^1(E_t) = 3\,E_t$$

This fall in the balanced-growth path level of output per worker means that in the very long run — after the economy has converged to its new balanced-growth path — one-seventh of its economic prosperity has been lost because of the increase in the rate of labor-force growth.

In the short run of a year or two, however, such an increase in the labor-force growth rate has little effect on output per worker. In the months and years after labor-force growth increases, the increased rate of labor-force growth has had no time to affect the economy's capital-output ratio. But over decades and generations, the capital-output ratio will fall as it converges to its new balanced-growth equilibrium level.

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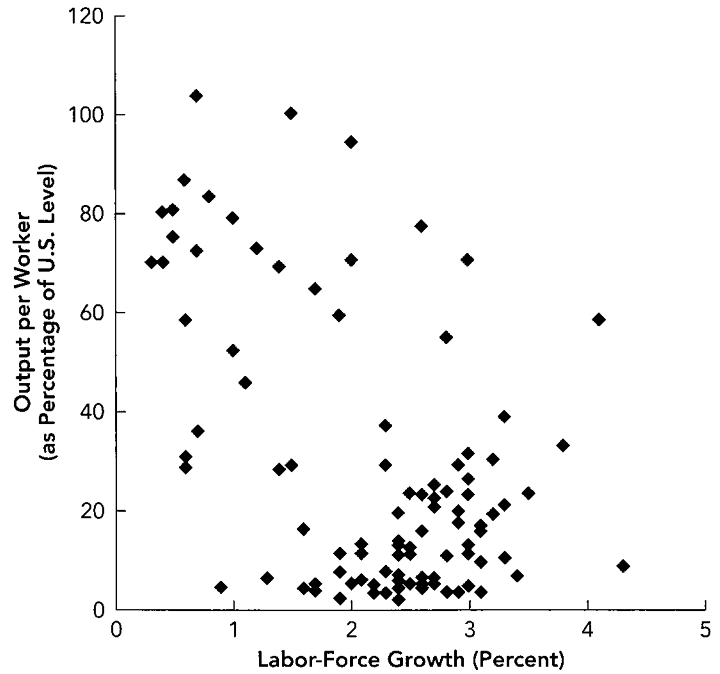
A sudden and permanent change in the rate of growth of the labor force will immediately and substantially change the level of output per worker along the economy's balanced-growth path: It will shift the balanced-growth path for output per worker up (if labor-force growth falls) or down (if labor-force growth rises). But there is no corresponding immediate jump in the actual level of output per worker in the economy. Output per worker doesn't immediately jump — it is just that the shift in the balanced-growth path means that the economy is no longer in its Solow growth model long-run equilibrium.

It takes time, decades and generations, for the economy to converge to its new balanced-growth path equilibrium, and thus for the shift in labor-force

FIGURE 4.12

The Labor-Force Growth Rate Matters

The average country with a labor-force growth rate of less than 1 percent per year has an output-per-worker level that is nearly 60 percent of the U.S. level. The average country with a labor-force growth rate of more than 3 percent per year has an output-per-worker level that is only 20 percent of the U.S. level. To some degree poor countries have fast labor-force growth rates because they are poor: Causation runs both ways. Nevertheless, high labor-force growth rates are a powerful cause of low capital intensity and relative poverty in the world today.



Source: Authors' calculations from Alan Heston, Robert Summers, and Bettina Aten, Penn World Table Version 6.1, Center for International Comparisons at the University of Pennsylvania (CICUP), October 2002, www.nber.org.

growth to affect average prosperity and living standards. But the time needed is reason for governments that value their countries' long-run prosperity to take steps now (or even sooner) to start assisting the demographic transition to low levels of population growth. Female education, social changes that provide women with more opportunities than being a housewife, inexpensive birth control — all these pay large long-run dividends as far as national prosperity levels are concerned.

U.S. President John F. Kennedy used to tell a story of a retired French general, Marshal Lyautey, "who once asked his gardener to plant a tree. The gardener objected that the tree was slow-growing and would not reach maturity for a hundred years. The Marshal replied, 'In that case, there is no time to lose, plant it this afternoon.'"

The Saving Rate and the Price of Capital Goods

The most frequent sources of shifts in the parameters of the Solow growth model are shifts in the economy's saving-investment rate. The rise of politicians eager to promise goodies — whether new spending programs or tax cuts — to voters induces large government budget deficits, which can be a persistent drag on an economy's saving rate and its rate of capital accumulation. Foreigners become alternately overoptimistic and overpessimistic about the value of investing in our country, and so either foreign saving adds to or foreign *capital flight* reduces our own saving-investment rate. And changes in households' fears of future economic disaster, in households' access to credit, or in any of numerous other factors change the share of household income that is saved and invested as well.

What effects do changes in saving rates have on the balanced-growth path levels of Y/L? The higher the share of national product devoted to saving and gross investment — the higher is s — the higher will be the economy's balanced-growth capital-output ratio $s/(n + g + \delta)$. Why? Because more investment increases the amount of new capital that can be devoted to building up the average ratio of capital to output. Double the share of national product spent on gross investment, and you will find that you have doubled the economy's capital intensity, or its average ratio of capital to output.

One way to think about this is that the equilibrium is the point at which the economy's investment effort and its investment requirements are in balance. Investment effort is simply s, the share of total output devoted to saving and investment. Investment requirements are the amount of new capital needed to replace depreciated and worn-out machines and buildings, plus the amount needed to equip new workers who increase the labor force, plus the amount needed to keep the stock of tools and machines at the disposal of workers increasing at the same rate as the efficiency of their labor. So double the saving rate and you double the balanced-growth capital-output ratio, as seen in Box 4.8.

4.8

AN INCREASE IN THE SAVING-INVESTMENT RATE: AN EXAMPLE

To see how an increase in the economy's saving rate s changes the balanced-growth path for output per worker, consider an economy in which the parameter α is 2/3, the rate of labor-force growth n is 1 percent per year, the rate of labor efficiency growth g is 1.5 percent per year, and the depreciation rate δ is 3.5 percent per year. Suppose that the saving rate s, which was 18 percent, suddenly and permanently jumped to 24 percent of output.

Before the increase in the saving rate, when s was 18 percent, the balanced-growth equilibrium capital-output ratio was

$$\frac{s}{n + g + \delta} = \frac{0.18}{0.01 + 0.015 + 0.035} = 3$$

After the increase in the saving rate, the new balanced-growth equilibrium capital-output ratio will be

$$\frac{s}{n + g + \delta} = \frac{0.24}{0.01 + 0.015 + 0.035} = 4$$

Before the increase in saving, the balanced-growth path for output per worker was

$$\frac{Y_t}{L_t} = \left(\frac{s}{n + g + \delta}\right)^{\left(\frac{\alpha}{1 - \alpha}\right)}(E_t) = (3)^{\left(\frac{2/3}{1 - 2/3}\right)}(E_t) = (3)^2(E_t) = 9E_t$$

After the increase in saving, the balanced-growth path for output per worker will be

$$\frac{Y_t}{L_t} = \left(\frac{s}{n + g + \delta}\right)^{\left(\frac{\alpha}{1 - \alpha}\right)}(E_t) = (4)^{\left(\frac{2/3}{1 - 2/3}\right)}(E_t) = (4)^2(E_t) = 16E_t$$

Divide the second equation by the first. We see that balanced-growth path output per worker after the jump in the saving rate is higher by a factor of 16/9, or fully 78 percent higher.

Just after the increase in saving has taken place, the economy is still on its old, balanced-growth path. But as decades and generations pass the economy converges to its new balanced-growth path, where output per worker is not 9 but 16 times the efficiency of labor. The jump in capital intensity makes an enormous difference for the economy's relative prosperity.

Note that this example has been constructed to make the effects of capital intensity on relative prosperity large: The high value for the diminishing-returns-to-investment parameter α means that differences in capital intensity have large and powerful effects on output-per-worker levels.

But even here, the shift in saving and investment does not *permanently* raise the economy's growth rate. After the economy has settled onto its new balanced-growth path, the growth rate of output per worker returns to the same 1.5 percent per year that is g, the growth rate of the efficiency of labor.

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The same consequences as a low saving rate — a lower balanced-growth capital-output ratio — would follow from a country that makes the purchase of capital goods expensive. An abnormally high price of capital goods can translate a reasonably high saving effort into a remarkably low outcome in terms of actual gross additions to the real capital stock. The late economist Carlos Diaz-Alejandro placed the blame for much of Argentina's poor growth performance since World War II on trade policies that restricted imports and artificially boosted the price of capital goods. Economist Charles Jones reached the same conclusion for India. And economists Peter Klenow and Chang-Tai Hsieh argued that the world structure of prices that makes capital goods relatively expensive in poor countries plays a major role in blocking development.

How important is all this in the real world? Does a high rate of saving and investment play a role in making countries relatively rich not just in economists' models but in reality? It turns out that it is important indeed, as Figure 4.13 shows. Of the 22 countries in the world with output-per-worker levels at least half of the U.S. level, 19 have investment that is more than 20 percent of output. The high capital-output ratios generated by high investment efforts are a very powerful source of relative prosperity in the world today.

Growth Rate of the Efficiency of Labor

By far the most important impact on an economy's balanced-growth path values of output per worker, however, is from shifts in the growth rate of the efficiency of labor g. We already know that growth in the efficiency of labor is absolutely essential for sustained growth in output per worker and that changes in g are the only things that cause permanent changes in growth rates that cumulate indefinitely.

Recall yet one more time the capital-output ratio form of the production function:

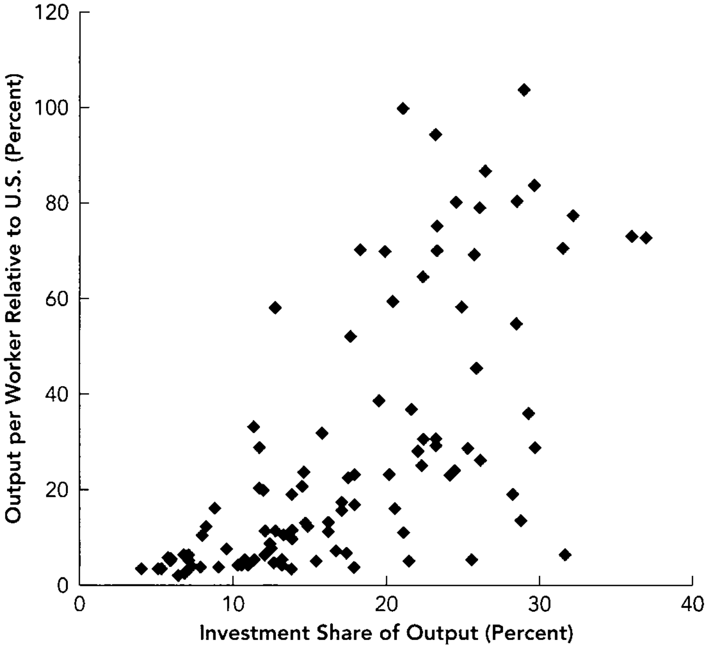
$$\frac{Y_t}{L_t} = \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}}(E_t)$$

The capital-output ratio K/Y is constant along the balanced-growth path. The returns-to-investment parameter α is constant. And so the balanced-growth path level of output per worker Y/L grows only if and only as fast as the efficiency of labor E grows.

FIGURE 4.13

Investment Shares of Output and Relative Prosperity The average country with an investment share of output of more than 25 percent has an output-per-worker level that is more than 70 percent of the U.S. level. The average country with an investment share of output of less than 15 percent has an output-per-worker level that is less than 15 percent of the U.S. level. This is not entirely due to a one-way relationship from a high investment effort to a high balanced-growth capital-output ratio: Countries are poor not just because they invest little; to some degree they invest little because they are poor. But much of the relationship is due to investment's effect on prosperity. High saving and investment rates are a very powerful cause of relative wealth in the world today.

Where is the United States on this graph? For these data it has an investment rate of 21 percent of GDP and an output-per-worker level equal (not surprisingly) to 100 percent of the U.S. level.



Source: Authors' calculations from the Penn World Table data constructed by Alan Heston, Robert Summers, and Bettina Aten, www.nber.org.

Increases or decreases in the rate of growth of the efficiency of labor g have effects on capital intensity that are in one sense just like changes in the rate of labor-force growth. An increase in the efficiency of labor growth rate g reduces the balanced-growth equilibrium capital-output ratio, just as an increase in labor-force growth did. And, as with a shift in labor-force growth, the level of output per worker after such a change in the labor efficiency growth rate begins the process of converging to its new balanced-growth path.

You might think that this means that an increase in g lowers output per worker Y/L — it lowers the capital-output ratio, after all. But you would be wrong. The effect on the capital-output ratio K/Y is only a small part of the story.

Changes in the efficiency of labor change the growth rate of output per worker along the balanced-growth path. In the very long run, no matter how large the

TABLE 4.2
Effects of Increases in Parameters on the Solow Growth Model

When there is an increase in the parameter . . .	The effect on . . . Equilibrium K/Y	Level of Y	Level of Y/L	Permanent Growth Rate of Y	Permanent Growth Rate of Y/L
s saving-investment rate	Increases	Increases	Increases	No change	No change
n labor-force growth rate	Decreases	Increases	Decreases	Increases	No change
δ depreciation rate	Decreases	Decreases	Decreases	No change	No change
g efficiency of labor growth rate	Decreases	Increases	Increases	Increases	Increases

effects of a shift in efficiency of labor growth g on the economy's capital-output ratio, these effects are overwhelmed by the direct effect of g on output per worker. It is the economy with a high rate of efficiency of labor force growth g that becomes by far the richest over time.

This is our most important conclusion. The growth rate of the standard of living — of output per worker — can change if and only if the growth rate of labor efficiency changes. Other factors — a higher saving-investment rate, lower labor-force growth rate, or lower depreciation rate — can shift output per worker up as noted in Table 4.2, but they do not permanently change the growth rate of output per worker. Only a change in the growth rate of labor efficiency can permanently change the growth rate of output per worker. If we are to increase the rate of growth of the standard of living, we must pursue policies that increase the rate at which labor efficiency grows — policies that enhance technological or organizational progress. Chapter 5 looks at centuries of economic history for examples of just those all-important changes in the growth rate of labor efficiency.

RECAP USING THE SOLOW GROWTH MODEL

Changes in the economic environment and in economic policy can have powerful effects on the economy's long-run economic growth path. In the Solow model we analyze the effects of such changes by looking at their effects on capital intensity and on the efficiency of labor. Shifts in the growth rate of the efficiency of labor have the most powerful effects: They change the long-run growth rate of the economy. Shifts in other parameters affect the economy's capital intensity, affect what multiple of the efficiency of labor the balanced-growth path of output per worker follows, and make the economy richer or poorer as it converges to a new, different balanced-growth path. But only a change in the growth rate of labor efficiency can produce a permanent change in the growth rate of output per worker.

Chapter Summary

1. One principal force driving long-run growth in output per worker is the set of improvements in the efficiency of labor springing from technological progress and advances in organization.
2. A second principal force driving long-run growth in output per worker is the increases in capital intensity, the ratio of the capital stock to output.
3. The balanced-growth equilibrium in the Solow growth model occurs when the capital output ratio K/Y is constant. When K/Y is constant, the capital stock and real output are growing at the same rate.
4. The Cobb-Douglas production function we use is
$$\frac{Y}{L} = \left(\frac{K}{L}\right)^{\alpha} E^{(1-\alpha)}$$
This function is equivalent to
$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\frac{\alpha}{1-\alpha}} (E)$$
An increase in the returns-to-investment parameter α makes the production function steeper. An increase in labor efficiency E makes the production function shift up.
5. In equilibrium, investment equals saving: $I = S = S^H + S^G + S^F$. We assume S/Y, the saving-investment rate s, is constant.
6. The balanced-growth equilibrium value of the capital output ratio K/Y is a constant equal to the saving rate s divided by the sum of the labor-force growth rate n, the labor efficiency growth rate g, and the depreciation rate δ: in balanced-growth equilibrium, $K/Y = s/(n + g + \delta)$.
7. If the economy's actual value of K/Y is initially greater than $s/(n + g + \delta)$, then K/Y will fall until it reaches its equilibrium value. If the economy's actual value of K/Y is initially less than $s/(n + g + \delta)$, then K/Y will rise until it reaches its equilibrium value. It can take decades or generations for K/Y to reach its balanced-growth equilibrium value.
8. An increase in the saving rate s, a decrease in the labor-force growth rate n, or a decrease in the depreciation rate δ increases output per worker Y/L. The growth rate of Y/L will accelerate as the economy moves to its new higher balanced-growth path. But once the economy is on its new balanced-growth path, output per worker will grow at the same rate as it did initially.
9. In balanced-growth equilibrium, the growth rate of output per worker equals the growth rate of labor efficiency g. So only an increase in the rate at which labor efficiency grows can produce a lasting increase in the rate of growth of output per worker.

Key Terms

economic growth (p. 82)
labor force (p. 83)
capital stock (p. 83)
efficiency of labor (p. 84)
capital intensity (p. 85)
balanced-growth path (p. 86)
production function (p. 87)
output per worker (p. 87)
saving rate (p. 91)
depreciation (p. 92)
capital-output ratio (p. 92)
balanced growth (p. 98)
balanced-growth equilibrium capital-output ratio (p. 98)
convergence (p. 105)

Analytical Exercises

1. Consider an economy in which the depreciation rate is 3 percent per year, the rate of population increase is 1 percent per year, the rate of technological progress is 1 percent per year, and the sum of household and foreign saving rates is 16 percent of GDP. Suppose that the government increases its budget deficit, which had been at 1 percent of GDP for a long time, to 3.5 percent of GDP and keeps it there indefinitely.
   a. What will be the effect of this shift in policy on the economy's equilibrium capital-output ratio?
   b. What will be the effect of this shift in policy on the economy's equilibrium balanced-growth path for

output per worker? How does your answer depend on the value of the diminishing-returns-to-investment parameter α?

c. Suppose that your forecast of output per worker 20 years in the future had been \$100,000. What is your new forecast of output per worker 20 years hence?

2. Suppose that a country has the production function

$$Y = K^{0.5}(LE)^{0.5}$$

a. Express output Y as a function of the level of the efficiency of labor E, the size of the labor force L, and the capital-output ratio K/Y.

b. What is the expression for output per worker Y/L?

3. Suppose that with the production function

$$Y = K^{0.5}(LE)^{0.5}$$

the depreciation rate on capital is 3 percent per year, the rate of population growth is 1 percent per year, and the rate of growth of the efficiency of labor is 1 percent per year.

a. Suppose that the saving rate is 10 percent of GDP. What is the equilibrium capital-output ratio? What is the value of output per worker on the balanced-growth path written as a function of the level of the efficiency of labor?

b. Suppose that the saving rate is 15 percent of GDP. What is the equilibrium capital-output ratio? What is the value of output per worker on the balanced-growth path?

c. Suppose that the saving rate is 20 percent of GDP. What is the equilibrium capital-output ratio? What is the value of output per worker on the balanced-growth path?

4. What happens to the equilibrium capital-output ratio if the rate of technological progress increases? Would the balanced-growth path of output per worker for the economy shift upward, shift downward, or remain in the same position?

5. Discuss the following proposition: "An increase in the saving rate will increase the equilibrium capital-output ratio and so increase both output per worker and the rate of economic growth in both the short run and the long run."

6. Would the balanced-growth path of output per worker for the economy shift upward, shift downward, or remain the same if capital were to become more durable — if the rate of depreciation on capital were to fall?

7. Suppose that a sudden disaster — an epidemic, say — reduces a country's population and labor force but does not affect its capital stock. Suppose further that the economy was on its equilibrium balanced-growth path before the epidemic.

a. What is the immediate effect of the epidemic on output per worker? On the total economywide level of output?

b. What happens subsequently?

8. According to the marginal productivity theory of distribution, in a competitive economy the real rate of return on a dollar's worth of capital — its profits or interest — is equal to capital's marginal productivity. With the production function

$$\frac{Y}{L} = \left(\frac{K}{L}\right)^{\alpha} E^{(1-\alpha)}$$

what is the marginal product of capital? That is, how much is total output (Y, not Y/L) boosted by the addition of an extra unit to the capital stock?

9. According to the marginal productivity theory of distribution, in a competitive economy the real rate of return on a dollar's worth of capital — its profits or interest — is equal to capital's marginal productivity. If this theory holds and the marginal productivity of capital is indeed

$$\frac{dY}{dK} = \alpha\frac{Y}{K}$$

how large are the total earnings received by capital? What share of total output will be received by the owners of capital as their income?

10. Suppose that environmental regulations lead to a slowdown in the rate of growth of the efficiency of labor in the production function but also lead to better environmental quality. Should we think of this as a "slowdown" in economic growth or not?

Policy Exercises

1. In the mid-1990s during the Clinton presidency the United States eliminated its federal budget deficit. The national saving rate was thus boosted by 4 percent of GDP, from 16 percent to 20 percent of real GDP. In the mid-1990s, the nation's rate of labor-force growth was 1 percent per year, the depreciation rate was 3 percent per year, the rate of increase of the efficiency of labor was 1 percent per year, and the diminishing-returns-to-investment parameter α was 1/3. Then when George W. Bush took office, the fiscal reforms of the Clinton administration were reversed, leading to deficits of 4 percent of GDP once again.

   a. Suppose that the federal budget deficit remains at 4 percent indefinitely. What will the U.S. economy's equilibrium capital-output ratio be? If the efficiency of labor in 2000 was $30,000 per year, what would be your forecast of output per worker in 2040?

   b. Suppose that George W. Bush had not taken office, and that Clinton's successor, Al Gore, and his successors had continued to run a balanced budget. What would be your calculation of the U.S. economy's balanced-growth equilibrium capital-output ratio? If the efficiency of labor in 2000 was $30,000 per year, what would be your forecast of output per worker in 2040?

2. How would your answers to question 1 change if your estimate of the diminishing-returns-to-investment parameter α was not 1/3 but 1/2 and if your estimate of the efficiency of labor in 2000 was not $30,000 but $15,000 a year?

3. How would your answers to question 1 change if your estimate of the diminishing-returns-to-investment parameter α was not 1/3 but 2/3?

4. What are the long-run costs as far as economic growth is concerned of a policy of taking money that could reduce the national debt — and thus add to national saving — and distributing it as tax cuts instead? What are the long-run benefits of such a policy? How can we decide whether such a policy is a good thing or not?

5. At the end of the 1990s it appeared that because of the computer revolution the rate of growth of the efficiency of labor in the United States had doubled, from 1 percent per year to 2 percent per year. Suppose this increase is permanent. And suppose the rate of labor-force growth remains constant at 1 percent per year, the depreciation rate remains constant at 3 percent per year, and the American saving rate (plus foreign capital invested in America) remains constant at 20 percent per year. Assume that the efficiency of labor in the United States in 2000 was $15,000 per year and that the diminishing-returns-to-investment parameter α was 1/3.

   a. What is the change in the balanced-growth equilibrium capital-output ratio? What is the new capital-output ratio?

   b. Would such a permanent acceleration in the rate of growth of the efficiency of labor change your forecast of the level of output per worker in 2040?

6. How would your answers to question 5 change if your estimate of the diminishing-returns-to-investment parameter α was not 1/3 but 1/2 and if your estimate of the efficiency of labor in 2000 was not $30,000 but $15,000 a year?

7. How would your answers to question 5 change if your estimate of the diminishing-returns-to-investment parameter α was not 1/3 but 2/3?

8. Output per worker in Mexico in the year 2000 was about $10,000 per year. Labor-force growth was 2.5 percent per year. The depreciation rate was 3 percent per year, the rate of growth of the efficiency of labor was 2.5 percent per year, and the saving rate was 16 percent of GDP. The diminishing-returns-to-investment parameter α is 0.5.

   a. What is Mexico's equilibrium capital-output ratio?

   b. Suppose that Mexico today is on its balanced-growth path. What is the current level of the efficiency of labor E?

   c. What is your forecast of output per worker in Mexico in 2040?

9. In the framework of question 8, how much does your forecast of output per worker in Mexico in 2040 increase if:

   a. Mexico's domestic saving rate remains unchanged but the nation is able to finance extra investment equal to 4 percent of GDP every year by borrowing from abroad?

   b. The labor-force growth rate immediately falls to 1 percent per year?

   c. Both *a* and *b* happen?

10. Consider an economy with a labor-force growth rate of 2 percent per year, a depreciation rate of 4 percent per year, a rate of growth of the efficiency of labor of 2 percent per year, and a saving rate of 16 percent of GDP. If the saving rate increases from 16 to 17 percent, what is the proportional increase in the equilibrium level of output per worker if the diminishing-returns-to-investment parameter α is 1/3? 1/2? 2/3? 3/4?

CHAPTER 5

The Reality of Economic Growth: History and Prospect

QUESTIONS

What is modern economic growth?

What was the post-1973 productivity growth slowdown? What were its causes?

Why has American growth been so rapid since 1995?

Why are some nations so (relatively) rich and other nations so (relatively) poor?

What policies can speed up economic growth? What policy mistakes can slow it down?

What are the prospects for successful and rapid economic development in tomorrow's world?

We are used to modern economic growth. We are used to having production rise by 3 percent to 4 percent each year and productivity rise by 2 percent to 3 percent each year. In our time, a year in which production stagnates or falls is unusual. In the United States, only 6 of the last 50 years have seen real GDP lower than that of the year before.

For most of human history, however, things have been very different. Since the invention of agriculture roughly 10,000 years ago (and, as far as we know, before that), economic progress was generally glacial or nonexistent. The transition to our modern era of growth took place about two centuries ago, with what is called the Industrial Revolution.

This chapter surveys the history of economic growth — especially of modern economic growth — and also attempts to peer into the future. It is informed by the models of economic growth set out in Chapter 4, but it does not depend on them; the theory tells us what questions to ask, but the questions and answers stand on their own.

The chapter opens with a survey of what the economy looked like before the Industrial Revolution, before the transition to the age of modern economic growth. It continues with the story of the Industrial Revolution and modern economic growth in the United States, before widening its view to take a look at modern economic growth all over the world. It concludes with a brief sketch of the relationship between economic policies and economic growth.

5.1 BEFORE MODERN ECONOMIC GROWTH

Before the Industrial Revolution

Taking what we know and what we guess about the economy from back in the deep mists of time up to today produces a picture like that of Table 5.1. The numbers in Table 5.1 are — save for the past century — guesses, and they are — save for the past three centuries — extremely shaky guesses. Nevertheless, they do tell a coherent and consistent story.

Industrial Revolution

The transformation of the British economy between 1750 and 1850 when, due to technological advances, largely handmade production was replaced by machine-made production.

Until the **Industrial Revolution** of the late eighteenth century began in Britain — until 1800 or so — the human population of the world grew only as rapidly as a glacier moves. Population growth between 5000 BC and AD 1800 averaged less than one-tenth of a percent per year. Nevertheless, the cumulative magnitude of population growth was impressive; over a long-enough time span even glaciers can move very far, and 7,000 years is a long time indeed. Preindustrial population growth carried the number of human beings alive on this planet from perhaps 5 million in 5000 BC to 900 million in AD 1800.

The glacial pace of human population growth before the Industrial Revolution was accompanied by complete or near-complete stagnation in median standards of living. Up until 1500, as best we can tell, there had been next to no growth in the material standard of living of the typical human for millennia. Even in 1800 the average human had a material standard of living (and an economic productivity level) at best twice that of the average human in the year 1.

The problem was not that there was no *technological progress*. There was. Humans have long been ingenious. Warrior, priestly, and bureaucratic elites in 1500 or 1800 lived much better than their counterparts in previous millennia had lived. But just because the ruling elite lived better does not mean that other people lived any better. From 4000 BC to at least AD 1500, the typical life expectancy at birth

TABLE 5.1
Economic Growth through Deep Time

Year	Population*	Real GDP per Capita†
5000 BC	5	$ 130
1000 BC	50	160
1 AD	170	135
1000	265	165
1500	425	175
1800	900	250
1900	1,625	850
1950	2,515	2,030
1975	4,080	4,640
2000	6,120	8,175

*World population in millions.

†Guesstimates of real GDP per capita measured in year-2000 international dollars.

Source: Joel Cohen, *How Many People Can the Earth Support?* (New York: Norton, 1995), plus authors' estimates.

was low (less than 30 years), and the typical adult human was short (5 feet, 4 inches or less, due to chronic undernutrition), lost his or her teeth early (although for him sugar was still a great luxury, George Washington needed false teeth because he was calcium-deprived and his body sacrificed the teeth to maintain the bones), and ate a remarkably monotonous diet (rations for the Roman legions in AD 1 consisted of two pounds of bread per soldier per day, plus salt, plus a pint or two of wine, plus "garnishes"; rations for the British navy in 1800 were worse — save that the liquor was stronger, and the diet was supplemented by weevils in the crackers and enough fruit and vegetables to fight off scurvy).

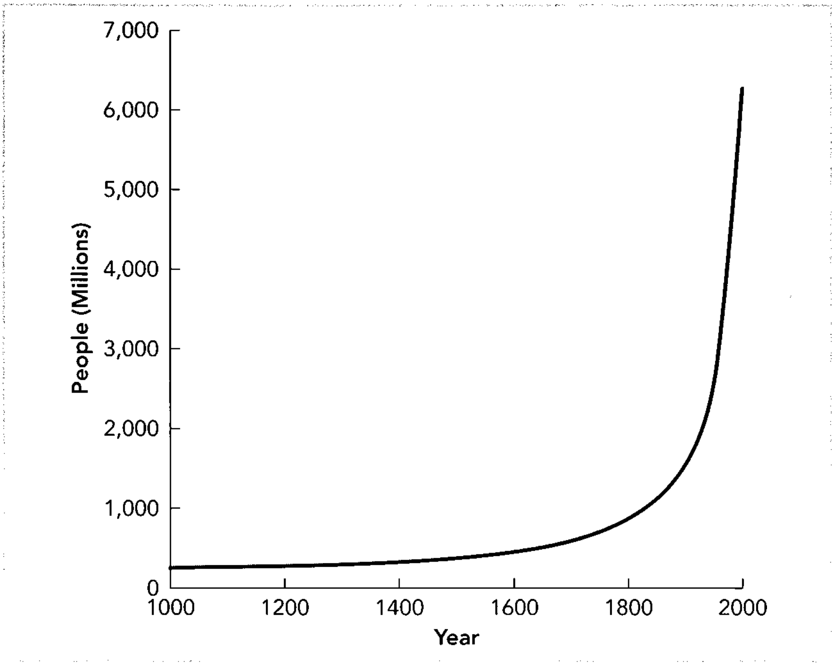
Only after 1800 do we see large, sustained increases in worldwide standards of living. Worldwide, output per capita grew at perhaps 0.15 percent per year between 1500 and 1800. It grew at roughly 1 percent per year worldwide between 1800 and 1900. And, as Table 5.1 implies, material output per capita has grown at an average pace of roughly 2 percent per year, worldwide, since 1900.

It is after 1800 that we also see extraordinary growth in human numbers, as the population explosion depicted in Figure 5.1 took hold. The population explosion carried the total world population to 6 billion before the year 2000. Population growth on a world scale accelerated from a rate of 0.2 percent per year between 1500 and 1800, to 0.6 percent per year between 1800 and 1900, to 0.9 percent per year between 1900 and 1950, and 1.9 percent per year between 1950 and 1975 before the first slowing of the global rate of population growth — 1.6 percent per year from 1975 to 2000.

Premodern Economies

Why did no sustained increases in the material productivity of human labor occur before 1500? The principal reasons are two. Improvements in human technology quickly ran aground on a combination of (1) resource scarcity and (2) expanding populations.

FIGURE 5.1
World Population Growth since 1000
The growth of human population was very slow until approximately 1800. The boom in population since 1800 is called, not surprisingly, the population explosion.



Source: Joel Cohen, *How Many People Can the Earth Support?* (New York: Norton, 1995).

In Chapter 4 we saw that output-per-worker levels depended on two factors: the economy's capital intensity K/Y and the efficiency of labor E. Understand the determinants of these two factors, and you understand the level of output per worker Y/L through the equation

$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\frac{\alpha}{1-\alpha}} E$$

where, you recall, α is a parameter that tells us how fast diminishing returns to investment set in.

We also saw that in the long run each economy's capital intensity K/Y tended to approach some equilibrium value and then stay there. Sustained growth in output per worker must be driven by sustained increases in the efficiency of labor. So the question, "Why no sustained increases in productivity?" is the same as the question, "Why didn't the efficiency of labor grow?"

resource scarcity
Shortage in natural resources such as fertile land and water, relative to population.

The answer is that the efficiency of labor depends not just on the storehouse of physical and organizational technologies at workers' disposal, but also on the natural resources available to the average worker. In modern times our skills at handling materials are so great that natural resources play only a small role: Soil bad? Dump some nitrogen on it. Plants too dry? Pipe water in from 300 miles away to irrigate them. Technology and capital make natural **resource scarcity** a much less important phenomenon now than in the past. But back before the Industrial Revolution natural resources and their scarcity played a very important role. It is no accident that for most of recorded history humanity has lived primarily in the great river valleys of the Nile, the Tigris and Euphrates, the Indus, the Ganges, the Yangtze, and the Yellow River — good silt and regular supplies of water were that important.

Before the Industrial Revolution, as human populations grew, the stocks of known natural resources had to be divided among more and more people. Miners had to exploit lower quality metal ores, and farmers had to farm lesser quality agricultural land. Over time, overcut forests vanished. Where today are the cedars of Lebanon? Over time, land that had been irrigated too long and seen too much water evaporate in the hot summer sun became poisoned with salt. What we call the northern deserts of the Middle East were once called the "Fertile Crescent" and were the home to at least a third of humanity's farmers. The net effect of resource scarcity and human fertility was that, in spite of technological progress, the world average efficiency of labor was little, if any, greater in AD 1500 than in 1500 BC.

The idea that increases in technological capability induce increases in fertility that inevitably run into natural resource scarcity is one of the oldest ideas in economics. It was introduced early, before the end of the eighteenth century, by Thomas R. Malthus, who became the first academic professor of economics ever (Adam Smith had been a professor of moral philosophy) at the East India Company's Haileybury College.

Malthus saw a world in which inventions and higher living standards led to increases in the rate of population growth. With higher living standards there were more pregnancies and more pregnancies were successfully carried to term. Better nourished children (and adults) had a better chance of resisting diseases. Moreover, when incomes were high, new farmsteads were relatively plentiful, and getting the permission of one's father or elder brother to marry was easier. For these reasons — both social and biological — before 1800 a higher standard of living inevitably led to a faster rate of population growth. The faster rate of population growth increased the scarcity of natural resources, and so lowered productivity. After a burst of invention, population would rise and resource scarcity increase until once again people were so poor and malnourished that population growth was back at roughly zero — to less than one-tenth of one percent per year characteristic of the preindustrial age.

UNDERSTANDING THE ECONOMY BEFORE THE INDUSTRIAL REVOLUTION: DETAILS

In the models of Chapter 4, we identified the efficiency of labor with "technology" broadly understood: the storehouse of techniques for manipulating matter and forms of social organization that we can use to boost the productivity of the average worker. Before the Industrial Revolution humans were certainly inventive. "Technology" broadly understood improved to a remarkable degree in the millennia before 1800. So why were there no improvements in the efficiency of labor?

Because the model of Chapter 4 made a shortcut. We lumped the effect of natural resources on production into the efficiency of labor *E*. And before the Industrial Revolution, depletion of natural resources typically offset the beneficial effects of technological improvement. So the net effect was no improvement in the efficiency of labor: a constant value of *E*.

◆

The End of the Malthusian Age

Malthusian age

A period in which natural-resource scarcity limits any gains from increases in technology; a larger population becomes poor and malnourished, lowering their standard of living, and ultimately lowering population growth to zero.

Whether Malthus saw clearly what was in the past or not, he would have been astonished by what we have seen of his future. We do not live in a **Malthusian age**. For at least 200 years improvements in the efficiency of labor made possible by new technologies and better organizations have not been neutralized by natural resource scarcity.

However, a Malthusian age may return. Suppose that population in the twenty-first and twenty-second centuries grows as fast as population did in the twentieth century, when it grew at an average rate of 1.33 percent per year. The rule of 72 tells us that a population growing at 1.33 percent per year doubles in 72/1.33 = 54 years. Two hundred years is time for 3.7 doublings, enough time to multiply population about 14-fold. Take the year-2000 estimated population of 6.125 billion, multiply it by 14, and get about 86. If population grows at its twentieth-century average rate for the next two centuries, there will be nearly 90 billion people on Earth in 2200.

Surely, should such a population increase come to pass, resource scarcity would once again be a dominant feature of our world. For the past two centuries we economists have been justified in writing down production functions in which the limited supply of natural resources plays only a small part in the determination of productivity and production on a global scale. In a world with a population of 90 billion, we would probably not be justified in doing so. We would have to place more stress on the insights of Malthus.

However, it is much more likely that the age of the population explosion is almost over. Current United Nations projections forecast a rise in world population from a bit over 6 billion today to around 10 billion by 2050, and there population increase may well stop. Even in a country like India today, fertility is only a little above two children per potential mother. And in a wide section of the rich world from Japan to Italy, the average woman has fewer than two children in her lifetime.

What caused the end of the Malthusian age? How did humanity escape from the trap in which invention and ingenuity increased the numbers but not the material well-being of humans?

The key is that even in the Malthusian age the pace at which inventions occurred increased steadily. First of all, the population grew. Inventions made communication easier; especially after the invention of printing, knowledge could spread widely and quickly. More people meant more inventions: Two heads are better than one. The rate of technological progress slowly increased over the millennia. By about 1500 technological progress passed the point at which it could offset increased scarcity of natural resources due to population growth. Sustained increases not just in population but in the productivity of labor followed. As real incomes and standards of living showed sustained growth, what we call the **demographic transition** began.

demographic transition

A period in history which sees first a rise and then a fall in birth rates and a sharp fall in death rates as material standards of living increase above "subsistence" levels.

The Demographic Transition

At first the rise in material standards of living brought sharp increases in the rate of population growth: the population explosion. But as material standards of living rose far above subsistence, countries began to undergo the demographic transition, sketched out in Figure 5.2. Birth control meant that those who did not wish to have more children could exercise their choice. Parents began to find more satisfaction in having a few children and paying a great deal of attention to each. The resources of the average household continued to increase, but the number of children born fell. The long-run relationship between levels of productivity and

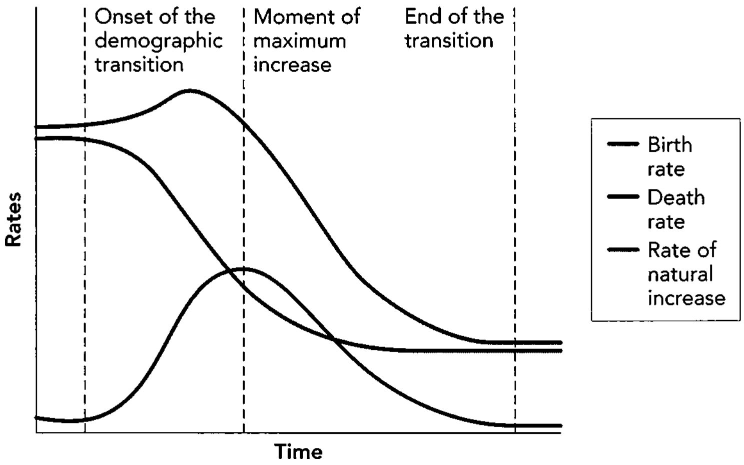


FIGURE 5.2

Stylized Picture of the Demographic Transition

The demographic transition sees, first, a rise in birth rates and a sharp fall in death rates as material standards of living increase above subsistence levels. But after a while birth rates start to decline rapidly too. The end of the demographic transition sees both birth and death rates at a relatively low level and the population nearly stable.

population growth rates was not — as Malthus thought — a spiral of ever-faster population growth rates as material standards of living increased. Instead, population growth rates peaked and began to decline.

In the world today not all countries have gone through their demographic transitions. Many countries are not rich enough to have begun the population growth declines seen in the second half of the demographic transition. Countries such as Nigeria, Iraq, Pakistan, and the Congo are currently projected to have population growth rates in excess of 2 percent per year over the next generation, as Figure 5.3 shows. But in a large group of developing countries like Thailand, China, Korea, and South Africa, population growth over the next generation is projected to be less than 1 percent per year. And in the industrialized countries like Japan, Italy, and Germany, populations are projected to stay nearly the same over the next generation.

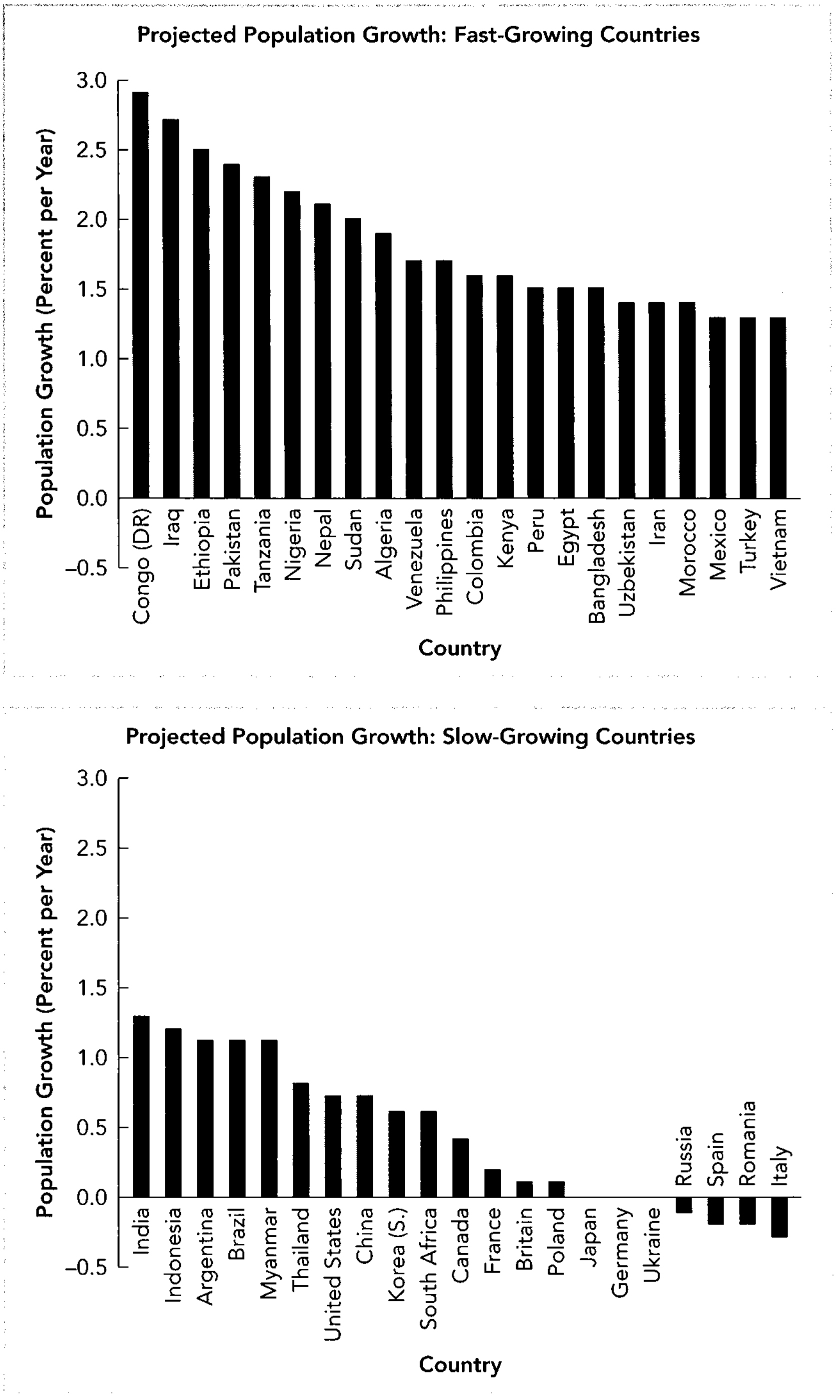
The Industrial Revolution

The century after 1750 saw the Industrial Revolution proper: the invention of the steam engine, the spinning jenny, the power loom, the hydraulic press, the railroad locomotive, the water turbine, and the electric motor, as well as the hot-air balloon, gas lighting, photography, and the sewing machine. But the Industrial Revolution was not just a burst of inventions. It was an economic transformation that revolutionized the process of invention as well. Since 1850 the pace of invention and innovation has further accelerated: steel making, the internal combustion engine, pasteurization, the typewriter, the cash register, the telephone, the automobile, the radio, the airplane, the tank, the limited-access highway, the photocopier, the computer, the pacemaker, nuclear weapons, superconductivity, genetic fingerprinting, and the human genome map. The coming of the Industrial Revolution marked the beginning of the era of modern economic growth in which new technological leaps routinely revolutionized industries and generated major improvements in living standards.

FIGURE 5.3

Expected Population Growth Rates, Present–2020

The population of India is projected to grow at 1.3 percent and that of China at 0.7 percent per year over the next generation. Demographers today believe that the world population has at most one more doubling to undergo before the demographic transition will have taken hold throughout the world.



Source: United Nations.

Yet it is important to recognize that the gulf that separates us in the world economy's industrial core from the citizens of Industrial Revolution Britain is much greater than the gulf that separated Britain in 1800 from medieval or ancient peasants and nobles. Economic historian N. F. R. Crafts calculated that 10 modern-day automobiles have more horsepower than all the steam engines of Britain in 1800, and the vehicles of Berkeley, California, today have more horsepower than the steam power of Britain in 1870. Growth during the Industrial Revolution was, by our standards, very slow. And the people who lived through the Industrial Revolution were very poor. Consider the standard of living portrayed in Charles Dickens's *Oliver Twist* — or Karl Marx's *Capital.*

The fact that Britain was the center of the Industrial Revolution meant that for a century, from 1800 to 1900, British levels of industrial productivity and British standards of living were the highest in the world. It also meant that English (rather than Hindi, Mandarin, French, or Spanish) became the world's de facto second language. But the technologies of the Industrial Revolution did not remain narrowly confined to Britain. Their spread was rapid to western Europe and the United States. It was less rapid — but still relatively thorough and complete — to southern and eastern Europe and, most interesting perhaps, Japan, as shown in Figure 5.4.

Why the Industrial Revolution took place in Britain and why it took place in the years around 1800 have long been and will long remain among the knottiest and most important puzzles in world economic history. The standard explanation sees two largely independent strands coming together: secure property rights for commercial and manufacturing property on the one hand, and modern science and technology on the other. The establishment of limited government, security of property, and freedom of contract in Britain after the Glorious Revolution of 1688 played a huge role. The creation of modern science and of the technological

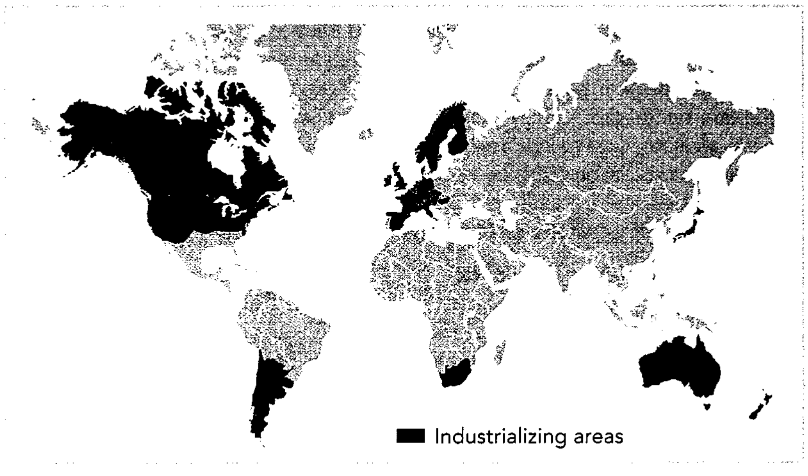


FIGURE 5.4

Industrializing Areas of the World, 1900

Perhaps the most important lesson to draw from this short look at economic history is that economists' standard growth models apply to a relatively narrow slice of time. For instance, the Solow growth model discussed in Chapter 4 does not illuminate very much regarding the period before 1800, yet it is very useful in analyzing what has happened over the past two centuries, as well as what is going on today with respect to the growth of different national economies.

Source: Steven Dorwick and J. Bradford DeLong, "Globalization and Convergence," in Michael D. Bordo, Alan M. Taylor, and Jeffrey G. Williamson, eds., *Globalization in Historical Perspective* (Chicago: University of Chicago Press, 2003).

tradition of sustained inquiry into how the world worked — free of constraints from theology — was the other.

Medieval China under the Sung Dynasty had a market economy and security of property, and Sung China did indeed produce more iron than Britain was to produce until the very end of the eighteenth century. Sung China was the heir of much technological innovation — printing, gunpowder, the compass, greatly improved forms of rice, river barges that in conjunction with the great civil engineering works like the Grand Canal made transport extraordinarily cheap — but no Scientific Revolution. Classical and Hellenistic Greece had the tradition of inquiry into how the world worked — but it would have been beneath the gentlemen who created Greek mathematics and science for them to devote themselves to improving processes of manufacture.

RECAP BEFORE MODERN ECONOMIC GROWTH

Up until 1800 human populations grew very slowly, and human living standards were stagnant. After 1800 we see sustained rises in living standards. And after 1800 human numbers grew as the population explosion took hold and carried our total population to 6 billion in 2004. At first the rise in material standards of living brought sharp increases in the rate of population growth: the population explosion. But as material standards of living rose far above subsistence, countries began to undergo the demographic transition, as population growth rates peaked and began to decline toward stability.

5.2 MODERN AMERICAN ECONOMIC GROWTH

Before 1500 human material standards of living and productivity levels rose at perhaps 0.01 percent per year. Between 1500 and 1800 they rose faster in the areas that were to become the industrial core of the modern world economy — first northwestern Europe and then northwestern Europe's settler colonies in North America — rising at a rate of perhaps 0.2 percent per year. The first half of the nineteenth century saw leading-edge economies' levels of productivity rise at about 0.5 percent per year, and the second half of the century saw productivity accelerate still further.

American Long-Run Growth, 1800–1973

The Pace of Economic Growth

Let us focus on the pace of long-run growth in what has been the world's leading-edge economy for the past 100 years: the United States. Growth in the years before and after the Civil War was faster than it had been in the first half of the nineteenth century. It accelerated still further as a second wave of industrialization took hold, fueled by new inventions and innovations such as steel making, organic chemicals manufacture, oil extraction, the internal combustion engine, pasteurization, the typewriter, the cash register, and the telephone. The accelerated pace of invention and economic growth has been maintained ever since.

Late-nineteenth-century *total factor productivity* growth was, by our standards, relatively slow: at most 1 percent per year. But the capital-output ratio increased mightily as America ceased being a country of riverboats and blacksmiths and became a country of railroads and steel mills. Once the railroads were built, the possibility of supplying an entire continental market from a large factory induced the entrepreneurs and robber barons (or is that "industrial statesmen"?) of what Mark Twain called America's Gilded Age to borrow and invest. On the other side of the capital market three important factors greased the skids and made it easy for Americans to boost their savings: the development of larger and better banks, the growing use and acceptability of bonds and other securities as forms of wealth, and the development of investment banking houses like Peabody-Morgan and then J. P. Morgan to make a market by assuring business investors that the financing for expansion would be there and assuring savers that their money would not be stolen.[1] Similar patterns of growth in labor productivity driven for a couple of generations by the mobilization of savings and a resulting increase in the capital-output ratio have been seen in other times and places: Germany before World Wars I and II, Japan from 1900 to 1970, and the rest of east Asia in the years since World War II.

But, as Chapter 4 argued, eventually the capital-output ratio reaches an equilibrium value, no matter how large the boost to the national saving-investment rate. And further growth depends not on increasing capital intensity but on increases in the efficiency of labor: education, invention, and reorganization.

productivity growth

The rate at which the economy's full-employment productivity expands from year to year as technology advances, as human capital increases, and as investment increases the economy's physical capital stock.

Throughout the nineteenth century and the first three-quarters of the twentieth century the measured pace of **productivity growth** continued to accelerate. The measured growth rate of output per worker rose from perhaps 0.5 percent per year between 1800 and 1870 to about 1.5 percent per year between 1870 and today. Growth has not been steady over that 135-year period. The growth rate was about 1.6 percent per year between 1870 and 1929 (the eve of the Great Depression), as is shown in Figure 5.5. Growth slowed slightly during the Great Depression and World War II decades — a measured growth rate of 1.4 percent per year from 1929 to 1950. But then it accelerated: The growth rate of output per worker between 1950 and 1973 in the United States was 2.1 percent per year. Next to none of the growth since 1929 was the result of increases in K/Y. Almost all of it was the result of increases in the efficiency of labor E. At least, that is what our best estimates of long-run economic growth tell us.

But should we believe what our best official and semiofficial estimates tell us? Perhaps not. Many economists believe that official estimates overstate inflation and understate real economic growth by 1 percent per year, in large part because national income accountants have a very hard time valuing the boost to productivity and standards of living generated by the invention of new goods and services. This was the conclusion reached by a blue-ribbon commission on consumer price measurement in the 1990s that was chaired by Stanford economist Michael Boskin. It is indeed very likely that true output-per-worker growth since 1870 has been even faster than our official statistics tell us. So for the average rate of output-per-worker growth in the United States since 1870, perhaps we should be thinking not of 1.5 percent per year, but rather of 2 to 2.5 percent per year.

Small differences in growth rates compounded over long periods of time make a huge difference. If Michael Boskin and his committee members are right (as we believe that they are), then those of us living in the United States today have a level of productivity — a material standard of living — somewhere between 14 and

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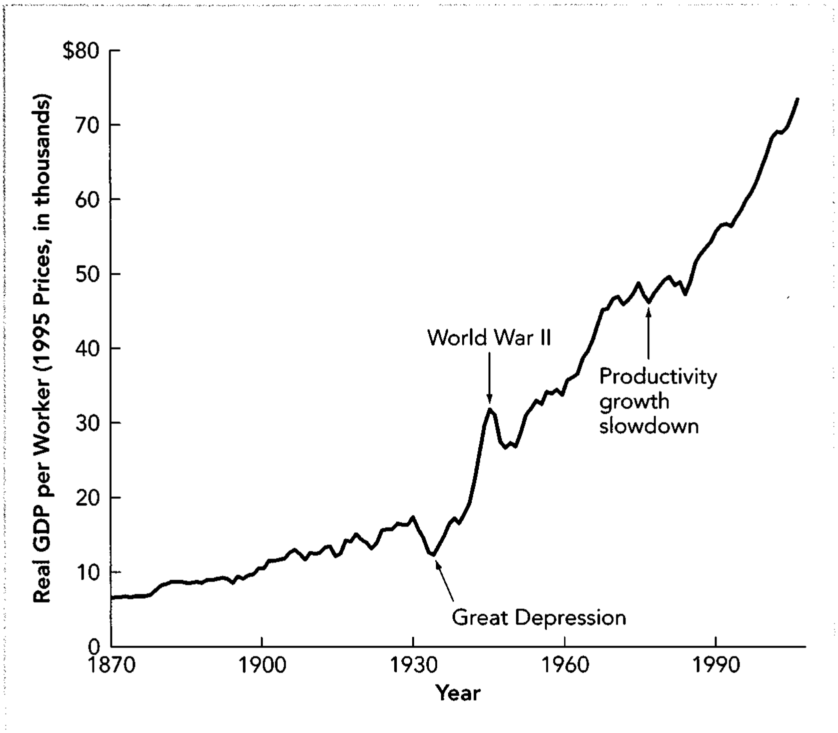
[1] As it sometimes was. Every student of American history should read Charles Francis Adams's *Chapters of Erie*, if only to marvel at the variety of financial frauds perpetrated by the executives of the Erie Railroad.

FIGURE 5.5

U.S. Measured Economic Growth: Real GDP per Worker, 1870–2004

With the exception of the Great Depression of the 1930s and the productivity growth slowdown period of the 1970s and 1980s, measured real GDP per worker in the United States has grown steadily with only minor interruptions.



Source: Authors' calculations from the 2004 edition of *The Economic Report of the President* (Washington, DC: Government Printing Office) and from *Historical Statistics of the United States* (Washington, DC: Government Printing Office, 1975).

25 times that of our counterparts in the late nineteenth century. For middle-class and richer consumers today such an estimate does not seem at all unreasonable. It takes only one-eighth as much time to earn the money to buy a hairbrush, one-twelfth as much time to earn the money to buy a chair, and one-thirty-fifth as much time to earn the money to buy a book today as it did in 1895 (see Table 5.2). And in 1895, no matter how long you worked, you couldn't earn enough money to buy a plane ticket, a TV, an iPod, a laptop computer, an automatic washing machine, an electric blender, or a microwave oven.

Consider that Nathan Meyer Rothschild — the richest man in the world in the first half of the nineteenth century — died in his fifties of an infected abscess in his back. Who is really richer, Nathan Meyer Rothschild in his day or a working-class American today who can go to a Kaiser Permanente clinic and get some penicillin? Who has a higher standard of living: a nineteenth-century robber baron with box seats to the theater to see *The Importance of Being Earnest* or a twenty-first-century American teenager ordering DVDs online from Netflix? Thinking about truly long run economic growth leads you to ask such questions, and the benefit is not in getting a single number as an answer but in thinking about what an answer might mean.

However, for the relatively poor of the world, or even of the United States, it is not reasonable to say that their incomes and material standards of living have multiplied to nearly as great an extent as those of America's great middle class. An

TABLE 5.2

Labor-Time Costs of Commodities, 1895 and 1997

Commodity	Time to Earn (Hours)* 1895	Time to Earn (Hours)* 1997	Productivity Multiple
Horatio Alger books (6 vols.)	21.0	0.6	35.0
One-speed bicycle	260.0	7.2	36.1
Cushioned office chair	24.0	2.0	12.0
100-piece dinner set	44.0	3.6	12.2
Hairbrush	16.0	2.0	8.0
Cane rocking chair	8.0	1.6	5.0
Solid gold locket	28.0	6.0	4.7
Encyclopaedia Britannica	140.0	4.0	35.0
Steinway piano	2,400.0	1,107.6	2.2
Sterling silver teaspoon	26.0	34.0	0.8
Oranges (dozen)	2.0	0.1	20.0
Ground beef (1 lb.)	0.8	0.2	4.0
Milk (1 gal.)	2.0	0.25	8.0
Television	∞	15.0	∞
Plane ticket: SFO-BOS	∞	20.0	∞
Antibiotic strep-throat cure	∞	1.0	∞
Dental X-ray	∞	2.0	∞
Laptop computer	∞	70.0	∞

*Time needed for an average worker to earn the purchase price of the commodity.

Source: 1895 Montgomery Ward catalogue and authors' calculations.

invention or innovation has no effect on people's material standard of living if they cannot afford to acquire it. The ability to fly from Minneapolis to Cancun in the middle of the winter is a very valuable thing, but only if you can afford to fly to Cancun.

Structural Change

Modern economic growth is also a shift in the kinds of things we do at work and play — in the way that we live. In the immediate aftermath of the Civil War perhaps half of all Americans were farmers. Today less than 2 percent of American workers are farmers and farm laborers; there are more gardeners, groundskeepers, and growers and maintainers of ornamental plants in the United States today than there are food-growing farmers and farm laborers. In the second half of the nineteenth century Americans traveled by foot, horse, wagon, train, and riverboat; at the end of the twentieth century, they traveled by foot (rarely), bicycle (rarely), automobile, bus, train, boat, and plane. Most Americans in the second half of the nineteenth century were literate, but very few had finished anything equivalent to today's high school. Modern economic growth is the large-scale shift of employment from agriculture to manufacturing and now to services. And it is the creation of large business organizations. At the start of the nineteenth century, a business with 100 people was a very large organization for its time.

America's Edge

Between approximately 1890 and 1930, or perhaps 1890 and 1950, a host of innovative technologies and business practices were adopted in the United States. Europeans speak of "Fordism": taking the part — Henry Ford's assembly lines in Detroit and his mass production of the Model-T Ford — for the whole. The fact that other industrial economies were unable to fully adopt American technologies of mass production and mass distribution in the first half of the twentieth century gave the United States a unique level of industrial dominance and technological leadership in the years after 1950.

This acceleration in American economic growth that placed America ahead of the rest of the industrialized countries seems, in the framework of Chapter 4, to have had two components. The first was a rise in America's investment effort propelled in part by the fact that more capital-intensive production processes — processes with a higher capital-output ratio — seemed more likely to be profitable in America, where you were serving a continent-sized market, than in Europe, where tariffs, language barriers, and other impediments to trade kept most production local and national. At some point in the late nineteenth and early twentieth centuries the American economy underwent what the late Stanford economist Moses Abramovitz and his colleague Paul David called a "great traverse" to a more capital-intensive growth path. This drive to a more capital-intensive growth path was also propelled, as Gavin Wright (yet a third Stanford economist) pointed out, by the extraordinary richness of the natural resource deposits discovered as the American continent was surveyed in the late nineteenth century.

The second component is the turn-of-the-last century acceleration in the rate of growth of the efficiency of labor, which in turn comes from two sources: the creation of the managerial and organizational structure of the modern corporation, on the one hand, and the routinization and industrialization of science and technology, on the other. When businesses began to spend serious money on their own research and development laboratories, the pace of technological innovation and thus of growth in the efficiency of labor sped up.

Why couldn't Great Britain, or the other industrial countries, maintain their lead or even keep up? Why was the twentieth century economically — and therefore also politically — an American century? Why didn't western Europe have its own Henry Ford, its own industrial R&D labs, and so forth?

Four factors appear to explain America's position at the leading edge of technology in the world economy throughout the twentieth century:

- The United States had an exceptional commitment to education — to schooling everyone (everyone who was white, that is; and boys more than girls) even in the largely rural economy of the nineteenth century and to making the achievement of a high school diploma the rule rather than the exception in the cities of the early twentieth century. An exceptionally educated workforce was the source of new ideas about how to make a better mousetrap, and it could quickly copy and adapt others' ideas as well.
- The United States was of extraordinarily large size — the largest market in the world. Thus the nation could take advantage of potential economies of scale in ways that other, smaller economies could not match. And this mattered for capital intensity.
- The United States was extraordinarily rich in natural resources, particularly energy. To the extent that energy-intensive and natural resource–intensive

industries were at the heart of early-twentieth-century industrial growth, the United States was again well positioned. By contrast, western Europe had been mined over and logged for at least a millennium.

- The United States avoided fratricide. Europeans killed each other and destroyed each other's buildings and factories (and we helped) at a historically unprecedented rate in the first half of the twentieth century. Your chances of meeting a violent or unnatural death in Europe between 1914 and 1945 were greater than in any other generation we know of except perhaps for those in the paths of the armies of Genghis Khan.

In the long run, however, western Europe did catch up to the United States. There is little difference in standards of living and productivity levels between western Europe and the United States today. Americans have somewhat more things and bigger houses but work longer hours and have fewer public services; Europeans have longer vacations and better public transportation but fewer opportunities to work and a harder time living in the suburbs.

Up until 1973, with the important exception of the Great Depression, the picture of American economic growth since the Industrial Revolution seemed to be one of increasing progress at an increasing rate. The rate of increase in the efficiency of labor had jumped upward with the original Industrial Revolution, and it had jumped upward again with the coming of modern science and technology and the industrial R&D laboratory. The capital intensity of the economy had increased as businesses had sought to exploit the continent-sized market by grasping for economies of scale.

But then came 1973, and American economic growth hit a large speed bump.

American Economic Growth 1973–1995: The Productivity Growth Slowdown

In 1973 the steady trend of climbing rates of productivity growth stopped cold. Between 1950 and 1973 the rate of labor productivity growth in the United States was 2.1 percent per year. Between 1973 and 1995 measured growth in output per worker in the U.S. economy grew at only 0.6 percent per year. The slowdown did not affect the U.S. economy alone: It hit — to different degrees and with different effects — the other major economies of the world's industrial core in western Europe, Japan, and Canada as well (see Table 5.3 on page 134).

What caused the **productivity growth slowdown**? Various observers at different times have attributed this slowdown in the growth rate of productivity to four different factors: increased problems of economic measurement, environmental protection expenditures, the baby boom, and oil prices.

productivity growth slowdown
The period from 1973 to about 1995 when the rate of productivity growth in the United States and other economies suddenly slowed, for still mysterious reasons.

The first two of these are really the same thing. The argument that the productivity growth slowdown can be explained by expenditures on environmental protection is a branch of the "problems-of-measurement" argument, and it is by far the most important branch of that argument. When the price of electricity goes up because power companies switch to burning higher priced low-sulfur coal or install sulfur-removing scrubbers in their chimneys, they are producing not just electric power but electric power plus cleaner air. But the NIPA does not count pollution reduction as a valued economic output. America has spent a fortune on environmental protection in the past generation, and it has received big benefits from this investment. But these gains aren't included in measured GDP.

The surge in investment in environmental protection in the United States started just about when the productivity growth slowdown did. Nevertheless, the argument

TABLE 5.3
The Magnitude of the Post-1973 Productivity Growth Slowdown in the G-7 Economies

	Output-per-Worker Annual Growth (%)	
Country	**1950–1973**	**1973–1995**
United States	2.1	0.6
Canada	2.7	1.6
Japan	7.4	2.6
Britain	2.4	1.8
Germany (West)	5.7	2.0
France	4.4	1.5
Italy	4.9	2.3

Source: Authors' calculations from the 2004 edition of *The Economic Report of the President* (Washington, DC: Government Printing Office).

that this can be the full rather than a partial and relatively small part of the explanation is difficult to win. The math doesn't seem to add up: The productivity growth slowdown we have experienced seems to be multiple times the size of the one that would have been expected from the redirection of investment from increasing productive capacity to environmental protection.

Aside from the failure to measure the benefits of pollution control, the rest of the argument that the productivity growth slowdown can be explained by problems of economic measurement is a bit too subtle to work. Few doubt that economic measurement entails big problems. These problems can reasonably be assumed to lead to significant understatements of the rate of economic growth. But to account for the productivity growth slowdown, the problems of measurement must have gotten worse. They must be much worse now than they were five decades ago. And how that can be true is not clear.

The third proposed explanation of the productivity growth slowdown is that in the 1970s the baby-boom generation of Americans began to enter the labor force. This generation is very large. We should know: Brad was born in 1960, the year in which more Americans were born than in any year either before or since. The relatively young labor force had many more workers with little experience than did the labor force of the 1960s and 1950s. Some economists argue that this fall in the average level of labor-force experience generated the productivity growth slowdown. Others point out that the baby-boom generation had little experience but a lot of education, and that in the past education had been a powerful booster of productivity. The average level of education in the labor force increased quite rapidly as the baby-boom generation entered the economy. Once again, this is an unlikely full explanation: Entry of the baby boomers into the labor force may be part of the answer, but the combination of their low experience and their high education makes it hard to sell the entry of the baby-boom generation as a large net reduction in labor-force quality.

The last explanation of the productivity growth slowdown is the tripling of world oil prices by the OPEC cartel in 1973, in the wake of the third Arab-Israeli war. Productivity growth slowed at almost exactly the same time that oil prices skyrocketed. Economists hypothesized that in response to the tripling of world oil prices firms began redirecting their capital expenditures from capital that produced more output to capital that used less energy; firms retired a large share of their most energy-intensive capital and began to substitute workers for energy use wherever possible.

The problem with this explanation is twofold. First, since 1986 real oil prices have been lower than they were before 1973; hence the productivity growth slowdown should have ended in the late 1980s, but it didn't. Second, energy costs are not that large a share of the typical business's costs. By the start of the 1990s the productivity growth slowdown had left America with real GDP levels about a quarter lower than they would have been had productivity growth continued at its pre-1973 rate. How could even the tripling of the price of a commodity that accounts for less than 4 percent of costs lead to a more than 25 percent reduction in output? Thus it is hard to see the oil price increases of the 1970s as a full accounting.

That an event as important as the productivity growth slowdown that started in the early 1970s remains so mysterious is extremely frustrating to economists. The causes of the productivity growth slowdown remain uncertain. The best theory combines all the others — the "a lot of different bad things happening all at once" theory. But it remains unsatisfactory.

Effects of the Productivity Growth Slowdown

At a productivity growth rate of 2.1 percent per year — the rate the United States enjoyed from 1950 to 1973 — output per worker doubles every 34 years. At the 1973–1995 growth rate of 0.6 percent per year, output per worker takes 120 years to double — three and a half times as long. Social psychologists tell us that 40-year-olds feel happiest not when their incomes are high but when their incomes are high relative to those of their households when they were growing up. Before 1973, when growth in output per worker was more rapid, most American voters felt much richer than their parents and hence were more willing to invest in social welfare programs and other liberal political initiatives. Between 1973 and 1995, slower growth made Americans feel much less well off than they had expected they would be.

Economic growth slowed sharply as a result of the productivity growth slowdown. But whether economic growth stopped for large numbers of Americans is not clear. Box 5.2 analyzes what we know about the "true" pace of economic growth during the productivity growth slowdown. The consequences of this are uncertain: Former president Jimmy Carter saw it as the origin of a national "malaise." Liberals have blamed it for a rightward shift in politics. American conservatives have blamed it for a rush to security and an unwillingness to undertake bold libertarian experiments. All have seen it as a cause of more (not necessarily unjustified) skepticism toward the government and its programs.

5.2

DID REAL STANDARDS OF LIVING DECLINE DURING THE SLOWDOWN PERIOD? THE DETAILS

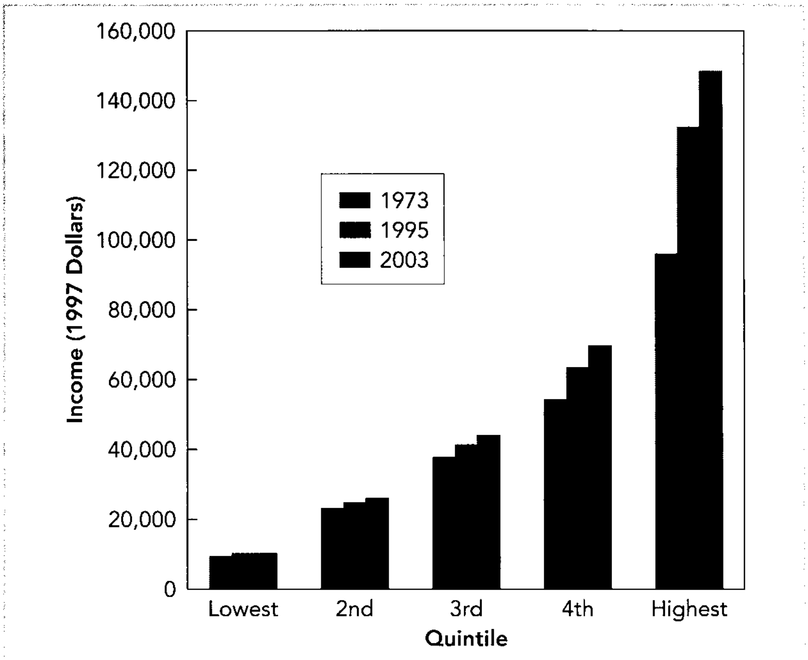
For some categories of workers (e.g., males in their twenties with less than a high-school diploma), the productivity growth slowdown of roughly 1973 to 1995 was accompanied by stagnant or declining measured real wages. Yet offsetting this are many improvements in quality of life — from cleaner air to the convenience of automated teller machines — that the national income accounting system cannot measure.

If we accept the estimates of the mid-1980s Boskin Commission (chaired by economist Michael Boskin), we conclude that unmeasured growth in material well-being is greatly uncertain but somewhere around 1 percent per year. If this is correct, then true total product-per-worker growth in the United States has slowed not to the 0.6 percent per year recorded in official statistics for 1973–1995 but to 1.6 percent per year. This is still a substantial drop from the estimated 3.1 percent per year that the same adjustment produces for growth before 1973.

And increased income inequality has produced declines in real income or near stagnation for some groups (see Figure 5.6). But it is not true that America's output per worker stagnated for all workers over the two decades before 1995. Whether we as a society have distributed the gains in productivity to persons and households and to private and public uses wisely and appropriately — that is another question.

FIGURE 5.6

Measured Real Mean Household Income, by Quintile The era of the productivity growth slowdown saw not just slow economic growth but a widening of the American distribution of income.



Source: Economic Policy Institute, www.epinet.org/.

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Productivity Growth Speedup: The New Economy

As computers improved and spread throughout the U.S. economy in the 1970s and 1980s, economists kept waiting to see the wonders of computing show through in national productivity. But that didn't happen. The productivity growth slowdown continued throughout the 1970s and 1980s. This surprising phenomenon came to be called the "computer paradox" after Robert Solow's famous 1987 observation: "We see the computer age everywhere except in the productivity statistics." Since

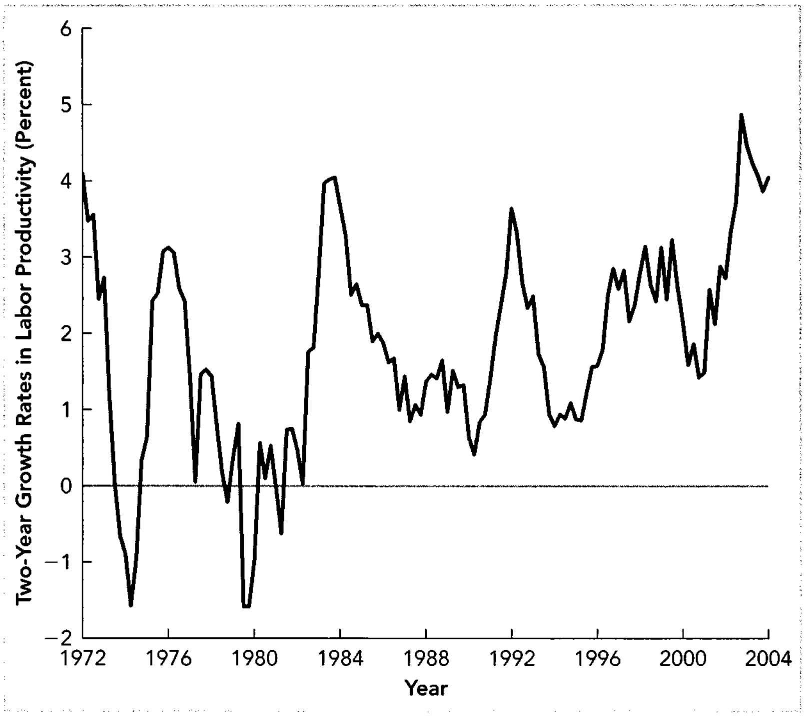


FIGURE 5.7

Two-Year Growth Rates in Labor Productivity

Trend productivity growth was low throughout the late 1970s, 1980s, and early 1990s, with the only hopeful news about productivity coming in the early stages of business-cycle recoveries. By contrast, in the late 1990s and early 2000s the news about labor productivity was good no matter what the phase of the business cycle.

Source: Authors' calculations from data available at www.bls.gov.

1995, however, labor productivity growth in the American economy has accelerated once again, first to a pace of 2.1 percent per year in the second half of the 1990s, and now to a pace of 3.5 percent per year so far in the first half of the 2000s.

The U.S. economy has benefited from a stunning investment boom since 1992. Between 1992 and 1998 real GDP rose by an average of 3.6 percent per year, and business fixed investment soared at a 10.1 percent average rate, almost three times as fast. As a consequence, the share of business fixed investment in GDP jumped from 9.2 percent to 13.2 percent, with much of the additional investment going into computers and related equipment. The consensus among economists is that the recent acceleration in productivity growth resulted from this boom in real investment, a huge share of which was driven by the rapidly falling price of computers. According to the Commerce Department's Bureau of Economic Analysis, the price of computing equipment fell by an average of 19 percent per year between 1990 and 2003. Each year the same nominal expenditure on computers bought 19 percent more in terms of real computer equipment.

Consensus opinion was tipped into believing that the post-1995 reversal of the productivity growth slowdown was a durable phenomenon by the fact that productivity growth in America despite falling somewhat during the short business-cycle recession of 2001, continued to be quite rapid throughout the period of uneven business-cycle recovery that followed in 2002, and the faster period of recovery in 2003 and 2004 as shown in Figure 5.7. The normal business cycle pattern is for productivity growth to be slow — not fast — during a recession. This normal pattern did not hold, as businesses used investment in high-tech equipment to continue to boost their productivity even when the labor market was a buyer's market.

A rapidly falling price of capital goods has the same effect on total investment as a rapidly rising saving rate. We know that the higher is the share of national product devoted to saving and gross investment — the higher is s — the higher will be the economy's balanced-growth capital-output ratio $s/(n + g + \delta)$. The same thing applies to falling prices of capital goods — in this case, the falling prices of information technology and communications equipment. Halve the price of capital goods, and you will find that in the long run you have doubled the economy's capital intensity — doubled its average ratio of capital to output — with important consequences for the level of output per worker.

One way to think about it is that, as long as the technological revolution in information technology continues and the price of computers and related goods keeps falling at an astronomical rate, the United States is undergoing a new "great traverse" — only this time it is not to a growth path with a higher ratio of industrial capital like steel mills to output, but to a growth path with a higher ratio of information capital like computer chips to output.

There is every reason to expect that technological progress in the computer and communications sectors will continue, and there is every reason to expect that these useful technologies will continue to diffuse throughout the economy. The best bet in forecasting future productivity growth is to make future projections on the basis of what has happened in the past half-decade. The productivity growth slowdown has been brought to an end by the technological revolution in computers and communications. But that is a subject to be explored further toward the end of this book, in Chapter 16.

RECAP MODERN AMERICAN ECONOMIC GROWTH

Over the past two centuries measured economic growth in the United States has raised output per worker at an average pace of between 1.5 and 2.0 percent per year. Moreover, it is likely that true output-per-worker growth since 1890 has been even faster. Many economists believe that official estimates overstate inflation and understate real economic growth by 1.0 percent per year, in large part because national income accountants have a very hard time valuing the boost to productivity and standards of living generated by the invention of new goods and services, and new types of goods and services.

Accompanying this increase in productivity and living standards is structural change: the move from the country to the city, the large-scale shift of employment from agriculture to manufacturing and now to services, and the creation of large business organizations. Starting in 1973 the steady trend of climbing rates of productivity growth stopped cold: Between 1973 and 1995 measured growth in output per worker in the U.S. economy grew at only 0.6 percent per year. Since 1995, however, productivity growth in the American economy has accelerated once again to a pace of 2.7 percent per year, the result of an investment boom, the rapidly falling prices of computers and communications equipment, and technological advances.

5.3 MODERN ECONOMIC GROWTH AROUND THE WORLD

Divergence, Big Time

The industrial core of the world economy saw its level of material productivity and standard of living explode in the nineteenth and twentieth centuries. Elsewhere the growth of productivity levels and standards of living and the spread of industrial technologies were slower. As the industrialized economies grew while industrial technologies spread slowly elsewhere, the world became a more and more unequal place. As development economist Lant Pritchett puts it, the dominant feature of world economic history from the Industrial Revolution up until 1980 or so is "divergence, big time." In terms of relative incomes and productivity levels, the world today is very unequal and very divergent, as Figure 5.8 shows.

divergence

The tendency for a per capita measurement such as income or standard of living in various countries to become less equal over a period of time.

Those who live in relatively poor regions of the world today have higher material living standards than did their predecessors who lived in those regions a century ago. But the relative gap vis-à-vis the industrial core has grown extraordinarily and extravagantly. In the first half of the nineteenth century the average inhabitant of an average country had perhaps one-half the material standard of living of a citizen of the world's leading industrial economy. Although the difficulties of making such comparisons are overwhelming (and Box 5.3 provides some insight into the difficulties of making such comparisons), our best estimate is that the average inhabitant of an average country has only one-sixth the material standard of living and productivity level of a leading nation like the United States today.

The Exception: OECD Economies

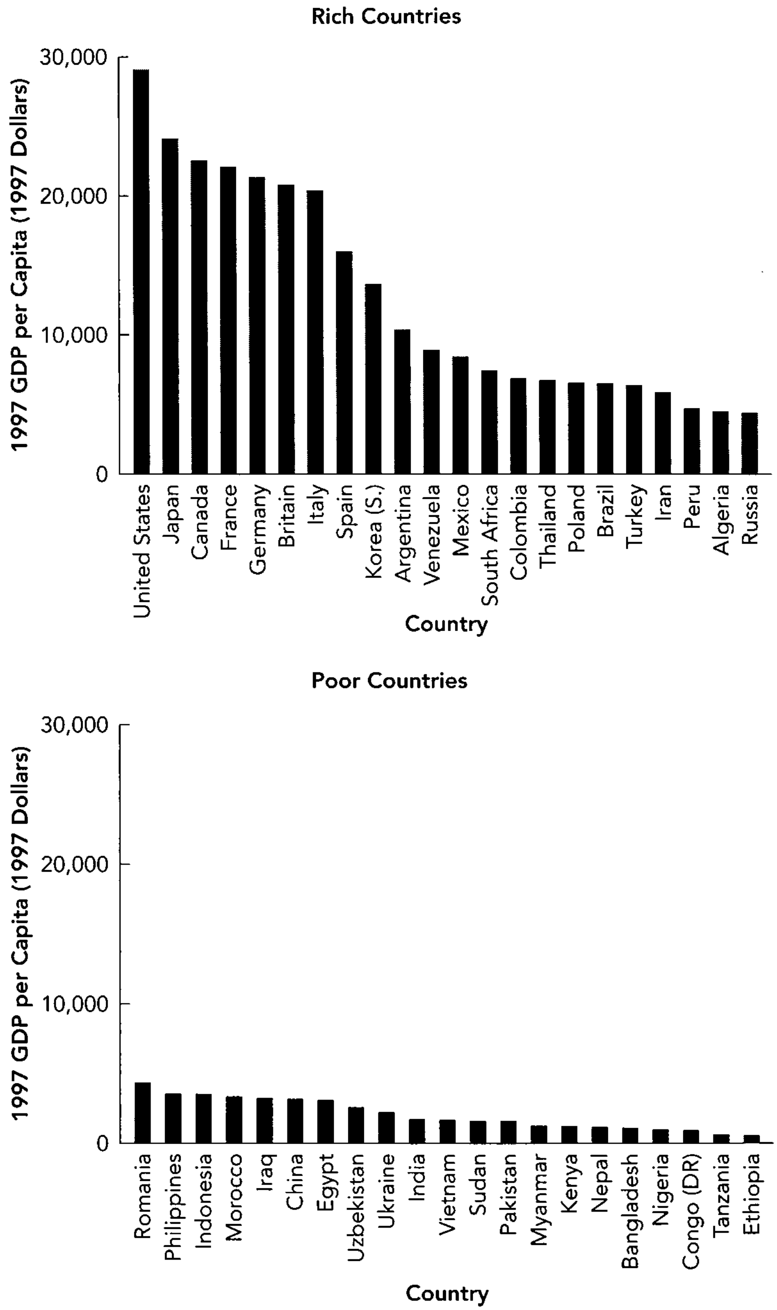
Such divergence is not inevitable. The United States, with its perhaps 14- to 25-fold increase in output per worker over the years since 1870, has not been the fastest growing economy in the world. A number of other economies at different levels of industrialization, development, and material productivity a century ago have now converged, and their levels of productivity, economic structures, and standards of living today are very close to those of the United States (see Box 5.4). The six largest of these converging economies and the United States make up the so-called Group of Seven (G-7) economies. The six non-U.S. members' steady process of convergence to the U.S. level from 1950 until about 2000 is shown in Figure 5.9 on page 142.

Most of these economies were much poorer than the United States in 1870. Most were significantly poorer in 1950. The Japanese economy, for example, went from a level of output per capita equal to 16 percent of the U.S. level in 1950 to 84 percent of the U.S. level in 1992 — before falling steeply backward during Japan's recent recession. Italian levels of GDP per capita have gone from 30 to 65 percent of the U.S. level; German levels, from 40 to 75 percent; Canadian levels, from 70 to 85 percent; and British levels, from 60 to 70 percent in the past half-century.

Moreover, much of the remaining differential between the United States and western Europe is the result of different institutions and tastes for leisure; for example, western Europeans take what many Americans would regard as extravagant vacations. Much of today's differential between the United States and Japan is the result of deliberate political choice: Japan's politicians have decided to keep their agriculture-based industries and their wholesale and retail distribution systems protected from competition, small scale, and thus — from an American standpoint — inefficient.

FIGURE 5.8
World Distribution of Income, Selected Countries

In some places modern economic growth has taken hold and propelled levels of productivity and living standards upward. In other places people on average live little, if any, better than their ancestors did. The world is a more unequal place, in relative income terms, than it has been since there were some human tribes that had fire and others that did not.



Source: Authors' calculations from Alan Heston, Robert Summers, and Bettina Aten's Penn World Table, www.nber.org.

5.3

PURCHASING-POWER-PARITY AND REAL EXCHANGE RATE COMPARISONS: SOME TOOLS

When our focus is on comparing standards of living, either across time or across countries, we get much more meaningful figures by correcting current (and even average trend) exchange rates for differences in *purchasing power parity (PPP)*. The differences between estimates of relative income levels based on current exchange rates and estimates based on PPP calculations can be very large. On a purchasing-power-parity basis GDP per worker in the United States today is some 13 times GDP per worker in India; by contrast, on an average exchange rate basis GDP per worker in the United States today is more than 70 times the level in India.

PPP-based calculations attempt (as the name implies) to translate one currency into another at a rate that preserves average purchasing power. But current exchange rates do not preserve purchasing power. If you exchange your dollars in the United States for rupees in India you will find that your rupees in India will buy about the same amount of internationally traded manufactured goods as your dollars would have bought in the United States. (Unless, of course, you try to buy something that the Indian government has decided to put up a trade barrier against.) But your rupees in India will buy you vastly more in the way of personal services, the products of skilled craftspeople, and any other labor-intensive goods and services.

Why? International *arbitrage* keeps the exchange rate at the level that makes easily traded manufactured goods roughly equally expensive. If they weren't, someone could make an easy fortune by shipping them from where they were cheap to where they were dear. But how — in this world of stringent immigration restrictions — can a cook in Bangalore take advantage of the fact that there is fierce demand in Marin County, north of San Francisco, for caterers who can prepare a good curry? Because relative productivity levels in labor services are much more equal than relative productivity levels in manufacturing, living standards throughout the world are more equal than exchange rate–based calculations suggest.

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5.4

WHY HAVE THESE ECONOMIES CONVERGED? A POLICY

By and large the economies that have converged are those that belong to the *Organization for Economic Cooperation and Development (OECD)*, which was started shortly after World War II, in the days of the Marshall Plan, as a group of countries that received (or gave) Marshall Plan aid to help rebuild and reconstruct after the war. Countries that received Marshall Plan aid adopted a common set of economic policies: large private sectors freed of government regulation of prices, investment with its direction determined by profit-seeking businesses, large social insurance systems to redistribute income, and governments committed to avoiding mass unemployment.

The original OECD members all wound up with *mixed economies*. In these, markets direct the flow of resources, while governments stabilize the economy, provide social insurance safety nets, and encourage entrepreneurship and enterprise. The member nations arrived at this setup largely due to good luck, partly due to the Cold War, and partly as a result of post–World War II institutional reforms.

This configuration was essentially the price countries had to pay for receiving Marshall Plan aid. The U.S. executive branch was unwilling to send much aid to countries that it thought were likely to engage in destructive economic policies, largely because it did not believe that it could win funding from the Republican-dominated Congress for a Marshall Plan that did not impose such strict conditionality upon recipients. By contrast, countries that were relatively rich after World War II but did not adopt OECD-style institutional arrangements — such as Argentina and Venezuela — lost relative ground.

As the OECD economies became richer, they completed their demographic transitions: Population growth rates fell. The policy emphasis on entrepreneurship and enterprise boosted national investment rates, so the OECD economies all had healthy investment rates as well. These factors boosted their equilibrium capital-output ratios. And the diffusion of technology from the United States did the rest of the job in bringing OECD standards of economic productivity close to the U.S. level. ◆

The G-7 economies have not been the only ones to buck the global trend. As Box 5.5 shows, the east Asian economies have also "converged."

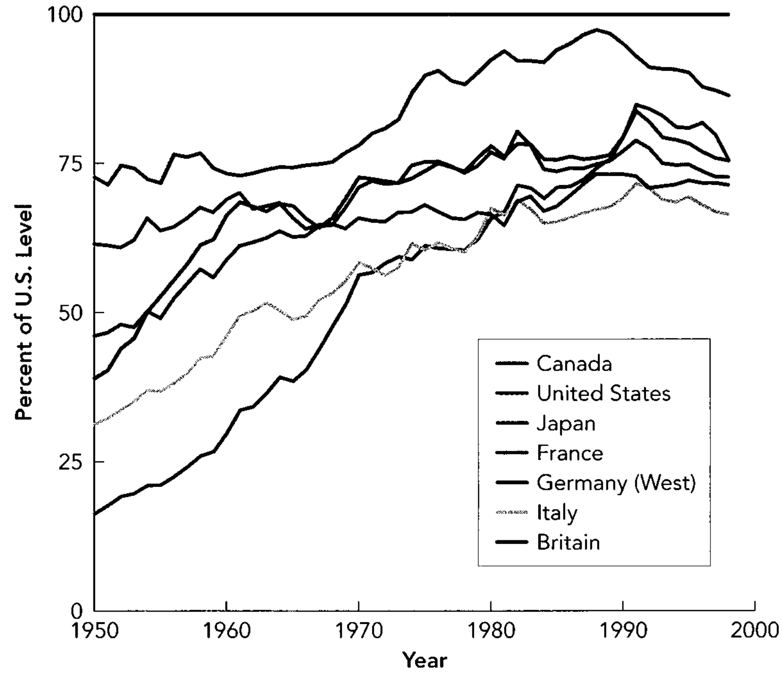
The Rule: Divergence behind the Iron Curtain

But convergence is the exception. Divergence is the rule. And perhaps the most important driving force behind divergence is communism: Being unlucky enough

FIGURE 5.9

Convergence among the G-7 Economies: Output per Capita as a Share of U.S. Level

In 1950 GDP per capita levels in the six nations that now are America's partners in the G-7 varied from 20 percent of the U.S. level (Japan) to 70 percent of the U.S. level (Canada). Today estimates of GDP per capita place levels in all six at more than 65 percent of the U.S. level — and they would be even closer to the U.S. level if the measurements took account of the shorter average work year abroad.



Source: Authors' calculations from Alan Heston, Robert Summers, and Bettina Aten's Penn World Table, www.nber.org.

5.5

THE EAST ASIAN MIRACLE: POLICY

The story of extraordinarily successful economies goes beyond the original OECD nations. The economies of the "*east Asian miracle*" have over the past two generations exhibited stronger growth than has ever before been seen anywhere in the world. They have not yet converged to the standards of living and levels of economic productivity found in the world economy's industrial core, but they are converging.

Immediately before World War II the regions that are now South Korea, Hong Kong, Singapore, and Taiwan had output-per-worker levels less than one-tenth the level of the United States. Today Singapore's GDP per capita is 90 percent, Hong Kong's is 70 percent, Taiwan's is 50 percent, and South Korea's is 45 percent of the U.S. level. A second wave of east Asian economies — Malaysia and Thailand — now average more than one-quarter of the U.S. level of GDP per capita.

The successful east Asian economies share a number of similarities with the OECD economies in terms of economic policy and structure. Resource allocation decisions are by and large left to the market. Governments regard the encouragement of entrepreneurship and enterprise as a major goal. And high saving and investment rates are encouraged by a number of different government policies.

Yet there are also a number of differences vis-à-vis the OECD. Governments in east Asia have been more aggressive in pursuing industrial policy and somewhat less aggressive in establishing social insurance systems than have the OECD economies. However, they have also had more egalitarian income distributions and hence less need for redistribution and social insurance. They have subsidized corporations that they believe are strategic for economic development, thinking that their bureaucrats know better than the market — heresy to economists. (However, it is worth noting that they have focused subsidies on the companies that have proved successful at exporting goods to other countries, so their bureaucrats have in a sense been rewarding the judgment of *foreign* markets.) The examples of successful catching up suggest that growth could have been faster in the world economy. Economies — even very poor ones — *can* rapidly adopt modern machine technologies and move their productivity levels close to first-world leading-edge standards.

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to have been ruled by communists in the twentieth century is a virtual guarantee of relative poverty.

Winston Churchill once labeled a snaky geographic line across Eurasia the "Iron Curtain." On one side were regimes that owed their allegiance to Karl Marx and to Marx's viceroys on Earth. On the other side were regimes that claimed, in the 1946–1989 Cold War, to be of the "free world" — regimes that were, if not good, at least less bad. Walk this geographic line from Poland to Korea and then hop over to the only Western hemisphere communist satellite, Cuba, looking first at the level of material welfare in the communist countries and then at the level of material welfare in the noncommunist countries. The location of the Iron Curtain is a historical accident: It is where Stalin's Russian armies stopped after World War II, where Mao's Chinese armies stopped in the early 1950s, and where Giap's Vietnamese armies stopped in the mid-1970s.

TABLE 5.4
The Iron Curtain: GDP-per-Capita Levels of Matched Pairs of Countries

East-Bloc Country	GDP per Capita	Matched West-Bloc Country	GDP per Capita	Relative Gap (%)
North Korea	$ 700	South Korea	$13,590	94
China	3,130	Taiwan	14,170	78
Vietnam	1,630	Philippines	3,520	54
Cambodia	1,290	Thailand	6,690	81
FSR Georgia	1,960	Turkey	6,350	69
Russia	4,370	Finland	20,150	78
Bulgaria	4,010	Greece	12,769	69
Slovenia	11,800	Italy	20,290	42
Hungary	7,200	Austria	22,070	67
Czech Republic	10,510	Germany	21,260	51
Poland	6,520	Sweden	19,790	67
Cuba	3,100	Mexico	8,370	63

Source: Authors' calculations from Alan Heston, Robert Summers, and Bettina Aten's Penn World Table, www.nber.org.

Notice as you walk that outside the Iron Curtain, the countries are far better off in terms of GDP per capita (see Table 5.4). They are not necessarily better off in education, health care, or the degree of income inequality. If you were in the poorer half of the population, you probably received a better education and had access to better medical care in Cuba than in Mexico. But the countries fortunate enough to lie outside what was the Iron Curtain were and are vastly more prosperous. Depending on how you count and how unlucky you are, between 40 and 94 percent of the potential material prosperity of a country was annihilated if it happened to fall under communist rule in the twentieth century. The fact that a large part of the globe was under communist rule in the twentieth century is one major reason for the world's divergence. A failure to successfully aid postcommunist economies in their transition would be a further blow, and, as Box 5.6 discusses, "transition" is not going well.

The Rule: Divergence in General

Even if attention is confined to non–communist-ruled economies, there still has been enormous divergence in relative output-per-worker levels over the past 100 years. Since 1870, the ratio of richest to poorest economies has increased sixfold. In 1870 two-thirds of all countries had GDP-per-capita levels between 60 and 160 percent of the average. Today the range that includes two-thirds of all countries extends from 35 to 280 percent of the average.

There is reason to hope that the era of widening world income and productivity gaps is over. China for the past 25 and India for the past 20 years have begun to grow much faster than before, and to begin the process of catching up to the world's industrial leaders. Together they are home to nearly 40 percent of the human race.

5.6

POSTCOMMUNISM: POLICY

The demolition of the Berlin Wall and the elimination of the Iron Curtain have not significantly improved the situation in what are euphemistically and optimistically called "economies in transition" (from socialism to capitalism, that is). Figuring out how to move from a stagnant, ex-communist economy to a dynamic, growing one is very difficult, and no one has ever done it before.

A few of the economies in transition appear to be on the path toward rapid convergence with western Europe: Slovenia, Hungary, the Czech Republic, and Poland have already successfully maneuvered through enough of the transition phase to have advanced their economies beyond the point reached before 1989. It seems clear that their economic destiny is to become, effectively, part of western Europe. Slovakia, Lithuania, Latvia, and Estonia appear to have good prospects of following their example.

Elsewhere, however, the news is bad. Whether reforms have taken place step-by-step or all at once, whether ex-communists have been excluded from or have dominated the government, and whether governments have been nationalist or internationalist, the results have been similar. Output has fallen, corruption has been rife, and growth has not resumed. Material standards of living in Ukraine today are less than half of what they were when General Secretary Gorbachev ruled from Moscow.

Economists debate ferociously the appropriate economic strategy for unwinding the inefficient centrally planned Soviet-style economy. The fact that such a transition has never been undertaken before should make advice givers cautious. And one other observation should make advice givers depressed: The best predictor of whether an eastern European country's transition will be rapid and successful or not appears to be its distance from western European political and financial capitals like Vienna, Frankfurt, and Stockholm.

◆

Sources of Divergence

The principal cause of the extraordinary variation in output per worker between countries today is differences in their respective equilibrium capital-output ratios. Two secondary causes are, first, openness to creating and adapting the technologies that enhance the efficiency of labor as measured by levels of development two generations ago and, second, the level of education today.

Productivity two generations ago is a good indicator of the level of technological knowledge that had been acquired as of a half-century ago. The level of education today captures the country's ability to invent and acquire further technological expertise today. Without education, inventing new and adopting foreign technological knowledge are simply not possible.

Global Patterns

Together these factors — the determinants of capital intensity (the capital-output ratio) and the two determinants of access to technology — account for the bulk of the differences between countries in their relative productivity levels.

The determinants of the equilibrium capital-output ratio play a very powerful role. A higher share of investment in national product is powerfully correlated with relative levels of output per worker. No country with an investment rate of less than 10 percent has an output-per-worker level even 20 percent that of the United

States. No country with an investment share of less than 20 percent has an output-per-worker level greater than 75 percent of the U.S. level.

A high level of labor-force growth is correlated, albeit less powerfully, with a low level of output per worker. The average country with a labor-force growth rate of more than 3 percent per year has an output-per-worker level of less than 20 percent of the U.S. level. The average country with a labor-force growth rate of less than 1 percent has an output-per-worker level that is greater than 60 percent of the U.S. level.

Together these determinants of the equilibrium capital-output ratio can, statistically, account for up to half of the variation in national economies' levels of productivity per worker in the world today. The power of these factors is central to the theoretical model of economic growth presented in Chapter 4 and should not be underestimated. Indeed, their power is the reason we spent so much space on the standard growth model in Chapter 4.

But the factors stressed in Chapter 4 are not the only major determinants of relative wealth and poverty in the world today. Differences in the efficiency of labor are as important as differences in equilibrium capital-output ratios. Differences in the efficiency of labor arise from the differential ability of workers to handle and utilize modern technologies. The efficiency of labor is high where education levels are high — so workers can use the modern technologies they are exposed to — and where economic contact with the industrial core is high — so workers and managers are exposed to the modern technologies invented in the world's R&D laboratories.

Schooling is the variable that has the strongest correlation with output per worker. Countries that have an average of four to six years of schooling have output-per-worker levels that average 20 percent of the U.S. level. Those with an average level of schooling of more than 10 years have output-per-worker levels of 65 percent of the U.S. level, as Figure 5.10 shows.

No single best indicator exists of a country's exposure to — and thus ability to adopt and adapt — the technologies invented in the industrial core that amplify the efficiency of labor. Some economists focus on trade and foreign investment as the main sources of increased efficiency and technological capability. Others focus on geographic and climatic factors that have influenced migration and still influence trade and intellectual exchange. Still others focus on institutions of governance and their effect on entrepreneurship as the key variable. But as much as economists dispute which variables are most important as determinants of *technology transfer* and the efficiency of labor, all agree that all these variables are important indeed to understanding why our world today is the way it is.

Cause and Effect, Effect and Cause

All the factors discussed are both causes and effects. High population growth and low levels of output per worker go together both because rapid population growth reduces the equilibrium capital-output ratio and because poor countries have not yet undergone their demographic transitions. This interaction — in which a high rate of population growth reduces the equilibrium capital-output ratio and a low equilibrium capital-output ratio means that the demographic transition is not far advanced — creates a vicious spiral that reinforces relative poverty.

Moreover, demography is not the only vicious spiral potentially present. A poor country must pay a high relative price for the capital equipment it needs to acquire in order to turn its saving into productive additions to its capital stock. This should

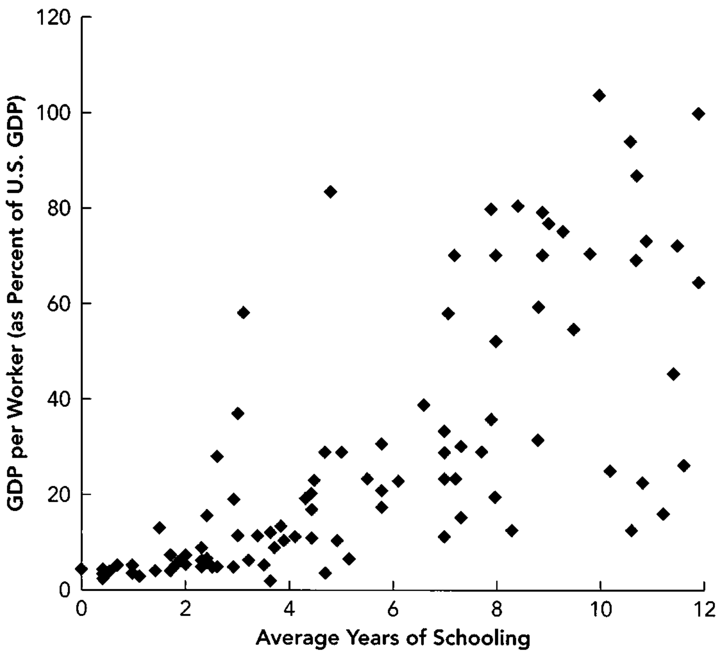

FIGURE 5.10

GDP-per-Worker Levels and Average Years of Schooling

Countries with a high number of average years of schooling have a better chance of being relatively well off. Education opens the door to acquiring the technologies of the Industrial Revolution.

Source: Authors' calculations from Alan Heston, Robert Summers, and Bettina Aten's Penn World Table, www.nber.org.

come as no surprise. The world's most industrialized and prosperous economies are the most industrialized and prosperous because they have attained very high levels of manufacturing productivity: Their productivity advantage in unskilled service industries is much lower than that in capital- and technology-intensive manufactured goods. The higher relative price of machinery in developing countries means that poor countries get less investment — a smaller share of total investment in real GDP — out of any given effort at saving some fixed share of their incomes.

Moreover, to the extent that education is an important kind of investment, a good education is much harder to provide in a poorer country. Even primary education requires at its base a teacher, some books, and a classroom — things that are relatively cheap and easy for a rich country to provide but expensive for a poor country. In western Kenya today the average primary school classroom has 0.4 book per pupil.

But virtuous circles are also possible. Anything that increases productivity and sets the demographic transition in motion will reduce the rate of growth of the labor force, increase the amount of investment bought by any given amount of saving, and make education easier.

How important are these vicious spirals and virtuous circles? It is hard to look at the cross-country pattern of growth over the past century without thinking that such vicious spirals and virtuous circles must have been very important. Otherwise, the massive divergence in relative productivity levels seems inexplicable.

RECAP MODERN ECONOMIC GROWTH AROUND THE WORLD

The industrial core of the world economy saw its level of material productivity and standards of living explode in the nineteenth and twentieth centuries. Elsewhere the growth of productivity levels and standards of living and the spread of industrial technologies were slower, and the gap between rich and poor countries has widened enormously over the past century.

High population growth and low levels of output per worker go together both because rapid population growth reduces the equilibrium capital-output ratio and because poor countries have not yet undergone their demographic transitions, which lower population growth. Low investment rates and low levels of output per worker go together both because low investment reduces the equilibrium capital-output ratio and because poor countries face adverse terms of trade and high prices for capital goods, which make investment difficult and expensive. Thus the obstacles to rapid growth in many poor countries in the world today are overwhelming.

5.4 POLICIES AND LONG-RUN GROWTH

Hopes for Convergence

Relative and Absolute Stagnation

Always keep in mind that in the context of economic growth "stagnation" and "failure" are relative terms. Consider Argentina once again, for it has been one of the world's most disappointing performers in terms of economic growth in the twentieth century. Argentina has experienced substantial economic growth. Officially measured labor productivity or national product per capita in Argentina today is perhaps three times what it was in 1900. True productivity, taking adequate account of the value of new commodities, is higher. But the much more smoothly running engine of capitalist development in Norway — no more, and probably less, rich and productive than Argentina in 1900 — has multiplied measured national product per capita there by a factor of 9.

A pattern of productivity growth like Argentina's is heartbreakingly slow when compared to what, reasonably, might have been and was achieved by the world's industrial leaders. What is bad about falling behind, or falling further behind, is not that second place is a bad place to be — it is false to think that the only thing that matters is to be top nation and that it is better to be poor but first than rich but second. What is bad about falling behind is that the world's industrial leaders provide an easily viewable benchmark of how things might have been different and of how much better things might have been. There was no destiny keeping Buenos Aires today from looking like and having its people as rich as those of Paris, Toronto, or Sydney.

Half Empty and Half Full

In many respects, it is decidedly odd that the world distribution of output per worker is as unequal as it is. World trade, migration, and flows of capital should all work to move resources and consumption goods from where they are cheap to where they are dear. As they travel with increasing speed and increasing volume as transportation and communication costs fall, these commodity and factor-of-production flows should erode differences in productivity and living standards between national economies. Moreover, most of the edge in standards of living and productivity levels held by the industrial core is no one's private property but, instead, is the common intellectual and scientific heritage of humankind. Hence every poor economy has an excellent opportunity to catch up with the rich by adopting and adapting from this open storehouse of modern machine technology.

We can view this particular glass either as half empty or as half full. Half full is that much of the world has already made the transition to sustained economic growth. Most people today live in economies that, while far poorer than the leading-edge postindustrial nations of the world's economic core, have successfully climbed onto the escalator of economic growth and thus the escalator to modernity. The economic transformation of most of the world is less than a century behind that of the leading-edge economies — only an eyeblink behind from the perspective of the six millennia since the spread of agriculture out of the Middle East's fertile crescent.

Moreover, perhaps we can look forward to a future in which convergence of relative income levels will finally begin to take place. The bulk of humanity is now achieving material standards of living at which the demographic transition takes hold. As population growth rates in developing countries fall, their capital-output ratios will begin to rise quickly. With tolerable government, reasonable security of property, and better ways of achieving an education, their output-per-worker levels and material standards of living will converge to the world's leading edge.

Half empty is that we live today in the most unequal age — in terms of the divergence in the life prospects of children born into different economies — that the world has ever seen. One and a half billion people today live in economies that have not made the transition to intensive economic growth and have not climbed onto the escalator to modernity. It is very hard to argue that the median inhabitant of Africa is any better off in material terms than his or her counterpart of a generation ago.

Policies for Saving, Investment, and Education

Any government can adopt policies that boost *national saving*, improve the ability to translate saving into productive investment, and accelerate the demographic transition.

Saving and Investment

Policies that ensure savers get reasonable rates of return on their savings have the potential to boost the saving rate. By contrast, systems of economic governance in which profits are diverted into the hands of the politically powerful through restrictions on entrepreneurship tend over time to diminish saving, as do economic policies that divert the real returns to savings into the hands of financiers or the government through inflation. Government deficits also have the potential to reduce the saving rate: Unless consumers and investors are farsighted enough to recognize that a government deficit now means a tax increase later, a government that spends more than it raises in revenue must borrow — and the amount borrowed is not a contribution to total national saving because it is not available to fund investment.

A number of potential policies work to boost investment for a given amount of saving. Policies that welcome foreign investors' money have the potential to cut a decade or a generation off the time needed to industrialize — if the foreign-funded capital is used wisely. Free-trade policies that allow businesses to freely earn and spend the foreign exchange they need to purchase new generations of machinery and equipment are an effective way of boosting investment. Policies that impose heavy tariffs or require scarce import licenses in order to purchase foreign-made capital equipment are a sure sign that a country will not get its money's worth out of a given nominal savings share but will, instead, find that real investment remains low. Indeed, many of the most successful developing states have done the opposite. They have provided large subsidies to fund investment and expansion by businesses that have demonstrated their competence and productivity by successfully exporting and thus competing in the world market.

Education

Universal education, especially of girls, pays a twofold benefit. Investments are more likely to be productive with a better educated workforce to draw on; hence investments are more likely to be made. Educated women are likely to want at least as much education for their children as they had, and they are likely to have relatively attractive opportunities outside the home, so the birthrate is likely to fall.

The developing countries of the world appear, for the most part, to be going through the demographic transition faster than the economies of today's industrial core did in the past three centuries. Thus current estimates of the world's population in 2050 are markedly lower than the estimates of a decade ago. Ten years ago the projected global population in 2050 was 16 billion or more; today it is 12 billion or less. This is due, in part at least, to rapid expansions in educational attainment in today's developing economies.

A high level of educational attainment also raises the efficiency of labor both by teaching skills directly and by making it easier to advance the general level of technological expertise. A leading-edge economy with a high level of educational attainment is likely to have more inventions. A follower economy with a high level of educational attainment is likely to have a more successful time at adapting to local conditions the inventions and innovations from the industrial core of the world economy. How large these effects are at the macroeconomic level is uncertain, but that they are there nobody doubts.

The east Asian economies, especially, provide examples of how uncorrupt and well-managed developing states can follow macroeconomic policies that accelerate economic growth and convergence. These economies, which have provided incentives to accelerate the demographic transition and boost saving and investment, have managed to close the gap vis-à-vis the world economy's industrial core faster than anyone would have believed possible.

Policies for Technological Advance

Without better technology, increases in capital stock produced by investment rapidly run into diminishing returns. And without improvements in the "technologies" of organization, government, and education, productivity stagnates.

Somewhat surprisingly, economists have relatively little to say about what governs technological progress. Why did better technology raise living standards by 2 percent annually two generations ago but by less than 1 percent during the subsequent two decades? Why did technology progress by only 0.25 percent per year in the early 1800s? Improving literacy, communications, and research and development may help explain faster progress since the Industrial Revolution than before it and faster progress in the twentieth than in the nineteenth century. Yet, as noted above, as important a feature of recent economic history as the 1973–1995 productivity growth slowdown remains largely a mystery.

Invention and Innovation

Economists note that technological progress has two components: science (solid-state physics and the invention of the transistor, the mapping of the human genome, the discovery that potassium nitrate, sulfur, and charcoal when mixed together and exposed to heat have interesting properties) and research and development that lead to successful innovation. About pure science economists have almost nothing to say. About research and development, and the innovations it generates, economists have rather more to say.

Economists note that perhaps 75 percent of all U.S. scientists and engineers work on research and development for private firms. R&D spending amounts to about 3 percent of GDP in the United States and other advanced industrial economies. One-fifth of total gross investment is research and development. More than half of net investment is research and development — investments in knowledge, as opposed to investments in machinery, equipment, structures, and infrastructure.

Businesses conduct investments in R&D to increase their profits. Firms spend money on R&D for reasons analogous to those that lead them to expand their capacity or improve their factories. If the expected present value of profits from an R&D project at the prevailing rate is greater than the costs of the project, then the business will spend money on the project. If not, then it will not.

Rivalry and Excludability

But some features of technology make thinking about the R&D process more complicated than thinking about other types of investment. First and most important, research and development is a public good. A firm that has discovered something — a new and more profitable process, a new and better way of organizing the factory, a new type of commodity that can be produced — will not reap the entire social benefit from its discovery. Other businesses can examine the innovation — the product, the process, the method of organization — and copy it. They can probably do so for a much lower cost than was needed to research and develop the innovation in the first place.

By contrast, a firm that has just spent a large sum to buy and move into a new building does not have to worry that any other firm will use that building as well. As a commodity, a building — or a machine, or even the skills and experience inside a worker's head — is both rival and excludable. To say that a commodity is rival means that if one firm is using it, another firm cannot do so: I cannot use that hammer to pound this nail if you are now using it to pound that other nail. To say that a commodity is excludable means that the "owner" of the commodity can easily monitor who is using it and can easily keep those whom he or she does not authorize from using it.

Most physical commodities are (or, with the assistance of the legal system, can easily be made) both rival and excludable. But by their nature ideas are not. Ideas are definitely not rival — nothing in the physical universe makes it impossible for me to use the same idea you are using. And ideas are hard to make excludable as well: How can you keep me from thinking what I want to think?

Patents and Copyrights

patent laws and copyrights

Laws designed to encourage invention and innovation by providing the right to exclude anyone else from using a discovery (patent) or intellectual property (copyright) for a period of years.

To protect ideas and intellectual property in general, countries have **patent laws and copyrights.** In fact, one of the few enumerated powers that the U.S. Constitution gives Congress is the power to set up limited-term patent and copyright laws. Patents give a firm that has discovered something new the right to exclude anyone else from using that discovery for a period of years. But even the strictest patent and copyright laws are incomplete. Often the most valuable part of the R&D process is figuring out not how to do something but whether it (or something very close to it) can be done at all. Once a patent has been granted, other firms can and do search for alternative ways of making it or ways of making something close to it that are not covered by the patent.

Governments seeking to establish patent laws face a difficult dilemma. If their patent laws are strong, then much of the modern technology in the economy will be restricted in use. Technology may be restricted to being used only by the inventor or restricted because the inventor is allowed to charge other firms high licensing fees to use it (or to not let them use it at all). Letting everyone use the idea or the process or the innovation, once it is discovered, entails no social cost. Information, after all, wants to be free. Thus a government that enacts strict patent laws is pushing the average level of technology used in its factories and businesses at some particular moment far below the level that could be achieved at that particular moment.

On the other hand, if the patent laws are weak and thus provide little protection to inventors and innovators, then the profits that inventors and innovators earn will be low. Why then should businesses devote money and resources to research and development? They will not. And the pace of innovation, and thus of technological improvement, will slow to a crawl.

This dilemma cannot be evaded. The profits from innovation derive from the innovator's monopoly right to the innovation — and hence the rest of the economy is excluded from using that item of technology. Reduce the degree of exclusion to lower the deadweight loss from using less-than-best-practice technology, and you will find that you have reduced the rewards to research and development (and thus presumably the pace of R&D as well). Increase the strength of the patent system to raise the rewards to research and development, and you will find that you have increased the gap between the average technology used in the economy and the feasible best practice.

Moreover, technological progress depends on more than the appropriability of research — the extent to which the increased productivity made possible by innovation boosts the profits of the innovating firm. It also depends on the productivity of research: How much in the way of new productivity-enhancing inventions is produced by a given investment in R&D? Economists don't know much about the interactions among product development, applied research, and basic research, so they have little to say about how to improve the productivity of research and the pace of productivity growth.

Government Failure

That governments can assist in growth and development does not mean that governments will. The broad experience of growth in developing economies — outside the Asian Pacific Rim, outside the OECD — has been that governments often won't.

Over the past two decades many have argued that typical systems of regulation in developing countries have retarded development by

- Embarking on "prestige" industrialization programs that keep resources from shifting to activities in which the country has a long-run comparative advantage.
- Inducing firms and entrepreneurs to devote their energies to seeking rents by lobbying governments, instead of seeking profits by lowering costs.
- Creating systems of regulation and project approval that have degenerated into extortion machines for manufacturing bribes for the bureaucrats.

Many governments — particularly unelected governments — are not that interested in economic development. Giving valuable industrial franchises to the nephews of the dictator; making sure that members of your ethnic group are in key places to extort bribes; or taking the foreign exchange that would have been spent importing productive machinery and equipment and using it instead to buy more modern weapons for the army — these can seem more attractive options. In the absence of political democracy, the checks on a government that does not seek economic development are few.

Moreover, checks on government that do exist may not be helpful. In a nondemocracy, or a shaky semidemocracy, government faces two possible sources of pressure: riots in the capital and coups by the soldiers. Even a government that seeks only the best for its people in terms of economic growth will have to deal with these sources of pressure and will have to avoid riots in the capital and coups by the soldiers.

Riots in the capital are best avoided by making sure that the price of food is low and that influential opinion leaders in the capital are relatively happy with their material standards of living. Coups by the soldiers are best avoided by spending money on the military. Thus governments find themselves driven to policies that redistribute income from the farms to the cities, from exporting businesses to urban consumers of imported goods, from those who have the power to invest and make the economy grow to those who have the power to overthrow the government.

If the rulers have the worst of motives, government degenerates into kleptocracy: rule by the thieves. If government has the best of motives, it is still hard to avoid policies that diminish saving and retard the ability to translate saving into productive investment. W. W. Rostow recounts a visit by President Kennedy to Indonesia in the early 1960s; Kennedy talked about economic development and a South Asian Development Bank to provide capital for Indonesia's economic growth. Indonesia's then-dictator, Sukarno, responded, "Mr. President, development takes too long. Give me West Irian [province, the western half of the island of New Guinea, to annex] instead."

Taken as a group, the poor countries of the world have not closed any of the gap relative to the world's industrial leaders since World War II.

Neoliberalism

Much thinking about the proper role of government in economic growth over the past two decades has led to conclusions that are today called neoliberal. The government has a sphere of core competencies — administration of justice, maintenance of macroeconomic stability, avoidance of deep recessions, some infrastructure development, provision of social insurance — at which it is effective. But there is a large area of potential activities in which governments (or, at least, governments that do not have the bureaucratic honesty and efficiency needed for a successful developing state) are more likely to be destructive than constructive, hence the neoliberal recommendation that governments attempt to shrink their role back to their core competencies and thus to deregulate industries and privatize public enterprises. Whether such policies will in fact lead to convergence rather than continued divergence is still an open question.

RECAP POLICIES AND LONG-RUN GROWTH

Most people today live in economies that, while far poorer than the leading-edge postindustrial nations of the world's economic core, have successfully climbed onto the escalator of economic growth and thus the escalator to modernity. A follower economy with a higher level of educational attainment is likely to have a much more successful time at adapting to local conditions inventions and innovations from the industrial core of the world economy. Thus education appears to be a key policy for successful economic growth outside the industrial core. Inside the industrial core, without better technology increases in the capital stock produced by investment rapidly run into diminishing returns. One-fifth of total gross investment is research and development. More than half of net investment is research and development — investment in knowledge, as opposed to investment in machinery, equipment, structures, and infrastructure.

That governments *can* assist in growth and development does not mean that governments *will*. Many governments — particularly unelected governments — are not that interested in economic development. In the absence of political democracy, the checks on a government that does not seek economic development are few.

Chapter Summary

1. Before the commercial revolution (1500 or so) economic growth was very slow. Populations grew at a glacial pace. And as best we can tell there were no significant increases in standards of living for millennia before 1500: Humanity was caught in a Malthusian trap.
2. The way out of the Malthusian trap opened about 1500. Thereafter populations grew, and standards of living and levels of material productivity grew as well.
3. The Industrial Revolution was the start of the current epoch: the epoch of modern economic growth. Beginning in the mid-eighteenth century the pace of invention and innovation ratcheted up. Key inventions replaced muscle with machine power, and material productivity levels boomed.
4. Modern economic growth is well described by the growth model in Chapter 4, which is why we spent so much time on it. Output per worker and capital per worker increase at a pace measured in percent per year, a pace that is extraordinarily rapid in long-term historical perspective.
5. Productivity growth rates slowed down worldwide after 1973, causing living standards to rise more slowly in the 1970s and 1980s than they otherwise would have. Several explanations have been offered for the productivity growth slowdown, but economists generally agree the causes remain a mystery.

6. Productivity growth rates sped up after 1995 and continue at this higher pace. The acceleration was due to a boom in real investment in computers and related equipment, driven largely by the decline in prices of computers.
7. Looked at across nations, the world today is an astonishingly unequal place in relative terms. The relative gap between rich and poor nations in material productivity is much greater than it has ever been before.
8. Combining the determinants of the balanced-growth capital-output ratio with the proximate determinants — the level of technological knowledge in a country after World War II and its average level of educational attainment — accounts for the overwhelming bulk of variation in the relative wealth and poverty of nations today.
9. Macro policies to increase economic growth are policies to accelerate the demographic transition (through education), to boost saving rates, to boost the amount of real investment that a country gets for a given saving rate, and (again through education) to boost the rate of invention or of technology transfer.

Key Terms

Industrial Revolution (p. 120)
resource scarcity (p. 122)
Malthusian age (p. 124)
demographic transition (p. 124)
productivity growth (p. 129)
productivity growth slowdown (p. 133)
divergence (p. 139)
patent laws and copyrights (p. 152)

Analytical Exercises

1. Why do many economists think that the consumer price index overstates the true rate of inflation?
2. Would an increase in the saving and investment share of U.S. total output raise productivity growth and living standards?
3. Many observers project that by the end of the twenty-first century the population of the United States will be stable. Using the Solow growth model, what would such a downward shift in the growth rate of the labor force do to the growth of output per worker and to the growth of total output? Consider both the effect on the balanced-growth equilibrium path *and* the transition from the "old" positive population growth to the "new" zero population growth balanced-growth path.
4. What are the arguments for having a strong patent system to boost economic growth? What are the arguments for having a weak system of protections of intellectual property? Under what systems do you think that the first will outweigh the second? Under what circumstances do you think that the second will outweigh the first?
5. What steps do you think that international organizations — the U.N., the World Bank, or the IMF — could take to improve political leaders' incentives to follow growth-promoting policies?
6. Suppose somebody who hasn't taken any economics courses asks you why humanity escaped from the Malthusian trap of very low standards of living and slow population growth rates, which nevertheless put pressure on available natural resources and kept output per worker from rising, in which humanity found itself between 8000 BC and AD 1800. What answer would you give?
7. Suppose somebody who hasn't taken any economics courses asks you why some countries are so very, very much poorer than others in the world today. What answer would you give?
8. The endogenous growth theorists, led by Stanford's Paul Romer, argue that separating the determinants of the efficiency of labor from investment is a mistake, because investment both raises the capital-worker ratio and increases the efficiency of labor as workers learn about the new technology installed with the purchase of new, modern capital goods. If the endogenous growth theorists are correct, is the case for government policies to boost national saving and investment rates strengthened or weakened? Why?

Policy Exercises

1. Look in the back of this book, after page 554, at the rate of growth of real GDP per worker in the United States over the past 10 years. Guess what the average magnitude of annual fluctuations in growth about its trend rate are. How large was the "trend" component of growth in the past year? How large was the "cycle" component of growth in the past year?
2. Take a look at the first three columns of the "U.S. Macroeconomic Data" table at the back of the book, after page 554. Identify the years that are business cycle peaks — years that are followed by a decline in real GDP or real GDP per worker. Are the two possible sets of business cycle peaks the same? Calculate economic growth rates between business cycle peaks, and make a table of these annual peak-to-peak growth rates. Is this a good way of looking for and estimating changes in long-run economic growth trends in the United States? Why or why not?
3. Look at the relative purchasing-power-parity levels of GDP per worker for the G-7 economies (Germany, France, Britain, Italy, Canada, Japan, and the United States). Have the nations drawn closer together in levels of GDP per worker in the past five years?
4. What items of news have you read about in the past week that you would classify as shifts in macro policies that encourage growth?
5. What items of news have you read about in the past week that you would classify as shifts in macro policies that discourage growth?
6. What items of news have you read about in the past week that you would classify as shifts in micro policies that encourage growth?
7. What items of news have you read about in the past week that you would classify as shifts in micro policies that discourage growth?
8. Do you believe that over the next three decades the lower income countries of the world will catch up to — or at least draw nearer in relative terms to — the high-income countries? Why or why not?
9. What are the prospects for successful rapid development in tomorrow's world? Do you see the glass as half empty or half full?