Chapter

6

Long-Run Economic Growth

A nation's ability to provide improving standards of living for its people depends crucially on its long-run rate of economic growth. Over a long period of time, even an apparently small difference in the rate of economic growth can translate into a large difference in the income of the average person.

Compare, for example, the historical experiences of Australia and Japan. In 1870 real GDP per person was about five times as large in Australia as in Japan, as the data on national growth performances in Table 6.1 show. Indeed, of sixteen

Table 6.1

Economic Growth in Eight Major Countries, 1870–1996

	Levels of Real GDP per Capita				
Country	**1870**	**1913**	**1950**	**1996**	**Annual Growth Rate 1870–1996**
Australia	3,123	4,523	5,931	15,076	1.3%
Canada	1,347	3,560	6,113	17,453	2.1
France	1,571	2,734	4,149	14,631	1.8
Germany	1,300	2,606	3,339	15,313	2.0
Japan	618	1,114	1,563	17,346	2.7
Sweden	1,316	2,450	5,331	14,912	1.9
United Kingdom	2,610	4,024	5,651	14,440	1.4
United States	2,247	4,854	8,611	19,638	1.7

Note: Figures are in U.S. dollars at 1985 prices, adjusted for differences in the purchasing power of the various national currencies.
Sources: Data from 1870, 1913, 1950 from Angus Maddison, *Dynamic Forces in Capitalist Development: A Long-Run Comparative View,* New York: Oxford University Press, 1991, Table 1.1. Data for 1996 computed by authors using growth rates of real GDP per capita from 1989 to 1996 reported in *OECD National Accounts, Main Aggregates, 1960–1996, Volume 1,* Part Four, Growth Triangles and 1989 levels of GDP per capita from Maddison. (The 1996 data for Germany apply the growth rate for unified Germany to the 1989 GDP per capita for West Germany and thus overstate GDP per capita for unified Germany in 1996 because income per capita was higher in West Germany than in East Germany in 1989.)

major economies considered by British economist Angus Maddison in his important research on long-run growth (and from whose work some of the data in Table 6.1 are taken), Australia was the richest and Japan the poorest in 1870. Australia's economy didn't stand still after 1870. Over the next 126 years, Australian real GDP per person grew by 1.3% per year so that by 1996 the real income of the average Australian was almost five times as great as it had been in 1870. However, during the same period Japanese real GDP per person grew at a rate of 2.7% per year, reaching a level in 1996 that was twenty-eight times larger than it had been in 1870.

The Japanese growth rate of 2.7% per year may not seem dramatically greater than the Australian growth rate of 1.3% per year. Yet by 1996 Japan, which had been far poorer than Australia a century earlier, had surpassed its Pacific neighbor in per capita GDP by a margin of 15%. Other, similar comparisons can be drawn from Table 6.1; compare, for example, the long-term growth performance of the United Kingdom against that of Canada or Sweden. Note, however, that even those countries that grew relatively slowly have dramatically increased their output per person during the past century and a quarter.

Although the comparisons highlighted by Table 6.1 span a long period of time, a change in the rate of economic growth can have important effects over even a decade or two. For example, since about 1973 the United States and other industrialized countries have experienced a sustained slowdown in their rates of growth. Between 1947 and 1973, total (not per capita) real GDP in the United States grew by more than 3.7% per year, but between 1973 and 1998 U.S. real GDP grew by only 2.7% per year. To appreciate the significance of this slowdown, imagine that the 1947–1973 growth trend had continued—that is, suppose that real GDP in the United States had continued to grow at 3.7% per year instead of at the 2.7% per year rate actually achieved. Then in 1998 the U.S. real GDP would have been more than 27% higher than its actual value—a bonus of about $2.4 trillion, or $9000 per person (in 1998 dollars).

No one understands completely why economies grow, and no one has a magic formula for inducing rapid growth. Indeed, if such a formula existed, there would be no poor nations. Nevertheless, economists have gained useful insights about the growth process. In this chapter we identify the forces that determine the growth rate of an economy over long periods of time and examine various policies that governments may use to try to influence the rate of growth. Once again, saving and investment decisions play a central role in the analysis. Along with changes in productivity, the rates at which a nation saves and invests—and thus the rate at which it accumulates capital goods—are important factors in determining the standard of living that the nation's people can attain.

6.1 The Sources of Economic Growth

An economy's output of goods and services depends on the quantities of available inputs, such as capital and labor, and on the productivity of those inputs. The relationship between output and inputs is described by the production function, introduced in Chapter 3:

$$Y = AF(K, N). \tag{6.1}$$

Equation (6.1) relates total output, Y, to the economy's use of capital, K, and labor, N, and to productivity, A.

If inputs and productivity are constant, the production function states that output also will be constant—there will be no economic growth. For the quantity of output to grow, either the quantity of inputs must grow or productivity must improve, or both. The relationship between the rate of output growth and the rates of input growth and productivity growth is

$$\frac{\Delta Y}{Y} = \frac{\Delta A}{A} + a_K \frac{\Delta K}{K} + a_N \frac{\Delta N}{N} \tag{6.2}$$

where

$\frac{\Delta Y}{Y}$ = rate of output growth;

$\frac{\Delta A}{A}$ = rate of productivity growth;

$\frac{\Delta K}{K}$ = rate of capital growth;

$\frac{\Delta N}{N}$ = rate of labor growth;

a_K = elasticity of output with respect to capital;

a_N = elasticity of output with respect to labor.

In Eq. (6.2) the elasticity of output with respect to capital, a_K, is the percentage increase in output resulting from a 1% increase in the capital stock, and the elasticity of output with respect to labor, a_N, is the percentage increase in output resulting from a 1% increase in the amount of labor used. The elasticities a_K and a_N both are numbers between 0 and 1 that must be estimated from historical data.[1]

Equation (6.2), called the **growth accounting equation,** is the production function (Eq. 6.1) written in growth rate form. Some examples will be helpful for understanding the growth accounting equation.

Suppose that a new invention allows firms to produce 10% more output for the same amount of capital and labor. In terms of the production function, Eq. (6.1), for constant capital and labor inputs, a 10% increase in productivity, A, raises output, Y, by 10%. Similarly, from the growth accounting equation, Eq. (6.2), if productivity growth, $\Delta A/A$, equals 10% and capital and labor growth are zero, output growth, $\Delta Y/Y$, will be 10%. Thus the production function and the growth accounting equation give the same result, as they should.

Now suppose that firms' investments cause the economy's capital stock to rise by 10% ($\Delta K/K = 10\%$) while labor input and productivity remain unchanged. What will happen to output? The production function shows that, if the capital stock grows, output will increase. However, because of the diminishing marginal productivity of capital (see Chapter 3), the extra capital will be less productive than that used previously, so the increase in output will be less than 10%. Diminishing marginal productivity of capital is the reason that the growth rate of capital, $\Delta K/K$, is multiplied by a factor less than 1 in the growth accounting equation. For the United States this factor, a_K,

1. Elasticities and growth rate formulas such as Eq. (6.2) are discussed further in Appendix A, Sections A.3 and A.7.

the elasticity of output with respect to capital, is about 0.3. Thus the growth accounting equation, Eq. (6.2), indicates that a 10% increase in the capital stock, with labor and productivity held constant, will increase U.S. output by about 3%, or (0.3)(10%).

Similarly, the elasticity of output with respect to labor, a_N, is about 0.7 in the United States. Thus, according to Eq. (6.2), a 10% increase in the amount of labor used ($\Delta N/N = 10\%$), with no change in capital or productivity, will raise U.S. output by about 7%, or (0.7)(10%).[2]

Growth Accounting

According to Eq. (6.2), output growth, $\Delta Y/Y$, can be broken into three parts:

1. that resulting from productivity growth, $\Delta A/A$,
2. that resulting from increased capital inputs, $a_K\,\Delta K/K$, and
3. that resulting from increased labor inputs, $a_N\,\Delta N/N$.

Growth accounting measures empirically the relative importance of these three sources of output growth. A typical growth accounting analysis involves the following four steps (see Table 6.2 for a summary and numerical example):

- *Step 1.* Obtain measures of the growth rates of output, $\Delta Y/Y$, capital, $\Delta K/K$, and labor, $\Delta N/N$, for the economy over any period of time. In the calculation of growth rates for capital and labor, more sophisticated analyses make adjustments for changing quality as well as quantity of inputs. For example, to obtain a quality-adjusted measure of N, an hour of work by a skilled worker is counted as more labor than an hour of work by an unskilled worker. Similarly, to obtain a quality-adjusted measure of K, a machine that can turn fifty bolts per minute is treated as being more capital than a machine that can turn only thirty bolts per minute.
- *Step 2.* Estimate values for the elasticities a_K and a_N from historical data. Keep in mind the estimates for the United States of 0.3 for a_K and 0.7 for a_N.
- *Step 3.* Calculate the contribution of capital to economic growth as $a_K\,\Delta K/K$ and the contribution of labor to economic growth as $a_N\,\Delta N/N$.
- *Step 4.* The part of economic growth assignable to neither capital growth nor labor growth is attributed to improvements in total factor productivity, A. The rate of productivity change, $\Delta A/A$, is calculated from the formula

$$\frac{\Delta A}{A} = \frac{\Delta Y}{Y} - a_K\frac{\Delta K}{K} - a_N\frac{\Delta N}{N},$$

which is the growth accounting equation, Eq. (6.2), rewritten with $\Delta A/A$ on the left side. Thus the growth accounting technique treats productivity change as a residual—that is, the portion of growth not otherwise explained.[3]

---

2. In Chapter 3 we examined the production function for the U.S. economy, $Y = AK^{0.3}N^{0.7}$. In that production function, called a Cobb-Douglas production function, the exponent on the capital stock, K, (0.3), equals the elasticity of output with respect to capital, and the exponent on the quantity of labor input, N, (0.7), equals the elasticity of output with respect to labor. See Appendix A, Section A.7.

3. The growth accounting method for calculating productivity growth is similar to the method we used to find productivity growth in Section 3.1, where we also determined productivity growth as the part of output growth not explained by increases in capital and labor. The differences are that growth accounting uses the growth accounting equation, which is the production function in growth rate form, instead of using the production function directly, as we did in Chapter 3; and growth accounting analyses usually adjust measures of capital and labor for changes in quality, which we did not do in Chapter 3.

Table 6.2
The Steps of Growth Accounting: A Numerical Example

Step 1. Obtain measures of output growth, capital growth, and labor growth over the period to be studied.

Example:

$$\text{output growth} = \frac{\Delta Y}{Y} = 40\%;$$

$$\text{capital growth} = \frac{\Delta K}{K} = 20\%;$$

$$\text{labor growth} = \frac{\Delta N}{N} = 30\%.$$

Step 2. Using historical data, obtain estimates of the elasticities of output with respect to capital and labor, a_K and a_N.

Example: $a_K = 0.3$ and $a_N = 0.7$.

Step 3. Find the contributions to growth of capital and labor.

Example:

$$\text{contribution to output growth of growth in capital} = a_K \frac{\Delta K}{K} = (0.3)(20\%) = 6\%;$$

$$\text{contribution to output growth of growth in labor} = a_N \frac{\Delta N}{N} = (0.7)(30\%) = 21\%.$$

Step 4. Find productivity growth as the residual (the part of output growth not explained by capital or labor).

Example:

$$\text{productivity growth} = \frac{\Delta A}{A} = \frac{\Delta Y}{Y} - a_K \frac{\Delta K}{K} - a_N \frac{\Delta N}{N}$$

$$= 40\% - 6\% - 21\% = 13\%.$$

Application

Growth Accounting and the East Asian "Miracle"

Several East Asian countries—sometimes called the East Asian tigers—exhibited remarkable rates of economic growth during the final third of the twentieth century. Between 1966 and 1991, Hong Kong averaged real GDP growth of more than 7% per year, and between 1966 and 1990, Singapore, South Korea, and Taiwan averaged real GDP growth of more than 8% per year. An 8% annual growth rate sustained over 25 years translates into a level of real output nearly seven times as high at the end of the period as at the beginning. These countries were hit by severe financial crises in the late 1990s, which slowed their GDP growth—and even caused negative GDP growth in some cases (see the Application "The Asian Crisis," p. 504). Nevertheless, the East Asian growth miracle remains an interesting example to economists, political leaders, and businesspeople who would like to find a way to create similar miracles in their own countries.

What caused the East Asian miracle? And will it continue? To address these questions, Alwyn Young of the University of Chicago applied the methodology of growth accounting in a particularly careful study of East Asian growth.[4] Young used a variety of data sources to develop comprehensive measures of the growth of output, capital, and labor for Hong Kong, Singapore, South Korea, and Taiwan. He

(*Continued*)

4. Alwyn Young, "The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience," *Quarterly Journal of Economics*, August 1995, pp. 641–680.

(*Continued*)
found that, to a surprising degree, the rapid economic growth of these East Asian economies has resulted from rapid growth in capital and labor inputs rather than improvements in total factor productivity (TFP). For example, all four countries experienced remarkable increases in labor-force participation rates, as well as general population growth. Similarly, extremely high rates of national saving (in some cases, enforced by government regulations) led to rapid growth in capital stocks.

After accounting for increases in inputs, Young found that rates of growth in TFP in the four East Asian countries were not so high as many people had thought: 2.3% for Hong Kong, 1.7% for South Korea, 2.6% for Taiwan, and only 0.2% for Singapore! These are good rates of TFP growth (except for Singapore's) but not "miraculous" rates; for example, over approximately the same period Italy enjoyed TFP growth of about 2.0% per year.

As we discuss in detail in this chapter, the declining marginal productivity of capital makes it very difficult to sustain growth over the very long term by increasing inputs alone. At some point, only advances in TFP can keep an economy on a path of rapid growth. Thus an implication of Young's research is that (even without the Asian financial crisis) the rapid growth in East Asia may have run out of steam on its own. Furthermore, the rapid growth of the East Asian tigers is unlikely to resume, unless those countries can find ways to stimulate growth in TFP.

Growth Accounting and the Productivity Slowdown. What does growth accounting say about the sources of U.S. economic growth? Among the best-known research using the growth accounting framework was done at the Brookings Institution by Edward Denison. Table 6.3 summarizes Denison's findings for the period 1929–1982 and provides more recent data from the Bureau of Labor Statistics covering the period 1982–1997.

The last entry in column (4) shows that, over the 1929–1982 period, output grew at an average rate of 2.92% per year. According to Denison's measurements (column 4), the growth of labor accounted for output growth of 1.34% per year. The growth of labor in turn resulted primarily from an increase in population, an increase in the percentage of the population in the labor force, and higher educational levels, which raised workers' skills. (Offsetting these trends to a degree was a decline in the number of hours worked per person.) According to Denison, the growth of the cap-

Table 6.3

Sources of Economic Growth in the United States (Denison) (Percent per Year)

	(1) 1929–1948	(2) 1948–1973	(3) 1973–1982	(4) 1929–1982	(5) 1982–1997
Source of Growth					
Labor growth	1.42	1.40	1.13	1.34	1.71
Capital growth	0.11	0.77	0.69	0.56	0.98
Total input growth	1.53	2.17	1.82	1.90	2.69
Productivity growth	1.01	1.53	–0.27	1.02	0.76
Total output growth	**2.54**	**3.70**	**1.55**	**2.92**	**3.45**

Sources: Columns (1)–(4) from Edward F. Denison, *Trends in American Economic Growth, 1929–1982,* Washington, D.C.: The Brookings Institution, 1985, Table 8.1, p. 111. Column (5) from Bureau of Labor Statistics Web site, Productivity and Related Issues, 1948–1997, Table 1, accessed through stats.bls.gov/mprhome.htm.

ital stock accounted for output growth of 0.56% per year. So, taken together, labor and capital growth contributed 1.90% to the annual growth rate of output.

The difference between total growth (2.92%) and the amount of growth attributed to capital and labor growth (1.90%) is 1.02%. By the growth accounting method, this remaining 1.02% per year of growth is attributed to increases in productivity. Thus, according to Denison, increased quantities of factors of production and improvements in the effectiveness with which those factors were used both played an important role in U.S. growth after 1929.

Data for three shorter periods are given in columns (1)–(3) of Table 6.3. This breakdown highlights a striking conclusion: productivity growth during 1973–1982 was negative (fourth entry in column 3). In other words, Denison estimated that any combination of capital and labor would have produced less output in 1982 than it could have in 1973! (See the application, "The Post–1973 Slowdown in Productivity Growth," for various hypotheses to explain this drop in productivity.) Comparing columns (2) and (3) reveals that the decline in U.S. productivity growth between the 1948–1973 and 1973–1982 periods of 1.80 percentage points (1.53 minus –0.27) accounts for the bulk of the overall slowdown in output growth between those periods of 2.15 percentage points (3.70 minus 1.55).

The slowdown in productivity growth after 1973 reported by Denison was confirmed by other studies, both for the United States and for other industrialized countries. This slowdown has generated widespread concern, because a sustained reduction in the rate of productivity growth would have an adverse effect on future real wages and living standards. In addition, to the extent that future Social Security benefits will be paid by taxing the wage income of future workers, a long-term productivity slowdown would threaten the future of the Social Security system. But will the productivity slowdown continue? To shed light on this question, the final column of Table 6.3 extends Denison's calculations by adding 15 years of more recent data. During the period 1982–1997, productivity grew at an average annual rate of 0.76%. Although the return to a positive rate of productivity growth was a welcome development, the 0.76% growth rate was only about half of the productivity growth rate seen during the 25-year period preceding the 1973 slowdown.

Application

The Post–1973 Slowdown in Productivity Growth

We have seen in Table 6.3 that productivity in the United States grew much more slowly after 1973 than in the quarter-century preceding 1973. Indeed, productivity growth was negative during the period 1973–1982. What caused productivity performance to deteriorate so sharply? In this application we discuss some alternative explanations, including possible measurement problems, deterioration in the legal and human environment, reduced rates of technological innovation, the effects of high oil prices, and the information technology revolution.

Measurement. Interestingly, several economists have suggested that the productivity slowdown really isn't a genuine economic problem. Instead, they argue, the slowdown is an illusion, the result of measurement problems that have overstated the extent of the decline.

The key issue in productivity measurement is whether the official output statistics adequately capture changes in quality. Consider the case of a firm producing personal computers that, using unchanged quantities of capital and labor, makes the same number of computers this year as last year. However, this year's computers

(*Continued*)

(*Continued*)
are of much higher quality than last year's because they are faster and have more memory. The firm's output this year has a greater real economic value than last year's output, so the true productivity of the firm's capital and labor has risen over the year, even though the firm produces the same number of computers as before. However, if statisticians measuring the firm's output counted only the number of computers produced and failed to adjust for quality change, they would miss this improvement in productivity. Similar issues arise in the construction of price indexes; see Box 2.3, "Does CPI Inflation Overstate Increases in the Cost of Living?", p. 49.

In fact, official output measures do try to account for quality improvements—for example, by counting a faster computer as contributing more to output than a slower model. However, measuring quality change is difficult, and to the extent that improvements are not fully accounted for in the data, productivity growth will be underestimated.

A careful study of the measurement issue was done for the Brookings Institution by Martin N. Baily, who served as chair of President Clinton's Council of Economic Advisers, and Robert J. Gordon of Northwestern University.[5] They found that measurement problems may be important for explaining the productivity slowdown in some industries. A striking example is the construction industry: According to the official data, productivity in the construction industry *declined* by 40% between 1967 and 1986! Baily and Gordon argue that this result is implausible and point to various quality improvements in residential construction (such as more frequent installation of central air-conditioning, more custom woodwork, and better insulation and landscaping), which official measures of construction output don't recognize.

However, Baily and Gordon also point out that measurement problems aren't new—they also existed before 1973. For inadequate measurement to explain the post-1973 productivity decline, it must be shown not only that current measurement procedures understate productivity growth but also that recent productivity growth is understated by much more than it was before 1973. Overall, Baily and Gordon conclude that measurement problems could explain at most one-third of the reported post-1973 slowdown. Thus the productivity slowdown is not, for the most part, simply a measurement problem.

The Legal and Human Environment. In his growth accounting study, Edward Denison didn't stop at reporting the decline in productivity growth but went on to offer some explanations for the decline. One explanation given by Denison for the negative productivity growth during 1973–1982 is the change in what he called *the legal and human environment*, which includes several diverse factors. For example, since 1973 a cleaner environment and worker safety and health have been emphasized. To the extent that capital and labor are devoted to these goals, measured output and productivity will decline.[6]

5. "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power," *Brookings Papers on Economic Activity*, 1988:2, pp. 347–420.
6. Of course, the reduction in measured productivity caused by reducing pollution or increasing worker safety is not in any way an argument against pursuing these goals. The proper criterion for evaluating proposed environmental regulations, for example, is whether the benefits to society of the regulations, in terms of cleaner air or water, exceed the costs they will impose. For a discussion of the problems of accounting for environmental quality when measuring output, see Box 2.1, p. 31.

In addition to pollution control and improvements in worker health and safety, changes in the legal and human environment include factors that reduce productivity but do not yield any benefit to the society. For example, Denison estimated that increased dishonesty and crime reduced the annual growth rate of output by 0.05% per year, because productive resources were diverted to protection against crime or were lost to theft, arson, or vandalism. A potentially more important problem was an apparent decline in educational quality during the 1970s, which led to slower improvement in workers' skills. A study by John H. Bishop[7] of Cornell University found that some slowdown in productivity growth could be attributed to declines in student achievement, as measured by standardized tests, that took place primarily between 1967 and 1980.

Technological Depletion and Slow Commercial Adaptation. Improvements in technology are a fundamental source of productivity growth and economic growth. The production processes used and the products and services available today are vastly different than those of 50 years ago. One explanation of the productivity slowdown is that the major technological advances of the past have now been largely exploited, but commercially significant new technologies haven't arrived fast enough to maintain earlier rates of productivity growth. The idea that technological innovation has at least temporarily dried up is part of the "depletion hypothesis" suggested by William Nordhaus[8] of Yale University.

Why should the pace of technological innovation have slowed down since 1973? One argument is that the high rate of innovation in the decades following World War II was abnormal, reflecting a backlog of technological opportunities that were not exploited earlier because of the Great Depression and World War II. According to this view, in recent years we have simply returned to a more normal rate of innovation. Some economists also point out that nothing requires economically valuable inventions to arrive at a steady rate. Perhaps the United States has just been unlucky in that the recent scientific and engineering breakthroughs in computerization and gene splicing, for example, haven't yet produced all the expected economic payoffs.

The Oil Price Explanation. A popular explanation for the productivity slowdown is the large increase in energy prices that followed the OPEC oil embargo in 1973. The idea is that, as companies responded to high energy prices by using less energy, the amount of output they could produce with the same amount of capital and labor declined, reducing productivity. What makes this explanation plausible is not only that the timing is right—the productivity decline appears to have begun in earnest in about 1973—but that, unlike several of the other explanations, the oil price story explains why all major industrial countries, not just the United States, experienced a slowdown.

Pinning the blame for the productivity slowdown on oil price increases isn't easy, though. For many industries energy costs are a relatively small part of total costs. Why then should energy price increases have had such dramatic effects? One

(*Continued*)

7. "Is the Test Score Decline Responsible for the Productivity Growth Decline?" *American Economic Review*, March 1989, pp. 178–197.
8. "Economic Policy in the Face of Declining Productivity Growth," *European Economic Review*, May/June 1982, pp. 131–158.

(*Continued*)

answer, proposed by Martin N. Baily,[9] is that the rise in oil prices may have made many older, more energy-intensive machines and factories unprofitable to operate, thus effectively reducing the nation's capital stock. Such a decline in the "true" capital stock below the measured capital stock would show up in the data as a drop in productivity. If Baily's explanation were correct, however, the prices of used capital goods should have dropped sharply when oil prices rose, reflecting their diminished economic value. Generally, though, the predicted decline in the prices of used capital goods didn't happen.[10]

In a detailed growth accounting analysis, Dale Jorgenson[11] of Harvard University argued that the impact of oil prices shows up in an analysis of productivity performance industry by industry. Some basic industries rely heavily on energy and were hurt badly by the oil price increases. According to Jorgenson, the effect of oil price increases on productivity is underestimated in economywide data. Despite these points, however, proponents of the oil price explanation face the problem of explaining why productivity growth did not resurge when oil prices fell in real terms in the 1980s.

The Beginning of a New Industrial Revolution? In an article titled simply "1974," Jeremy Greenwood of the University of Rochester and Mehmet Yorukoglu of the University of Chicago[12] argue that the slowdown in productivity after 1973 may have resulted from the onset of the information technology (IT) revolution. The development and commercial implementation of new information technologies required a substantial period of learning by both the developers of the new technology and the skilled workers who would work with the technology. During the learning process, productivity was temporarily depressed as developers and workers groped toward developing more powerful technologies and operating those technologies more efficiently. To support their view that productivity was depressed following the introduction of a new range of technologies, Greenwood and Yorukoglu present data showing that productivity in Great Britain fell in the late eighteenth century during the early part of the Industrial Revolution in that country. In the United States, productivity fell in the 1830s as the young country was beginning its industrialization.

This view of the post-1973 productivity slowdown offers an optimistic prospect for the future. In the previous industrial revolutions examined by Greenwood and Yorukoglu, the revolutionary ideas eventually paid off in terms of very large increases in productivity after a few decades of learning. If the productivity slowdown in the 1970s did, in fact, result from the IT revolution, then we should see increases in productivity growth in the not-too-distant future. In fact, proponents of this view suggest that the improved productivity growth in the 1990s reflects the

9. "Productivity and the Services of Capital and Labor," *Brookings Papers on Economic Activity*, 1982:2, pp. 423–454.
10. See Charles R. Hulten, James W. Robertson, and Frank C. Wykoff, "Energy, Obsolescence, and the Productivity Slowdown," in D. Jorgenson and R. Landers, eds., *Technology and Capital Formation*, Cambridge, Mass.: MIT Press, 1989.
11. "Productivity and Economic Growth," in E. Berndt and J. Triplett, eds., *Fifty Years of Economic Measurement*, Chicago: University of Chicago Press, 1990.
12. Jeremy Greenwood and Mehmet Yorukoglu, "1974," *Carnegie-Rochester Conference Series on Public Policy*, June 1997, pp. 49–95.

IT revolution. Additional support for this hypothesis is provided by Bart Hobijn and Boyan Jovanovic,[13] both of New York University, who argue that the stock market fell during the 1970s because the IT revolution would eventually benefit new firms that had not yet been formed, at the expense of existing firms then traded on the stock market. As these new firms were born, flourished, and became traded on the stock market in the 1980s and 1990s, the stock market boomed. Of course, only time will tell whether predicted gains in productivity will materialize and whether the rise in the stock market in the 1990s will continue into the twenty-first century.

Conclusion. The problem involved in explaining the post-1973 slowdown in productivity growth may not be a lack of reasonable explanations but too many. We should not dismiss the possibility that there was no single cause of the slowdown but that many factors contributed to it. Unfortunately, if there are multiple explanations for the slowdown, no single policy action by itself is likely to rev up the productivity engine. Instead, policies to improve productivity growth will have to address many problems at the same time.

13. Bart Hobijn and Boyan Jovanovic, "The Information Technology Revolution and the Stock Market: Preliminary Evidence," mimeo, New York University, August 1999.

6.2 Growth Dynamics: The Solow Model

Although growth accounting provides useful information about the sources of economic growth, it doesn't completely explain a country's growth performance. Because growth accounting takes the economy's rates of input growth as given, it can't explain why capital and labor grow at the rates that they do. The growth of the capital stock in particular is the result of the myriad saving and investment decisions of households and firms. By taking the growth of the capital stock as given, the growth accounting method leaves out an important part of the story.

In this section we take a closer look at the dynamics of economic growth, or how the growth process evolves over time. In doing so, we drop the assumption made in Chapter 3 that the capital stock is fixed and study the factors that cause the economy's stock of capital to grow. Our analysis is based on a famous model of economic growth developed in the late 1950s by Nobel laureate Robert Solow[14] of MIT, a model that has become the basic framework for most subsequent research on growth. Besides clarifying how capital accumulation and economic growth are interrelated, the Solow model is useful for examining three basic questions about growth:

1. What is the relationship between a nation's long-run standard of living and fundamental factors such as its saving rate, its population growth rate, and its rate of technical progress?

14. The original article is Robert M. Solow, "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, February 1956, pp. 65–94.

2. How does a nation's rate of economic growth evolve over time? Will economic growth stabilize, accelerate, or stop?
3. Do economic forces exist that will ultimately allow poorer countries to catch up with the richest countries in terms of living standards?

Setup of the Solow Model

The Solow model examines an economy as it evolves over time. To analyze the effects of labor force growth as well as changes in capital, we assume that the population is growing and that at any particular time a fixed share of the population is of working age. For any year, t,

$$N_t = \text{the number of workers available.}$$

We assume that the population and work force both grow at fixed rate n. So, if $n = 0.05$, the number of workers in any year is 5% greater than in the previous year.

At the beginning of each year, t, the economy has available a capital stock, K_t. (We demonstrate shortly how this capital stock is determined.) During each year, t, capital, K_t, and labor, N_t, are used to produce the economy's total output, Y_t. Part of the output produced each year is invested in new capital or in replacing worn-out capital. We further assume that the economy is closed and that there are no government purchases,[15] so the uninvested part of output is consumed by the population. If

$$Y_t = \text{output produced in year } t,$$
$$I_t = \text{gross (total) investment in year } t\text{, and}$$
$$C_t = \text{consumption in year } t,$$

the relationship among consumption, output, and investment in each year is

$$C_t = Y_t - I_t. \tag{6.3}$$

Equation (6.3) states that the uninvested part of the economy's output is consumed.

Because the population and the labor force are growing in this economy, focusing on output, consumption, and the capital stock *per worker* is convenient. Hence we use the following notation:

$$y_t = \frac{Y_t}{N_t} = \text{output per worker in year } t;$$

$$c_t = \frac{C_t}{N_t} = \text{consumption per worker in year } t;$$

$$k_t = \frac{K_t}{N_t} = \text{capital stock per worker in year } t.$$

The capital stock per worker, k_t, is also called the **capital–labor ratio.** An important goal of the model is to understand how output per worker, consumption per worker, and the capital–labor ratio change over time.[16]

15. Analytical Problem 3 at the end of this chapter adds government purchases to the model.

16. For purposes of analysis, discussing output and consumption per worker is more convenient than discussing output and consumption per member of the population as a whole. Under the assumption that the work force is a fixed fraction of the population, anything we say about the growth rate of output or consumption per worker also will be true of the growth rate of output or consumption per member of the population.

The Per-Worker Production Function. In general, the amount of output that can be produced by specific quantities of inputs is determined by the production function. Until now we have written the production function as a relationship between total output, Y, and the total quantities of capital and labor inputs, K and N. However, we can also write the production function in per-worker terms as

$$y_t = f(k_t). \tag{6.4}$$

Equation (6.4) indicates that, in each year t, output per worker, y_t depends on the amount of available capital per worker, k_t.[17] Here we use a lower case f instead of an upper case F for the production function to emphasize that the measurement of output and capital is in *per-worker* terms. For the time being we focus on the role of the capital stock in the growth process by assuming no productivity growth and thus leaving the productivity term out of the production function, Eq. (6.4).[18] We bring productivity growth back into the model later.

The per-worker production function is graphed in Fig. 6.1. The capital–labor ratio (the amount of capital per worker), k_t, is measured on the horizontal axis, and output per worker, y_t, is measured on the vertical axis. The production function slopes upward from left to right because an increase in the amount of capital per worker allows each worker to produce more output. As with the standard pro-

17. To write the production function in the form of Eq. (6.4) requires the assumption of constant returns to scale, which means that an equal percentage increase in both capital and labor inputs results in the same percentage increase in total output. So, for example, with constant returns to scale, a 10% increase in both capital and labor raises output by 10%. In terms of the growth accounting equation, Eq. (6.2), constant returns to scale requires that $a_K + a_N = 1$. See Analytical Problem 6 at the end of this chapter.
18. More precisely, we set the total factor productivity term A equal to 1.

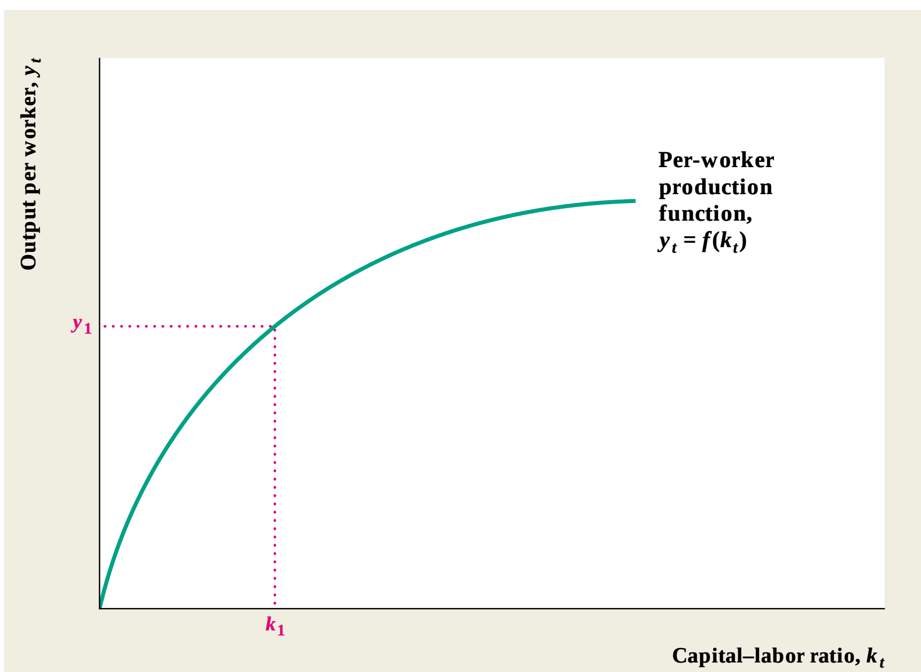


Figure 6.1
The per-worker production function
The per-worker production function, $y_t = f(k_t)$, relates the amount of output produced per worker, y_t, to the capital–labor ratio, k_t. For example, when the capital–labor ratio is k_1, output per worker is y_1. The per-worker production function slopes upward from left to right because an increase in the capital–labor ratio raises the amount of output produced per worker. The bowed shape of the production function reflects the diminishing marginal productivity of capital.

duction function, the bowed shape of the per-worker production function reflects the diminishing marginal productivity of capital. Thus when the capital–labor ratio is already high, an increase in the capital–labor ratio has a relatively small effect on output per worker.

Steady States. One of the most striking conclusions obtained from the Solow model is that in the absence of productivity growth the economy reaches a steady state in the long run. A **steady state** is a situation in which the economy's output per worker, consumption per worker, and capital stock per worker are constant—that is, in the steady state, y_t, c_t, and k_t don't change over time.[19] To explain how the Solow model works, we first examine the characteristics of a steady state and then discuss how the economy might attain it.

Let's begin by looking at investment in a steady state. In general, gross (total) investment in year t, I_t, is devoted to two purposes: (1) replacing worn-out or depreciated capital, and (2) expanding the size of the capital stock. If d is the capital depreciation rate, or the fraction of capital that wears out each year, the total amount of depreciation in year t is dK_t. The amount by which the capital stock is increased is net investment. What is net investment in a steady state? Because capital per worker, K_t/N_t, is constant in a steady state, the total capital stock grows at the same rate as the labor force—that is, at rate n. Net investment is therefore nK_t in a steady state.[20] To obtain steady-state gross investment, we add steady-state net investment nK_t and depreciation dK_t:

$$I_t = (n + d)K_t \quad \text{(in a steady state).} \tag{6.5}$$

To obtain steady–state consumption (output less investment), we substitute Eq. (6.5) into Eq. (6.3):

$$C_t = Y_t - (n + d)K_t \text{ (in a steady state).} \tag{6.6}$$

Equation (6.6) measures consumption, output, and capital as economywide totals rather than in per-worker terms. To put them in per-worker terms, we divide both sides of Eq. (6.6) by the number of workers, N_t, recalling that $c_t = C_t/N_t$, $y_t = Y_t/N_t$, and $k_t = K_t/N_t$. Then we use the per-worker production function, Eq. (6.4), to replace y_t with $f(k_t)$ and obtain

$$c = f(k) - (n + d)k \quad \text{(in a steady state).} \tag{6.7}$$

Equation (6.7) shows the relationship between consumption per worker, c, and the capital–labor ratio, k, in the steady state. Because consumption per worker and the capital–labor ratio are constant in the steady state, we dropped the time subscripts, t.

Equation (6.7) shows that an increase in the steady-state capital–labor ratio, k, has two opposing effects on steady-state consumption per worker, c. First, an increase in the steady-state capital–labor ratio raises the amount of output each worker can produce, $f(k)$. Second, an increase in the steady-state capital–labor ratio

19. Note that if output, consumption, and capital per worker are constant, then total output, consumption, and capital all are growing at rate n, the rate of growth of the work force.

20. Algebraically, net investment in year t is $K_{t+1} - K_t$. If total capital grows at rate n, then $K_{t+1} = (1 + n)K_t$. Substituting for K_{t+1} in the definition of net investment, we find that net investment $= (1 + n)K_t - K_t = nK_t$ in a steady state.

increases the amount of output per worker that must be devoted to investment, $(n + d)k$. More goods devoted to investment leaves fewer goods to consume.

Figure 6.2 shows the trade-off between these two effects. In Fig. 6.2(a) different possible values of the steady-state capital–labor ratio, k, are measured on the horizontal axis. The curve is the per-worker production function, $y = f(k)$, as in Fig. 6.1. The straight line shows steady-state investment per worker, $(n + d)k$. Equation (6.7) indicates that steady-state consumption per worker, c, equals the height of the curve, $f(k)$, minus the height of the straight line, $(n + d)k$. Thus consumption per worker is the height of the shaded area.

The relationship between consumption per worker and the capital–labor ratio in the steady state is shown more explicitly in Fig. 6.2(b). For each value of the steady-state capital–labor ratio, k, steady-state consumption, c, is the difference between the production function and investment in Fig. 6.2(a). Note that, starting from low and medium values of k (values less than k_1 in Fig. 6.2(b)), increases in the steady-state capital–labor ratio lead to greater steady-state consumption per worker. The level of the capital–labor ratio that maximizes consumption per worker in the steady state, shown as k_1 in Fig. 6.2, is known as the **Golden Rule capital–labor ratio,** so-called because it maximizes the economic welfare of future generations.[21]

However, for high values of k (values greater than the Golden Rule capital–labor ratio k_1), increases in the steady-state capital–labor ratio actually result in lower steady-state consumption per worker because so much investment is needed to maintain the high level of capital per worker. In the extreme case, where $k = k_{max}$ in Fig. 6.2, all output has to be devoted to replacing and expanding the capital stock, with nothing left to consume!

Policymakers often try to improve long-run living standards with policies aimed at increasing the capital–labor ratio by stimulating saving and investment. Figure 6.2 shows the limits to this strategy. A country with a low amount of capital per worker may hope to improve long-run (steady-state) living standards substantially by increasing its capital–labor ratio. However, a country that already has a high level of capital per worker may find that further increases in the capital–labor ratio fail to raise steady-state consumption much. The fundamental reason for this outcome is the diminishing marginal productivity of capital—that is, the larger the capital stock already is, the smaller the benefit from expanding the capital stock further. Indeed, Fig. 6.2 shows that, theoretically, capital per worker can be so high that further increases will actually *lower* steady-state consumption per worker.

In any economy in the world today, could a higher capital stock lead to less consumption in the long run? An empirical study of seven advanced industrial countries concluded that the answer is "no." Even for high-saving Japan, further increases in capital per worker would lead to higher steady-state consumption per worker.[22] Thus in our analysis we will always assume that an increase in the steady-state capital–labor ratio raises steady-state consumption per worker.

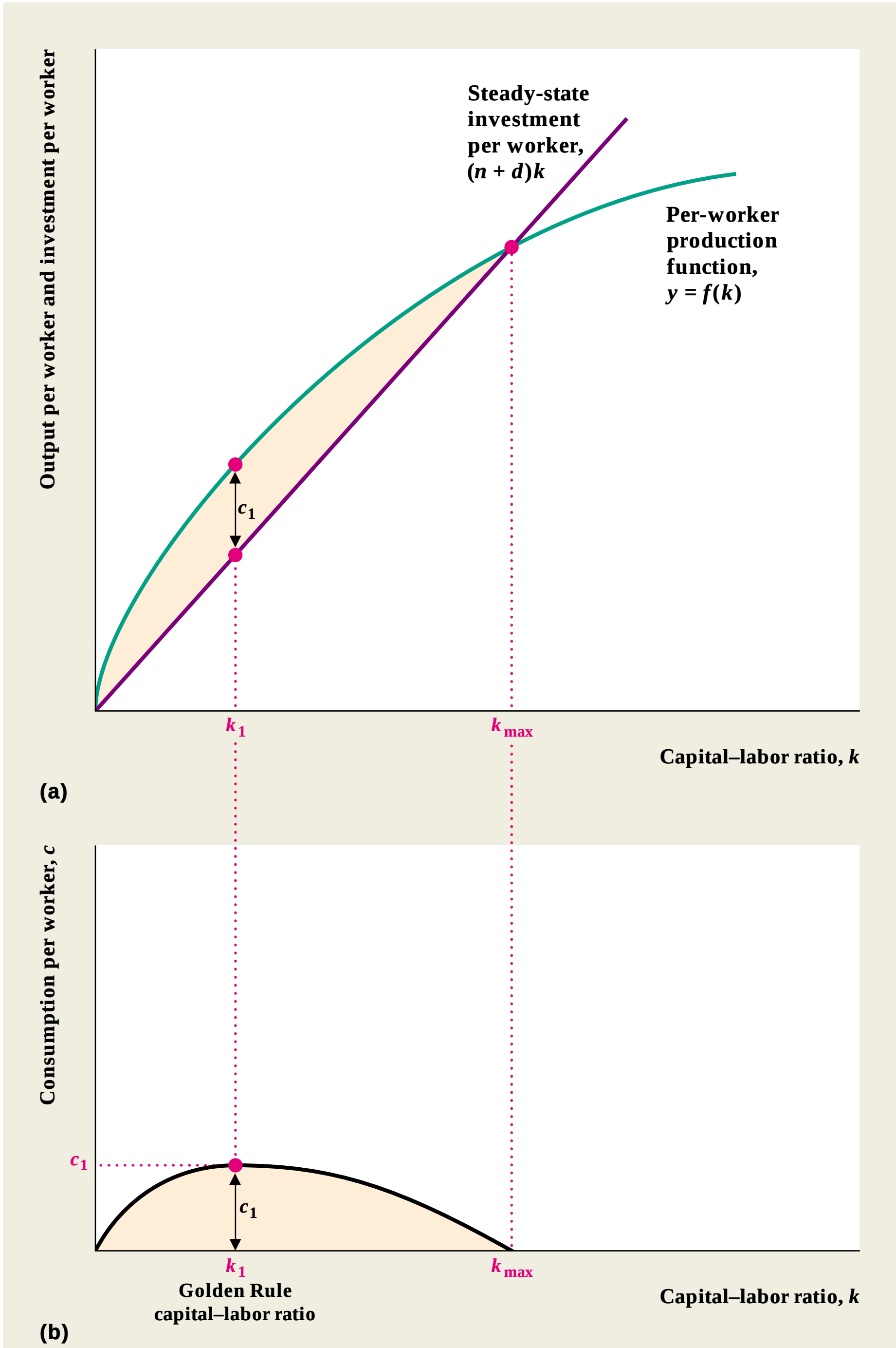
---

21. Readers familiar with calculus might try to use Eq. (6.7) to show that, at the Golden Rule capital–labor ratio, the marginal product of capital equals $n + d$.

22. See Andrew B. Abel, N. Gregory Mankiw, Lawrence H. Summers, and Richard J. Zeckhauser, "Assessing Dynamic Efficiency: Theory and Evidence," *Review of Economic Studies*, January 1989, pp. 1–20.

Figure 6.2
The relationship of consumption per worker to the capital–labor ratio in the steady state

(a) For each value of the capital–labor ratio, k, steady-state output per worker, y, is given by the per-worker production function, $f(k)$. Steady-state investment per worker, $(n + d)k$, is a straight line with slope $n + d$. Steady-state consumption per worker, c, is the difference between output per worker and investment per worker (the peach-shaded area). For example, if the capital–labor ratio is k_1, steady-state consumption per worker is c_1.
(b) For each value of the steady-state capital–labor ratio, k, steady-state consumption per worker, c, is derived in (a) as the difference between output per worker and investment per worker. Thus the shaded area (peach) in (b) corresponds to the shaded area in (a). Note that, starting from a low value of the capital–labor ratio, an increase in the capital–labor ratio raises steady-state consumption per worker. However, starting from a capital–labor ratio greater than the Golden Rule level, k_1, an increase in the capital–labor ratio actually lowers consumption per worker. When the capital–labor ratio equals k_{max}, all output is devoted to investment, and steady-state consumption per worker is zero.



Reaching the Steady State. Our discussion of steady states leaves two loose ends. First, we need to say something about why an economy like the one we describe here eventually will reach a steady state, as we claimed earlier. Second, we have not yet shown *which* steady state the economy will reach; that is, we would like to know the steady-state level of consumption per worker and the steady–state capital–labor ratio that the economy will eventually attain.

To tie up these loose ends, we need one more piece of information: the rate at which people save. To keep things as simple as possible, suppose that saving in this economy is proportional to current income:

$$S_t = sY_t, \tag{6.8}$$

where S_t is national saving[23] in year t and s is the saving rate, which we assume to be constant. Because a \$1 increase in current income raises saving, but by less than \$1 (see Chapter 4), we take s to be a number between 0 and 1. Equation (6.8) ignores some other determinants of saving discussed in earlier chapters, such as the real interest rate. However, including these other factors wouldn't change our basic conclusions, so for simplicity we omit them.

In every year, national saving, S_t, equals investment, I_t. Therefore

$$sY_t = (n + d)K_t \text{ (in a steady state)}, \tag{6.9}$$

where the left side of Eq. (6.9) is saving (see Eq. 6.8) and the right side of Eq. (6.9) is steady-state investment (see Eq. 6.5).

Equation (6.9) shows the relation between total output, Y_t, and the total capital stock, K_t, that holds in the steady state. To determine steady-state capital per worker, we divide both sides of Eq. (6.9) by N_t. We then use the production function, Eq. (6.4), to replace y_t with $f(k_t)$:

$$sf(k) = (n + d)k \text{ (in the steady state)}. \tag{6.10}$$

Equation (6.10) indicates that saving per worker, $sf(k)$, equals steady-state investment per worker, $(n + d)k$. Because the capital–labor ratio, k, is constant in the steady state, we again drop the subscripts, t, from the equation.

With Eq. (6.10) we can now determine the steady-state capital–labor ratio that the economy will attain, as shown in Fig. 6.3. The capital–labor ratio is measured along the horizontal axis. Saving per worker and investment per worker are measured on the vertical axis.

The bowed curve shows how the amount of saving per worker, $sf(k)$, is related to the capital–labor ratio. This curve slopes upward because an increase in the capital–labor ratio implies higher output per worker and thus more saving per worker. The saving-per-worker curve has the same general shape as the per-worker production function, because saving per worker equals the per-worker production function, $f(k)$, multiplied by the fixed saving rate, s.

The line in Fig. 6.3 represents steady-state investment per worker, $(n + d)k$. The steady-state investment line slopes upward because, as the capital–labor ratio rises, more investment per worker is required to replace depreciating capital and equip new workers with the same high level of capital.

23. With no government in this model, national saving and private saving are the same.

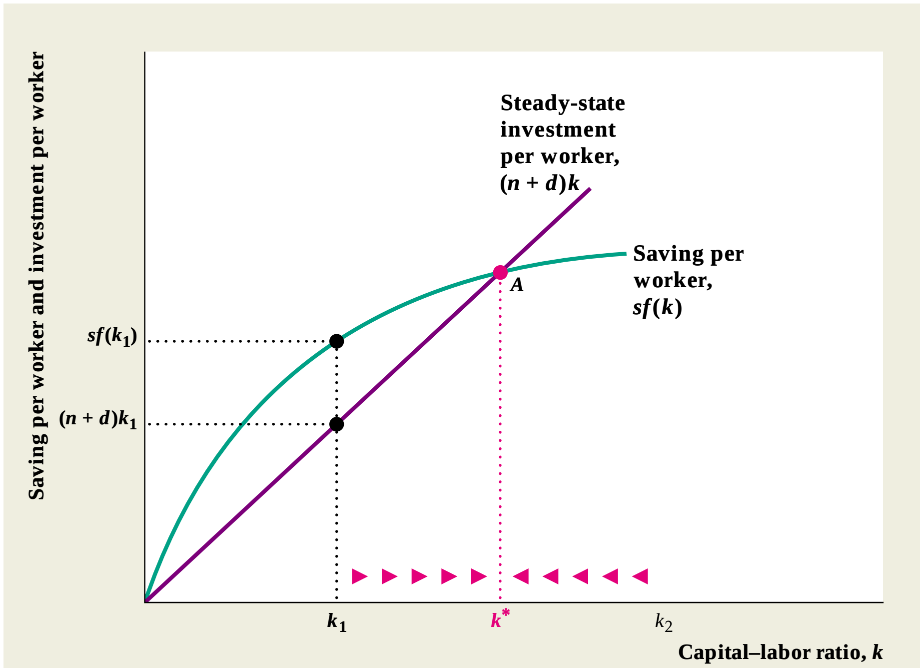


Figure 6.3
Determining the capital–labor ratio in the steady state
The steady-state capital–labor ratio, k^*, is determined by the condition that saving per worker, $sf(k)$, equals steady-state investment per worker, $(n + d)k$. The steady-state capital–labor ratio, k^*, corresponds to point A, where the saving curve and the steady-state investment line cross. From any starting point, eventually the capital–labor ratio reaches k^*. If the capital–labor ratio happens to be below k^* (say, at k_1), saving per worker, $sf(k_1)$, exceeds the investment per worker, $(n + d)k_1$, needed to maintain the capital–labor ratio at k_1. As this extra saving is converted into capital, the capital–labor ratio will rise, as indicated by the arrows. Similarly, if the capital–labor ratio is greater than k^* (say, at k_2), saving is too low to maintain the capital–labor ratio, and it will fall over time.

According to Eq. (6.10), the steady-state capital–labor ratio must ensure that saving per worker and steady-state investment per worker are equal. The one level of the capital–labor ratio for which this condition is satisfied is shown in Fig. 6.3 as k^*, the value of k at which the saving curve and the steady-state investment line cross. For any other value of k, saving and steady-state investment won't be equal. Thus k^* is the only possible steady-state capital–labor ratio for this economy.[24]

With the unique steady-state capital–labor ratio, k^*, we can also find steady-state output and consumption per worker. From the per-worker production function, Eq. (6.4), if the steady-state capital–labor ratio is k^*, steady-state output per worker, y^*, is

$$y^* = f(k^*).$$

From Eq. (6.7) steady-state consumption per worker, c^*, equals steady-state output per worker, $f(k^*)$, minus steady-state investment per worker, $(n + d)k^*$:

$$c^* = f(k^*) - (n + d)k^*.$$

Recall that, in the empirically realistic case, a higher value of the steady-state capital–labor ratio, k^*, implies greater steady-state consumption per worker, c^*.

Using the condition that in a steady state, national saving equals steady-state investment, we found the steady-state capital–labor ratio, k^*. When capital per worker is k^*, the amount that people choose to save will just equal the amount of investment necessary to keep capital per worker at k^*. Thus, when the economy's capital–labor ratio reaches k^*, it will remain there forever.

24. Actually, there is also a steady state at the point $k = 0$, at which the capital stock, output, and consumption are zero forever. However, as long as the economy starts out with a positive amount of capital, it will never reach the zero-capital steady state.

But is there any reason to believe that the capital–labor ratio will ever reach k^* if it starts at some other value? Yes, there is. Suppose that the capital–labor ratio happens to be less than k^*; for example, it equals k_1 in Fig. 6.3. When capital per worker is k_1, the amount of saving per worker, $sf(k_1)$, is greater than the amount of investment needed to keep the capital–labor ratio constant, $(n + d)k_1$. When this extra saving is invested to create new capital, the capital–labor ratio will rise. As indicated by the arrows on the horizontal axis, the capital–labor ratio will increase from k_1 toward k^*.

If capital per worker is initially greater than k^*—for example, if k equals k_2 in Fig. 6.3—the explanation of why the economy converges to a steady state is similar. If the capital–labor ratio exceeds k^*, the amount of saving that is done will be less than the amount of investment that is necessary to keep the capital–labor ratio constant. (In Fig. 6.3, when k equals k_2, the saving curve lies below the steady-state investment line.) Thus the capital–labor ratio will fall over time from k_2 toward k^*, as indicated by the arrows. Output per worker will also fall until it reaches its steady-state value.

To summarize, if we assume no productivity growth, the economy must eventually reach a steady state. In this steady state the capital–labor ratio, output per worker, and consumption per worker remain constant over time. (However, total capital, output, and consumption grow at rate n, the rate of growth of the labor force.) This conclusion might seem gloomy because it implies that living standards must eventually stop improving. However, that conclusion can be avoided if, in fact, productivity continually increases.

The Fundamental Determinants of Long-Run Living Standards

What determines how well off the average person in an economy will be in the long run? If we measure long-run well-being by the steady-state level of consumption per worker, we can use the Solow model to answer this question. Here, we discuss three factors that affect long-run living standards: the saving rate, population growth, and productivity growth (see Summary table 8).

Summary 8

The Fundamental Determinants of Long-Run Living Standards

An increase in	Causes long-run output, consumption, and capital per worker to	Reason
The saving rate, s	Rise	Higher saving allows for more investment and a larger capital stock.
The rate of population growth, n	Fall	With higher population growth more output must be used to equip new workers with capital, leaving less output available for consumption or to increase capital per worker.
Productivity	Rise	Higher productivity directly increases output; by raising incomes, it also raises saving and the capital stock.

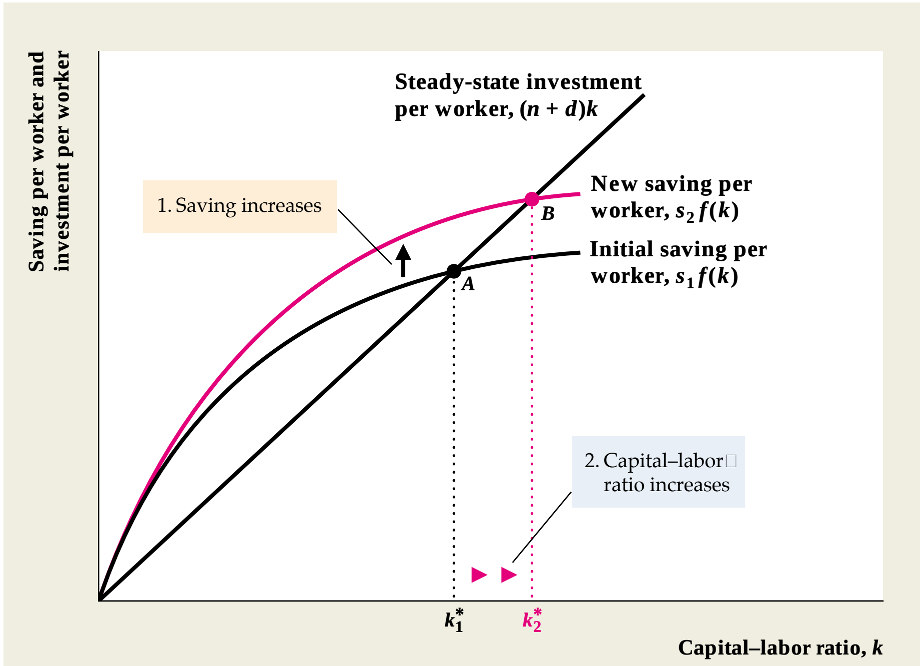


Figure 6.4
The effect of an increased saving rate on the steady-state capital–labor ratio
An increase in the saving rate from s_1 to s_2 raises the saving curve from $s_1f(k)$ to $s_2f(k)$. The point where saving per worker equals steady-state investment per worker moves from point *A* to point *B*, and the corresponding capital–labor ratio rises from k_1^* to k_2^*. Thus a higher saving rate raises the steady-state capital–labor ratio.

The Saving Rate. According to the Solow model, a higher saving rate implies higher living standards in the long run, as illustrated in Fig. 6.4. Suppose that the economy's initial saving rate is s_1 so that saving per worker is $s_1f(k)$. The saving curve when the saving rate is s_1 is labeled "Initial saving per worker." The initial steady-state capital–labor ratio, k_1^*, is the capital–labor ratio at which the initial saving curve and the investment line cross (point *A*).

Suppose now that the government introduces policies that strengthen the incentives for saving, causing the country's saving rate to rise from s_1 to s_2. The increased saving rate raises saving at every level of the capital–labor ratio. Graphically, the saving curve shifts upward from $s_1f(k)$ to $s_2f(k)$. The new steady-state capital–labor ratio, k_2^*, corresponds to the intersection of the new saving curve and the investment line (point *B*). Because k_2^* is larger than k_1^*, the higher saving rate has increased the steady-state capital–labor ratio. Gradually, this economy will move to the higher steady-state capital–labor ratio, as indicated by the arrows on the horizontal axis. In the new steady state, output per worker and consumption per worker will be higher than in the original steady state.

An increased saving rate leads to higher output, consumption, and capital per worker in the long run, so it seems that a policy goal should be to make the country's saving rate as high as possible. However, this conclusion isn't necessarily correct: Although a higher saving rate raises consumption per worker in the long run, an increase in the saving rate initially causes consumption to fall. This decline occurs because, at the initial level of output, increases in saving and investment leave less available for current consumption. Thus higher future consumption has a cost in terms of lower present consumption. Society's choice of a saving rate should take into account this trade-off between current and future consumption.

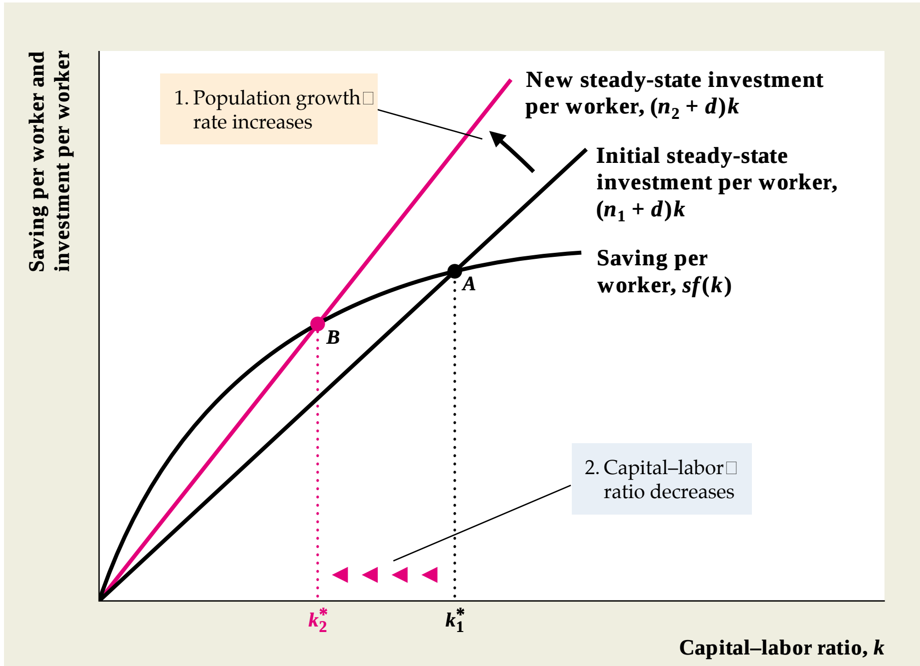


Figure 6.5
The effect of a higher population growth rate on the steady-state capital–labor ratio
An increase in the population growth rate from n_1 to n_2 increases steady-state investment per worker from $(n_1 + d)k$ to $(n_2 + d)k$. The steady-state investment line pivots up and to the left as its slope rises from $n_1 + d$ to $n_2 + d$. The point where saving per worker equals steady-state investment per worker shifts from point *A* to point *B*, and the corresponding capital–labor ratio falls from k_1^* to k_2^*. A higher population growth rate therefore causes the steady-state capital–labor ratio to fall.

Beyond a certain point the cost of reduced consumption today will outweigh the long-run benefits of a higher saving rate.

Population Growth. In many developing countries a high rate of population growth is considered to be a major problem, and reducing it is a primary policy goal. What is the relationship between population growth and a country's level of development, as measured by output, consumption, and capital per worker?

The Solow model's answer to this question is shown in Fig. 6.5. An initial steady-state capital–labor ratio, k_1^*, corresponds to the intersection of the steady-state investment line and the saving curve at point *A*. Now suppose that the rate of population growth, which is the same as the rate of labor force growth, rises from an initial level of n_1 to n_2. What happens?

An increase in the population growth rate means that workers are entering the labor force more rapidly than before. These new workers must be equipped with capital. Thus, to maintain the same steady-state capital–labor ratio, the amount of investment per current member of the work force must rise. Algebraically, the rise in n increases steady-state investment per worker from $(n_1 + d)k$ to $(n_2 + d)k$. This increase in the population growth rate causes the steady-state investment line to pivot up and to the left, as its slope rises from $(n_1 + d)$ to $(n_2 + d)$.

After the pivot of the steady-state investment line, the new steady state is at point *B*. The new steady-state capital–labor ratio is k_2^*, which is lower than the original capital–labor ratio, k_1^*. Because the new steady-state capital–labor ratio is lower, the new steady-state output per worker and consumption per worker will be lower as well.

Thus the Solow model implies that increased population growth will lower living standards. The basic problem is that when the work force is growing rapidly, a large part of current output must be devoted just to providing capital for the new workers to use. This result suggests that policies to control population growth will indeed improve living standards.

There are some counterarguments to the conclusion that policy should aim to reduce population growth. First, although a reduction in the rate of population growth n raises consumption *per worker*, it also reduces the growth rate of *total* output and consumption, which grow at rate n in the steady state. Having fewer people means more for each person but also less total productive capacity. For some purposes (military, political) a country may care about its total output as well as output per person. Thus, for example, some countries of Western Europe are concerned about projections that their populations will actually shrink in the next century, possibly reducing their ability to defend themselves or influence world events.

Second, an assumption in the Solow model is that the proportion of the total population that is of working age is fixed. When the population growth rate changes dramatically, this assumption may not hold. For example, declining birth rates in the United States imply that the ratio of working-age people to retirees will become unusually low early in the twenty-first century, a development that may cause problems for Social Security funding and other areas such as health care.

Productivity Growth. A significant aspect of the basic Solow model is that, ultimately, the economy reaches a steady state in which output per capita is constant. But in the introduction to this chapter we described how Japanese output per person has grown by a factor of 28 since 1870! How can the Solow model account for that sustained growth? The key is a factor that we haven't yet made part of the analysis: productivity growth.

The effects of a productivity improvement—the result of, say, a new technology—are shown in Figs. 6.6 and 6.7. An improvement in productivity corresponds to an upward shift in the per-worker production function because, at any prevailing capital–labor ratio, each worker can produce more output. Figure 6.6 shows a shift from the original production function, $y = f_1(k)$, to a "new, improved" production function, $y = f_2(k)$. The productivity improvement corresponds to a beneficial supply shock, as explained in Chapter 3.

Figure 6.7 shows the effects of this productivity improvement in the Solow model. As before, the initial steady state is determined by the intersection of the saving curve and the steady-state investment line at point A; the corresponding steady-state capital–labor ratio is k_1^*. The productivity improvement raises output per worker for any level of the capital–labor ratio. As saving per worker is a constant fraction, s, of output per worker, saving per worker also rises at any capital–labor ratio. Graphically, the saving curve shifts upward from $sf_1(k)$ to $sf_2(k)$, now intersecting the steady-state investment line at point B. The new steady-state capital–labor ratio is k_2^*, which is higher than the original steady-state capital–labor ratio, k_1^*.

Overall, a productivity improvement raises steady-state output and consumption per worker in two ways. First, it directly increases the amount that can be produced at any capital–labor ratio. Second, as Fig. 6.7 shows, by raising the supply of saving, a productivity improvement causes the long-run capital–labor ratio to rise. Thus a productivity improvement has a doubly beneficial impact on the standard of living.

Figure 6.6
An improvement in productivity
An improvement in productivity shifts the per-worker production function upward from the initial production function, $y = f_1(k)$, to the new production function, $y = f_2(k)$. After the productivity improvement, more output per worker, y, can be produced at any capital–labor ratio, k.

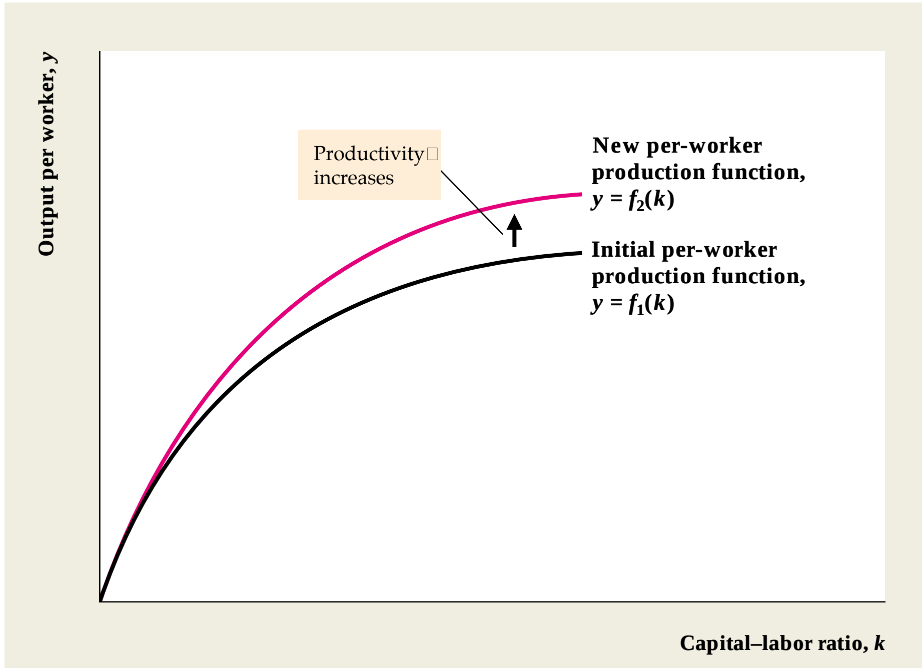
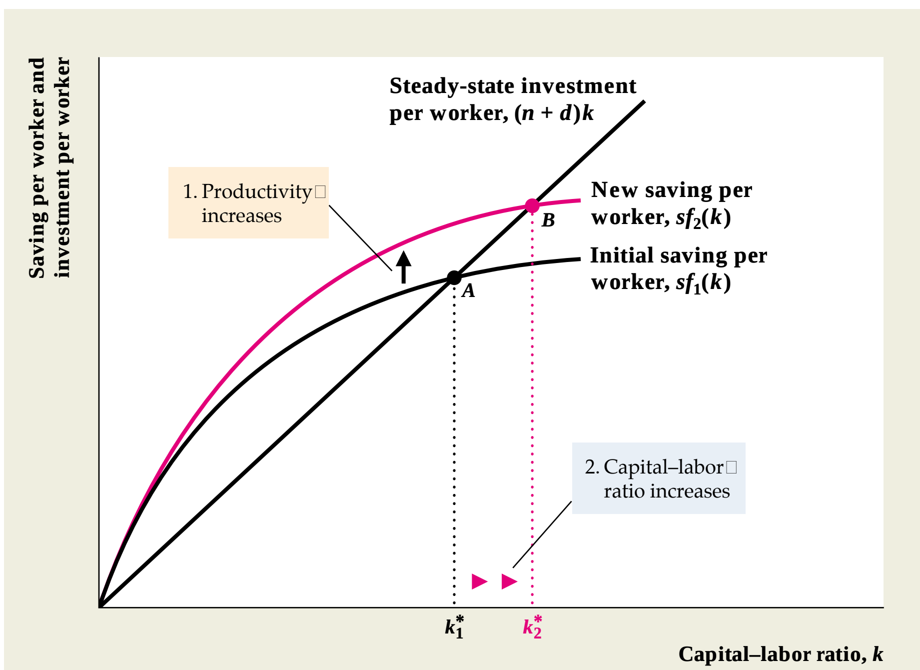


Figure 6.7
The effect of a productivity improvement on the steady-state capital–labor ratio
A productivity improvement shifts the production function upward from $f_1(k)$ to $f_2(k)$, raising output per worker for any capital–labor ratio. Because saving is proportional to output, saving per worker also rises, from $sf_1(k)$ to $sf_2(k)$. The point where saving per worker equals steady-state investment per worker shifts from point A to point B, and the corresponding steady-state capital–labor ratio rises from k_1^* to k_2^*. Thus a productivity improvement raises the steady-state capital–labor ratio.



Like a one-time increase in the saving rate or decrease in the population growth rate, a one-time productivity improvement shifts the economy only from one steady state to a higher one. When the economy reaches the new steady state, consumption per worker once again becomes constant. Is there some way to keep consumption per worker growing indefinitely?

In reality, there are limits to how high the saving rate can rise (it certainly can't exceed 100%!) or how low the population growth rate can fall. Thus higher saving rates or slower population growth aren't likely sources of continually higher living standards. However, since the Industrial Revolution, if not before, people have shown remarkable ingenuity in becoming more and more productive. In the very long run, according to the Solow model, only these continuing increases in productivity hold the promise of perpetually better living standards. Thus we conclude that, *in the long run, the rate of productivity improvement is the dominant factor determining how quickly living standards rise.*

Application

Do Economies Converge?

A wide gulf separates living standards in the richest and the poorest nations of the world. Will this difference persist forever? Will, indeed, the "rich get richer and the poor get poorer"? Or will national living standards ultimately converge? These questions obviously are of immense importance for humanity's future. In this Application we discuss what the Solow model says about the prospects for convergence and then turn to the empirical evidence.

There are at least three possible scenarios for the evolution of living standards throughout the world: unconditional convergence, conditional convergence, and no convergence.

By **unconditional convergence** we mean that the poor countries eventually will catch up to the rich countries so that in the long run living standards around the world become more or less the same. The Solow model predicts unconditional convergence under certain special conditions. For example, let's suppose that the world's economies differed principally in terms of their capital–labor ratios, with rich countries having high capital–labor ratios and high levels of output per worker, and poor countries having low capital–labor ratios and low levels of output per worker. Suppose, however, that in other respects—specifically in terms of saving rates, population growth rates, and the production functions to which they had access—rich and poor countries were the same. If each of a group of countries has the same saving rate, population growth rate, and production function, the Solow model predicts that—despite any differences in initial capital–labor ratios—these countries all will eventually reach the same steady state. In other words, according to the Solow model, if countries have the same fundamental characteristics, capital–labor ratios and living standards will unconditionally converge, even though some countries may start from way behind.

But if countries differ in characteristics such as their saving rates, population growth rates, and access to technology, according to the Solow model they will converge to different steady states, with different capital–labor ratios and different living standards in the long run. If countries differ in fundamental characteristics, the Solow model predicts **conditional convergence,** by which we mean that living standards will converge only within groups of countries having similar characteristics. For example, if there is conditional convergence, a poor country with a low

(*Continued*)

saving rate may catch up someday to a richer country that also has a low saving rate, but it will never catch up to a rich country that has a high saving rate.

For a variety of reasons (such as different cultures, political systems, and economic policies) countries do differ in characteristics such as saving rates, so conditional convergence seems to be the most likely outcome. However, our discussion so far assumes that these economies are all closed economies. According to the Solow model, if economies are open and international borrowing and lending flow freely, some additional economic forces support unconditional convergence. In particular, as poor countries have less capital per worker and thus higher marginal products of capital than do rich countries, savers in all countries will be able to earn the highest return by investing in poor countries. Thus foreign investment should cause capital stocks in poor countries to grow rapidly, even if domestic saving rates are low. Eventually, borrowing abroad should allow initially poor countries' capital–labor ratios and output per worker to be the same as in initially rich countries.[25]

The third possibility is *no convergence*, by which we mean that poor countries don't catch up over time. Living standards may even diverge (the poor get poorer and the rich get richer). Although reconciling the no-convergence scenario with the Solow model isn't impossible (for example, permanent differences in productivity growth rates across countries could lead to divergence), this outcome would be inconsistent with the spirit of that model, which tends to favor the general idea of convergence.

What is the evidence? Unfortunately (from the perspective of the world's poor countries), there is little empirical support for unconditional convergence: Most studies have uncovered little tendency for poor countries to catch up with rich ones. For example, in a study of seventy-two countries over the period 1950–1985, William Baumol[26] of Princeton University and New York University found no overall tendency toward convergence. Using data beginning in 1870, Baumol did find some evidence for convergence among a group of sixteen major free-market economies, with the countries in the sample that were relatively poorest in 1870 growing somewhat more rapidly over the period. However, J. Bradford DeLong[27] of the University of California at Berkeley pointed out that the countries Baumol studied were the richest countries as of 1980. In choosing this set of countries, DeLong argued, Baumol created a bias in favor of finding convergence, because countries that failed to converge to high levels of output per hour would not be included among the sample of currently rich countries. DeLong showed that if Baumol's sample were expanded to include countries that were relatively rich in 1870 but are not among the richest countries today—countries such as Argentina, Chile, the former East Germany, Ireland, New Zealand, Portugal, and Spain—Baumol's evidence for convergence disappears.

The evidence for conditional convergence, however, seems much better. For example, an article by N. Gregory Mankiw of Harvard University, David Romer of

(*Continued*)

25. Although output per worker in poor countries converges to that of rich countries, consumption per worker will remain at a lower level in poor countries because part of output must be used to repay foreign investors.
26. "Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show," *American Economic Review*, December 1986, pp. 1072–1085.
27. "Productivity Growth, Convergence and Welfare: Comment," *American Economic Review*, December 1988, pp. 1138–1154.

(*Continued*)
the University of California at Berkeley, and David Weil[28] of Brown University examined a sample of ninety-eight countries for the period 1960–1985. Although they found no evidence for unconditional convergence in their data, Mankiw, Romer, and Weil showed that the failure of poor countries to catch up reflected high rates of population growth and low rates of saving (defined broadly to include resources devoted to education along with those devoted to accumulation of physical capital). After correcting for differences in national saving rates and population growth rates, Mankiw, Romer, and Weil found strong tendencies for countries with similar characteristics to converge. Similar results were obtained by Robert Barro of Harvard University and Xavier Sala-i-Martin[29] of Columbia University, who also demonstrated a convergence of living standards among the states of the United States. Because the states are similar in fundamental economic characteristics, such as saving rates and access to technology, this result also is consistent with conditional convergence.

The findings in support of conditional convergence are encouraging for the Solow model, and they provide some empirical confirmation that factors such as the saving rate (including the provision of resources for education) are important for growth. These results also suggest that international capital markets linking rich and poor countries are not as efficient as we might hope because evidently foreign investment in poor countries has been insufficient to overcome the problem of low domestic saving rates. Possibly, political barriers such as legal limits or high taxes on foreign investment prevent enough foreign lending from flowing into poor countries. Alternatively, potential lenders in rich nations may not be able to obtain adequate information about investment opportunities in countries that are physically distant and have different languages, cultures, and legal systems.

28. "A Contribution to the Empirics of Economic Growth," *Quarterly Journal of Economics*, May 1992, pp. 407–438.
29. "Convergence," *Journal of Political Economy*, April 1992, pp. 223–251.

Endogenous Growth Theory

The traditional Solow model of economic growth has proved quite useful, but it nevertheless has at least one serious shortcoming as a model of economic growth. According to the Solow model, productivity growth is the only source of long-run growth of output per capita, so a full explanation of long-run economic growth requires an explanation of productivity growth. The model, however, simply takes the rate of productivity growth as given, rather than trying to explain how it is determined. That is, the Solow model *assumes*, rather than *explains*, the behavior of the crucial determinant of the long-run growth rate of output per capita.

In response to this shortcoming of the Solow model, a new branch of growth theory, **endogenous growth theory,** has been developed to try to explain productivity growth—and hence the growth rate of output—*endogenously*, or *within the model*.[30]

30. Two important early articles in endogenous growth theory are Paul Romer, "Increasing Returns and Long-Run Growth," *Journal of Political Economy*, October 1986, pp. 1002–1037, and Robert E. Lucas, Jr., "On the Mechanics of Economic Development," *Journal of Monetary Economics*, July 1988, pp. 3–42. A more accessible description of endogenous growth theory is in Paul Romer, "The Origins of Endogenous Growth," *Journal of Economic Perspectives*, Winter 1994, pp. 3–22.

As we will see, an important implication of endogenous growth theory is that a country's long-run growth rate depends on its rate of saving and investment, not only on exogenous productivity growth (as implied by the Solow model).

Here we present a simple endogenous growth model in which the number of workers remains constant, a condition implying that the growth rate of output per worker is simply equal to the growth rate of output. Our simple endogenous growth model is based on the aggregate production function

$$Y = AK \tag{6.11}$$

where Y is aggregate output and K is the aggregate capital stock. The parameter A in Eq. (6.11) is a positive constant. According to the production function in Eq. (6.11), each additional unit of capital increases output by A units, regardless of how many units of capital are used in production. Because the marginal product of capital, equal to A, does not depend on the size of the capital stock K, the production function in Eq. (6.11) does not imply diminishing marginal productivity of capital. The assumption that the marginal productivity is constant, rather than diminishing, is a key departure from the Solow growth model.

Endogenous growth theorists have provided a number of reasons to explain why, for the economy as a whole, the marginal productivity of capital may not be diminishing. One explanation emphasizes the role of **human capital,** the economist's term for the knowledge, skills, and training of individuals. As economies accumulate capital and become richer, they devote more resources to "investing in people," through improved nutrition, schooling, health care, and on-the-job training. This investment in people increases the country's human capital, which in turn raises productivity. If the physical capital stock increases while the stock of human capital is remains fixed, there will be diminishing marginal productivity of physical capital, as each unit of physical capital effectively works with a smaller amount of human capital. Endogenous growth theory argues that, as an economy's physical capital stock increases, its human capital stock tends to increase in the same proportion. Thus, when the physical capital stock increases, each unit of physical capital effectively works with the same amount of human capital, so the marginal productivity of capital need not decrease.

A second rationalization of a constant marginal productivity of capital is based on the observation that, in a growing economy, firms have incentives to undertake research and development (R&D) activities. These activities increase the stock of commercially valuable knowledge, including new products and production techniques. According to this R&D-focused explanation, increases in capital and output tend to generate increases in technical know-how, and the resulting productivity gains offset any tendency for the marginal productivity of capital to decline.

Having examined why a production function like Eq. (6.11) might be a reasonable description of the economy as a whole, once factors such as increased human capital and research and development are taken into account, let's work out the implications of this equation. As in the Solow model, let's assume that national saving, S, is a constant fraction s of aggregate output, AK, so that $S = sAK$. In a closed economy, investment must equal saving. Recall that total investment equals net investment (the net increase in the capital stock) plus depreciation, or $I = \Delta K + dK$. Therefore, setting investment equal to saving, we have

$$\Delta K + dK = sAK. \tag{6.12}$$

Next, we divide both sides of Eq. (6.12) by K and then subtract d from both sides of the resulting equation to obtain the growth rate of the capital stock.

$$\frac{\Delta K}{K} = sA - d. \tag{6.13}$$

Because output is proportional to the capital stock, the growth rate of output $\frac{\Delta Y}{Y}$ equals the growth rate of the capital stock $\frac{\Delta K}{K}$. Therefore Eq. (6.13) implies

$$\frac{\Delta Y}{Y} = sA - d. \tag{6.14}$$

Equation (6.14) shows that, in the endogenous growth model, the growth rate of output depends on the saving rate s. As we are assuming that the number of workers remains constant over time, the growth rate of output per worker equals the growth rate of output given in Eq. (6.14), and thus depends on the saving rate s. The result that the saving rate affects the long-run growth rate of output stands in sharp contrast to the results of the Solow model, in which the saving rate does not affect the long-run growth rate. Saving affects long-run growth in the endogenous growth framework because, in that framework, higher rates of saving and capital formation stimulate greater investment in human capital and R&D. The resulting increases in productivity help to spur long-run growth. In summary, in comparison to the Solow model, the endogenous growth model places greater emphasis on saving, human capital formation, and R&D as sources of long-run growth.

Although endogenous growth theory remains in a developmental stage, the approach appears promising in at least two dimensions. First, this theory attempts to explain, rather than assumes, the economy's rate of productivity growth. Second, it shows how the long-run growth rate of output may depend on factors, such as the country's saving rate, that can be affected by government policies. Many economists working in this area are optimistic that endogenous growth theory will yield further insights into the creative processes underlying productivity growth, while providing lessons that might be applied to help the poorest nations of the world achieve substantially higher standards of living.

6.3 Government Policies to Raise Long-Run Living Standards

Increased growth and a higher standard of living in the long run often are cited by political leaders as primary policy goals. Let's take a closer look at government policies that may be useful in raising a country's long-run standard of living. (The box "The Political Environment: Economic Growth and Democracy" discusses whether changing the *form* of government—democratic or nondemocratic—affects the long-run growth rate of an economy.)

Policies to Affect the Saving Rate

The Solow model suggests that the rate of national saving is a principal determinant of long-run living standards. However, this conclusion doesn't necessarily mean that policymakers should try to force the saving rate upward, because more saving means less consumption in the short run. Indeed, if the "invisible hand" of free markets is working well, the saving rate freely chosen by individuals should be the one that optimally balances the benefit of saving more (higher future living standards) against the cost of saving more (less present consumption).

The Political Environment

Economic Growth and Democracy

Economic growth is an important social goal, but it is certainly not the only one. Most people also highly value political freedom and a democratic political process. Are these two goals conflicting or mutually supporting? If the citizens of poor countries succeed in achieving democracy, as many did during the 1980s and early 1990s, can they expect to enjoy faster economic growth as well? Or does increased political freedom involve economic sacrifice?

There are several reasons to believe that democracy may promote growth. Relative to dictatorships, democratic governments that command popular support might be expected to be more stable, to be less likely to start wars, and to have better relations with the advanced industrial nations, most of which are democracies. Constitutional protections of both human and property rights should increase the willingness of both foreigners and residents to invest in the country, and freedoms of speech and expression probably are essential for the full development of a nation's educational and scientific potential. However, the ability of a democratic government to undertake unpopular but necessary economic reforms or make other tough choices may be hampered by pressures of interest groups or fluctuations of public opinion. Similarly, a dictatorial government may be better able than a democratic one to enforce a high national saving rate and keep government spending under control.

What does empirical evidence show about the relationship between democracy and economic growth? A simple fact is that, for the most part, the richest countries of the world are democratic, and the poorest nations are nondemocratic. (There are exceptions: India is poor but is more democratic than wealthy Saudi Arabia or Singapore.) Not too much should be read into this fact, however, because many wealthy nations that are currently democratic initially achieved economic leadership under kings, princes, or emperors.

A more direct empirical test is to examine the growth performance of countries that experienced sharp changes in their level of democracy. Jenny Minier of the University of Miami* identified thirteen countries that experienced sharp increases in democracy and twenty-two countries that experienced sharp decreases in democracy during the period 1965–1987. To get a clear measure of the impact of changes in the level of democracy on the subsequent rate of economic growth, for each change in the level of democracy Minier formed a control group of countries. She chose the control groups so that prior to the change in democracy, the levels of income per capita and of democracy were the same in the control group as in the country undergoing the change. She found that over the five-year period following an increase in democracy, countries experienced economic growth that averaged almost 2%, compared with growth of –1% in the control groups. Countries that experienced a decrease in democracy had economic growth of almost 8% in the five-year period following the change, compared with almost 15% growth in the control groups. Thus, relative to the control groups, increases in democracy tended to increase economic growth, and decreases in democracy tended to decrease economic growth. These findings were strengthened by Minier's examination of growth in the fifteen-year period following a change in the level of democracy. Countries that increased democracy experienced economic growth of 32% in the fifteen years after the change (compared with 6% growth for the control groups), and countries that decreased democracy saw their economies grow by less than 8% in the fifteen years after the change (compared to 35% for the control groups).

* Jenny A. Minier, "Democracy and Growth: Alternative Approaches," *Journal of Economic Growth*, September 1998, pp. 241–266.

Despite the argument that saving decisions are best left to private individuals and the free market, some people claim that Americans save too little and that U.S. policy should aim at raising the saving rate. One possible justification for this claim is that existing tax laws discriminate against saving by taxing away part of the returns to saving; a "pro-saving" policy thus is necessary to offset this bias. Another view is that Americans are just too shortsighted in their saving decisions and must be encouraged to save more.

What policies can be used to increase saving? If saving were highly responsive to the real interest rate, tax breaks that increase the real return that savers receive would be effective. For example, some economists advocate taxing households on how much they consume rather than on how much they earn, thereby exempting from taxation the income that is saved. But, as we noted in Chapter 4, although saving appears to increase when the expected real return available to savers rises, most studies find this response to be small.

An alternative and perhaps more direct way to increase the national saving rate is by increasing the amount that the government saves; in other words, the government should try to reduce its deficit or increase its surplus. Our analysis of the "twin deficits" debate (Chapter 5) indicated that reducing the deficit by reducing government purchases will lead to more national saving. Many economists also argue that raising taxes to reduce the deficit or increase the surplus will also increase national saving by leading people to consume less. However, believers in Ricardian equivalence contend that tax increases without changes in current or planned government purchases won't affect consumption or national saving.

Policies to Raise the Rate of Productivity Growth

Of the factors affecting long-run living standards, the rate of productivity growth may well be the most important in that—according to the Solow model—only ongoing productivity growth can lead to continuing improvement in output and consumption per worker. Government policy can attempt to increase productivity in several ways.[31]

Improving Infrastructure. Some research findings suggest a significant link between productivity and the quality of a nation's infrastructure—its highways, bridges, utilities, dams, airports, and other publicly owned capital.[32] The construction of the interstate highway system in the United States, for example, significantly reduced the cost of transporting goods and stimulated tourism and other industries. In the past quarter-century the rate of U.S. government investment in infrastructure has fallen, leading to a decline in the quality and quantity of public capital.[33] Reversing this trend, some economists argue, might help achieve higher productivity. However, not everyone agrees that more infrastructure investment is needed. For example, some critics have pointed out that the links between productivity growth and infrastructure aren't clear. If rich countries are more likely to build roads and hospitals, perhaps higher productivity growth leads to more infrastructure, rather than vice versa. Others worry that infrastructure investments by the government may involve political considerations (for example, favoring the districts of powerful members of Congress) more than promoting economic efficiency.

---

31. According to endogenous growth theory, an increase in the saving rate will increase the rate of productivity growth and hence increase the growth rates of output and consumption per worker. Thus, in addition to the policies discussed here, government may attempt to increase productivity growth by trying to increase the saving rate.
32. See, for example, David A. Aschauer, "Rx for Productivity: Build Infrastructure," *Chicago Fed Letter*, Federal Reserve Bank of Chicago, September 1988.
33. For data and discussion, see Clifford Winston and Barry Bosworth, "Public Infrastructure," in Henry J. Aaron and Charles L. Schultze, eds., *Setting Domestic Priorities: What Can Government Do?*, Washington: Brookings Institution, 1992.

Building Human Capital. Recent research findings point to a strong connection between productivity growth and human capital. The government affects human capital development through educational policies, worker training or relocation programs, health programs, and in other ways. Specific programs should be examined carefully to see whether benefits exceed costs, but a case may be made for greater commitment to human capital formation as a way to boost productivity growth.

One crucial form of human capital, which we haven't yet mentioned, is entrepreneurial skill. People with the ability to build a successful new business or to bring a new product to market play a key role in economic growth. Productivity growth may increase if the government were to remove unnecessary barriers to entrepreneurial activity (such as excessive red tape) and give people with entrepreneurial skills greater incentives to use those skills productively.[34]

Encouraging Research and Development. The government also may be able to stimulate productivity growth by affecting rates of scientific and technical progress. The U.S. government directly supports much basic scientific research (through the National Science Foundation, for example). Most economists agree with this type of policy because the benefits of scientific progress, like those of human capital development, spread throughout the economy. Basic scientific research may thus be a good investment from society's point of view, even if no individual firm finds such research profitable. Some economists would go further and say that even more applied, commercially oriented research deserves government aid.

Industrial Policy

Beyond support for basic science and technology, an aggressive approach that has been proposed for encouraging technological development is industrial policy. Generally, **industrial policy** is a growth strategy in which the government—using taxes, subsidies, or regulation—attempts to influence the nation's pattern of industrial development. More specifically, some advocates of industrial policy argue that the government should subsidize and promote "high-tech" industries, so as to try to achieve or maintain national leadership in technologically dynamic areas.

The idea that the government should try to determine the nation's mix of industries is controversial. Economic theory and practice suggest that under normal circumstances the free market can allocate resources well without government assistance. Thus advocates of industrial policy must explain why the free market fails in the case of high technology. Two possible sources of market failure that have been suggested are borrowing constraints and spillovers.

Borrowing constraints are limits imposed by lenders on the amounts that individuals or small firms can borrow.[35] Because of borrowing constraints, private companies, especially start-up firms, may have difficulty obtaining enough financ-

34. For a discussion of the importance of entrepreneurial activity and how it is affected by government policy and the social environment, see William J. Baumol, "Entrepreneurship: Productive, Unproductive, and Destructive," *Journal of Political Economy*, October 1990 (part 1), pp. 893–921.
35. In the Appendix to Chapter 4, we present a further discussion of borrowing constraints.

ing for some projects. Development of a new supercomputer, for example, is likely to require heavy investment in research and development and involve a long period during which expenses are high and no revenues are coming in.

Spillovers occur when one company's innovation—say, the development of an improved computer memory chip—stimulates a flood of related innovations and technical improvements by other companies and industries. The innovative company thus may enjoy only some of the total benefits of its breakthrough while bearing the full development cost. Without a government subsidy (argue advocates of industrial policy), such companies may not have a sufficiently strong incentive to innovate.

A third argument for industrial policy has less to do with market failure and more to do with nationalism. In some industries (such as aerospace) the efficient scale of operation is so large that the world market has room for only a few firms. For the world, the most desirable outcome is that those few firms be the most efficient, lowest-cost producers. However, in terms of a single country, say, the United States, at least some of the firms in the market should be U.S. firms so that profits from the industry will accrue to the United States. Moreover, having U.S. firms in the market may enhance U.S. prestige and yield military advantages. These perceived benefits might lead the United States to subsidize its firms in that industry, helping them to compete with the firms of other nations in the race to capture the world market. Of course, other nations may well retaliate by introducing or increasing existing subsidies to their own firms.

These theoretical arguments for government intervention all assume that the government is skilled at picking "winning" technologies and that its decisions about which industries to subsidize would be free from purely political considerations. However, both assumptions are questionable. A danger of industrial policy is that the favored industries would be those with the most powerful congressional supporters, rather than those with the most economic promise.

The available evidence on the arguments for industrial policy has been surveyed by Gene Grossman[36] of Princeton University. Grossman concludes that, in general, industrial policy is not desirable because, in choosing industries to target, governments have frequently "backed the wrong horse"; the costly attempt of European governments to develop the supersonic transport (SST) and other new types of commercial airplanes is a case in point. Grossman also points out that alternative policies—such as a tax break for all research and development spending—promote technology without requiring the government to target specific industries.

However, Grossman also concedes that government intervention may be desirable in some cases, notably in the early development stages of technologically innovative products, such as computers and CAT scanners. Empirically, the potential for beneficial spillovers in these cases appears so large that government intervention may be justified, even though many projects the government may choose to support ultimately will not prove worthwhile.

36. "Promoting New Industrial Activities: A Survey of Recent Arguments and Evidence," *OECD Economic Studies*, Spring 1990, pp. 87–125.

CHAPTER SUMMARY

1. Economic growth is the principal source of improving standards of living over time. Over long periods, even small differences in growth rates can have a large effect on nations' standards of living.
2. Growth accounting is a method for breaking total output growth into the portions resulting from growth in capital inputs, growth in labor inputs, and growth in productivity. All three factors have contributed to long-run economic growth in the United States. However, the slowdown in U.S. output growth after 1973 (and in other countries) primarily reflects a sharp decline in productivity growth. Part of this slowdown may be illusory, a product of measurement problems. Other explanations of the decline in productivity growth include problems in the legal and human environment, slower technical progress, increased oil prices, and the cost of adopting new information technologies.
3. The Solow model of economic growth examines the interaction of growth, saving, and capital accumulation over time. It predicts that in the absence of productivity growth the economy will reach a steady state in which output, consumption, and capital per worker are constant.
4. According to the Solow model, each of the following leads to higher output, consumption, and capital per worker in the long run: an increase in the saving rate, a decline in the population growth rate, and an increase in productivity.
5. The Solow model implies that living standards of countries with similar saving rates, population growth rates, and production functions will tend to converge over time (conditional convergence). Empirical evidence tends to support conditional convergence. Unconditional convergence—the idea that living standards in most poor countries will eventually catch up to those of rich countries—is not supported by the data.
6. Endogenous growth theory attempts to explain, rather than assumes, the economywide rate of productivity growth. One strand of this approach emphasizes the formation of human capital, including the acquisition of skills and training by workers. A second strand focuses on research and development activity by firms. Endogenous growth theorists argue that, because growth in capital and output engenders increased human capital and innovation, the marginal productivity of capital may not be diminishing for the economy as a whole. An implication of this theory is that the saving rate can affect the long-run rate of economic growth.
7. Government policies to raise long-run living standards include raising the rate of saving and increasing productivity. Possible ways of increasing productivity involve investing in public capital (infrastructure), encouraging the formation of human capital, and increasing research and development. A more aggressive strategy is industrial policy, in which the government uses subsidies and other tools to influence the nation's pattern of industrial development—and, in particular, to stimulate high-tech industries. Theoretical arguments for the use of industrial policy include the possible existence of borrowing constraints and spillovers. Critics of this approach contend that in practice the government cannot successfully pick and subsidize only "winning" technologies.

Key Terms

Key Equations

$$\frac{\Delta Y}{Y} = \frac{\Delta A}{A} + a_K \frac{\Delta K}{K} + a_N \frac{\Delta N}{N} \qquad (6.2)$$

The growth accounting equation states that output growth, $\Delta Y/Y$, depends on the growth rate of productivity, $\Delta A/A$, the growth rate of capital, $\Delta K/K$, and the growth rate of labor, $\Delta N/N$. The elasticity of output with respect to capital, a_K, gives the percentage increase in output that results when capital increases by 1%. The elasticity of output with respect to labor, a_N, gives the percentage increase in output that results when labor increases by 1%.

$$y_t = f(k_t) \qquad (6.4)$$

For any year, t, the per-worker production function relates output per worker, y_t, to capital per worker (also called the capital–labor ratio), k_t.

$$c = f(k) - (n + d)k \qquad (6.7)$$

Steady-state consumption per worker, c, equals steady-state output per worker, $f(k)$, minus steady-state investment per worker, $(n + d)k$. Steady-state output per worker is determined by per-worker production, $f(k)$, where k is the steady-state capital–labor ratio. Steady-state investment per worker has two parts: equipping new workers with the per-worker capital stock, nk, and replacing worn-out or depreciated capital, dk.

$$sf(k) = (n + d)k \qquad (6.10)$$

The steady state is determined by the condition that saving per worker, $sf(k)$, equals steady-state investment per worker, $(n + d)k$. Saving per worker equals the saving rate s times output per worker, $f(k)$.

$$Y = AK \qquad (6.11)$$

Endogenous growth theory replaces the assumption of diminishing marginal productivity of capital with the assumption that the marginal productivity of capital is independent of the level of the capital stock. In the production function relating aggregate output Y to the aggregate capital stock K in Eq. (6.11), the marginal product of capital is constant and equal to the parameter A.

$$\frac{\Delta Y}{Y} = sA - d \qquad (6.14)$$

In an endogenous growth model, the growth rate of output, $\frac{\Delta Y}{Y}$, is determined endogenously by the saving rate, s. An increase in the saving rate increases the growth rate of output.

Review Questions

1. According to the growth accounting approach, what are the three sources of economic growth? From what basic economic relationship is the growth accounting approach derived?
2. Of the three sources of growth identified by growth accounting, which one is primarily responsible for the slowdown in U.S. economic growth after 1973? What explanations have been given for the decline in this source of growth?
3. According to the Solow model of economic growth, if there is no productivity growth, what will happen to output per worker, consumption per worker, and capital per worker in the long run?
4. True or false? The higher the steady-state capital–labor ratio is, the more consumption each worker can enjoy in the long run. Explain your answer.
5. What effect should each of the following have on long-run living standards, according to the Solow model?
   a. An increase in the saving rate.
   b. An increase in the population growth rate.
   c. A one-time improvement in productivity.
6. What is *convergence?* Explain the difference between *unconditional convergence* and *conditional convergence*. What prediction does the Solow model make about convergence? What does the evidence say?
7. What two explanations of productivity growth does endogenous growth theory offer? How does the production function in an endogenous growth model differ from the production function in the Solow model?
8. What types of policies are available to a government that wants to promote economic growth? For each type of policy you identify, explain briefly how the policy is supposed to work and list its costs or disadvantages. How does endogenous growth theory possibly change our thinking about the effectiveness of various pro-growth policies, such as increasing the saving rate?

Numerical Problems

1. Two economies, Hare and Tortoise, each start with a real GDP per person of $5000 in 1950. Real GDP per person grows 3% per year in Hare and 1% per year in Tortoise. In the year 2000, what will be real GDP per person in each economy? Make a guess first; then use a calculator to get the answer.

2. Over the past twenty years an economy's total output has grown from 1000 to 1300, its capital stock has risen from 2500 to 3250, and its labor force has increased from 500 to 575. All measurements are in real terms. Calculate the contributions to economic growth of growth in capital, labor, and productivity

a. assuming that $a_K = 0.3$ and $a_N = 0.7$.

b. assuming that $a_K = 0.5$ and $a_N = 0.5$.

3. For a particular economy, the following capital input K and labor input N were reported in four different years:

Year	K	N
1	200	1000
2	250	1000
3	250	1250
4	300	1200

The production function in this economy is

$$Y = K^{0.3}N^{0.7},$$

where Y is total output.

a. Find total output, the capital–labor ratio, and output per worker in each year. Compare year 1 with year 3 and year 2 with year 4. Can this production function be written in per-worker form? If so, write algebraically the per-worker form of the production function.

b. Repeat part (a) but assume now that the production function is $Y = K^{0.3}N^{0.8}$.

4. Use the data from Table 6.1 to calculate annual growth rates of GDP per capita for each country listed over the period 1950–1996. [*Note*: The annual growth rate z will satisfy the equation $(1 + z)^{46} = \text{GDP}_{1996}/\text{GDP}_{1950}$. To solve this equation for z using a calculator, take logs of both sides of the equation.] You will find that Germany and Japan, two countries that suffered extensive damage in World War II, had the two highest growth rates after 1950. Give a reason, based on the analysis of the Solow model, for these countries' particularly fast growth during this period.

5. An economy has the per-worker production function

$$y_t = 3k_t^{0.5},$$

where y_t is output per worker and k_t is the capital–labor ratio. The depreciation rate is 0.1, and the population growth rate is 0.05. Saving is

$$S_t = 0.3Y_t,$$

where S_t is total national saving and Y_t is total output.

a. What are the steady-state values of the capital–labor ratio, output per worker, and consumption per worker?

The rest of the problem shows the effects of changes in the three fundamental determinants of long-run living standards.

b. Repeat part (a) for a saving rate of 0.4 instead of 0.3.

c. Repeat part (a) for a population growth rate of 0.08 (with a saving rate of 0.3).

d. Repeat part (a) for a production function of

$$y_t = 4k_t^{0.5}.$$

Assume that the saving rate and population growth rate are at their original values.

6. Consider a closed economy in which the population grows at the rate of 1% per year. The per-worker production function is $y = 6\sqrt{k}$, where y is output per worker and k is capital per worker. The depreciation rate of capital is 14% per year.

a. Households consume 90% of income and save the remaining 10% of income. There is no government. What are the steady-state values of capital per worker, output per worker, consumption per worker, and investment per worker?

b. Suppose that the country wants to increase its steady-state value of output per worker. What steady-state value of the capital–labor ratio is needed to double the steady-state value of output per capita? What fraction of income would households have to save to achieve a steady-state level of output per worker that is twice as high as in part (a)?

7. Both population and the work force grow at the rate of $n = 1\%$ per year in a closed economy. Consumption is $C = 0.5(1 - t)Y$, where t is the tax rate on income and Y is total output. The per-worker production function is $y = 8\sqrt{k}$, where y is output per worker and k is the capital–labor ratio. The depreciation rate of capital is $d = 9\%$ per year. Suppose for now that there are no government purchases and the tax rate on income is $t = 0$.

a. Find expressions for national saving per worker and the steady-state level of investment per worker as functions of the capital–labor ratio, k. In the steady state, what are the values of the capital–labor ratio, output per worker, consumption per worker, and investment per worker?

b. Suppose that the government purchases goods each year and pays for these purchases using taxes on income. The government runs a balanced budget in each period and the tax rate on income is $t = 0.5$. Repeat part (a) and compare your results.

Analytical Problems

1. According to the Solow model, how would each of the following affect consumption per worker in the long run (that is, in the steady state)? Explain.

a. The destruction of a portion of the nation's capital stock in a war.

b. A permanent increase in the rate of immigration (which raises the overall population growth rate).

c. A permanent increase in energy prices.

d. A temporary rise in the saving rate.

e. A permanent increase in the fraction of the population in the labor force (the population growth rate is unchanged).

2. An economy is in a steady state with no productivity change. Because of an increase in acid rain, the rate of capital depreciation rises permanently.

a. According to the Solow model, what are the effects on steady-state capital per worker, output per worker, consumption per worker, and the long-run growth rate of the total capital stock?

b. In an endogenous growth model, what are the effects on the growth rates of output, capital, and consumption of an increase in the depreciation rate of capital?

3. This problem adds the government to the Solow model. Suppose that a government purchases goods in the amount of g per worker every year; with N_t workers in year t, total government purchases are gN_t. The government has a balanced budget so that its tax revenue in year t, T_t, equals total government purchases. Total national saving, S_t, is

$$S_t = s(Y_t - T_t),$$

where Y_t is total output and s is the saving rate.

a. Graphically show the steady state for the initial level of government purchases per worker.

b. Suppose that the government permanently increases its purchases per worker. What are the effects on the steady-state levels of capital per worker, output per worker, and consumption per worker? Does your result imply that the optimal level of government purchases is zero?

4. In a Solow-type economy, total national saving, S_t, is

$$S_t = sY_t - hK_t.$$

The extra term, $-hK_t$, reflects the idea that when wealth (as measured by the capital stock) is higher, saving is lower. (Wealthier people have less need to save for the future.)

Find the steady-state values of per-worker capital, output, and consumption. What is the effect on the steady state of an increase in h?

5. Two countries are identical in every way except that one has a much higher capital–labor ratio than the other. According to the Solow model, which country's total output will grow more quickly? Does your answer depend on whether one country or the other is in a steady state? In general terms, how will your answer be affected if the two countries are allowed to trade with each other?

6. Suppose that total capital and labor both increase by the same percentage amount, so that the amount of capital per worker, k, doesn't change. Writing the production function in per-worker terms, $y = f(k)$, requires that this increase in capital and labor must not change the amount of output produced per worker, y. Use the growth accounting equation to show that equal percentage increases in capital and labor will leave output per worker unaffected only if $a_K + a_N = 1$.

7. An economy has a per-capita production function $y = Ak^a h^{1-a}$, where A and a are fixed parameters, y is per-worker output, k is the capital–labor ratio, and h is human capital per worker, a measure of the skills and training of the average worker. The production function implies that, for a given capital–labor ratio, increases in average human capital raise output per worker.

The economy's saving rate is s, and all saving is used to create physical capital, which depreciates at rate d. Workers acquire skills on the job by working with capital; the more capital with which they have to work, the more skills they acquire. We capture this idea by assuming that human capital per worker is always proportional to the amount of capital per worker, or $h = Bk$, where B is a fixed parameter.

Find the long-run growth rates of physical capital, human capital, and output in this economy.

The Conference Board® Exercises

For The Conference Board® Business Cycle Indicators Database, go to www.awlonline.com/abel_bernanke.

1. This problem asks you to do your own growth accounting exercise. Using data since 1948, make a table of annual growth rates of real GDP, the capital stock (private equipment capital plus private structures capital), and civilian employment. Assuming $a_K = 0.3$ and $a_N = 0.7$, find the productivity growth rate for each year.

a. Graph the contributions to overall economic growth of capital growth, labor growth, and productivity growth for the period since 1948. Contrast the behavior of each of these variables in the post-1973 period to their behavior in the earlier period.

b. Compare the post-1973 behavior of productivity growth with the graph of the relative price of energy, shown in Figure 3.13. To what extent do you think the productivity slowdown can be blamed on higher energy prices?

2. Graph the U.S. capital–labor ratio since 1948 (use the sum of private equipment capital and private structures capital as the measure of capital, and civilian employment as the measure of labor). Do you see evidence of convergence to a steady state during the postwar period? Now graph real output per worker and real consumption per worker for the same period. According to the Solow model, what are the two basic explanations for the upward trends in these two variables? Can output per worker and consumption per worker continue to grow even if the capital–labor ratio stops rising?

3. Does unconditional convergence hold among the states of the United States? In other words, do states with per capita income lower (higher) than the national average tend to grow faster (slower) than the country as a whole? This problem asks you to check for convergence for your own state.

a. For your state, find real per capita personal income for 1950 and the latest date available (state data are not included in the database, but you can obtain data on state personal income from the Bureau of Economic Analysis's Web site at www.bea.doc.gov/bea/regional/spi/index.html). Was your state richer or poorer than the national average in 1950? Has it grown faster or slower than the nation as a whole since 1950? Is the evidence for your state consistent with unconditional convergence? Try this exercise for five other states from different parts of the country.

b. Repeat part (a), but compare the Southeastern region of the United States (instead of a single state) against the country as a whole. The South was poorer than the rest of the country in 1950. Is it catching up?

Reference (includes data sources for state per capita income): Robert Barro and Xavier Sala-i-Martin, "Convergence," *Journal of Political Economy*, April 1992, pp. 223–251.