chapter: 13

>> Long-Run Economic Growth

TALL TALES

CHINA IS GROWING—AND SO ARE THE CHINESE. According to official statistics, children in China are almost 2½ inches taller now than they were 30 years ago. The average Chinese citizen is still a lot shorter than the average American, but at the current rate of growth the difference may be largely gone in a couple of generations.

If that does happen, China will be following in Japan's footsteps. Older Americans tend to think of the Japanese as short, but today young Japanese men are more than 5 inches taller on average than they were in 1900, which makes them almost as tall as their American counterparts.

There's no mystery about why the Japanese grew taller—it's because they grew richer. In the early twentieth century, Japan was a relatively poor country in which many families couldn't afford to give their children adequate nutrition. As a result, their children grew up to be short adults. However, since World War II, Japan has become an economic powerhouse in which food is ample and young adults are much taller than before.

At 7'6", China's Yao Ming illustrates the positive relationship between a country's rate of long-run economic growth and its average population height.

The same phenomenon is now happening in China. Although it is still a relatively poor country, China has made great economic strides over the past 30 years. Its recent history is probably the world's most dramatic example of long-run economic growth—a sustained increase in output per capita. Yet despite its impressive performance, China is currently playing catch-up with economically advanced countries like the United States and Japan. It's still a relatively poor country because these other nations began their own processes of long-run economic growth many decades ago—and in the case of the United States and European countries, more than a century ago.

Many economists have argued that long-run economic growth—why it happens and how to achieve it—is the single most important issue in macroeconomics. In this chapter, we present some facts about long-run growth, look at the factors that economists believe determine the pace at which long-run growth takes place, examine how government policies can help or hinder growth, and address questions about the environmental sustainability of long-run growth.

WHAT YOU WILL LEARN IN THIS CHAPTER:

- Why long-run economic growth is measured as the increase in real GDP per capita, how this measure has changed over time, and how it varies across countries
- Why **productivity** is the key to long-run economic growth and how productivity is driven by **physical capital, human capital,** and progress in **technology**
- The factors that explain why long-run growth rates differ so much among countries
- How growth has varied among several important regions of the world and why the **convergence hypothesis** applies to economically advanced countries
- The question of **sustainability** and the challenges to growth posed by scarcity of natural resources and environmental degradation

Comparing Economies Across Time and Space

Before we analyze the sources of long-run economic growth, it's useful to have a sense of just how much the U.S. economy has grown over time and how large the gaps are between wealthy countries like the United States and countries that have yet to achieve comparable growth. So let's take a look at the numbers.

Real GDP per Capita

The key statistic used to track economic growth is *real GDP per capita*—real GDP divided by the population size. We focus on GDP because, as we learned in Chapter 11, GDP measures the total value of an economy's production of final goods and services as well as the income earned in that economy in a given year. We use *real* GDP because we want to separate changes in the quantity of goods and services from the effects of a rising price level. We focus on real GDP *per capita* because we want to isolate the effect of changes in the population. For example, other things equal, an increase in the population lowers the standard of living for the average person—there are now more people to share a given amount of real GDP. An increase in real GDP that only matches an increase in population leaves the average standard of living unchanged.

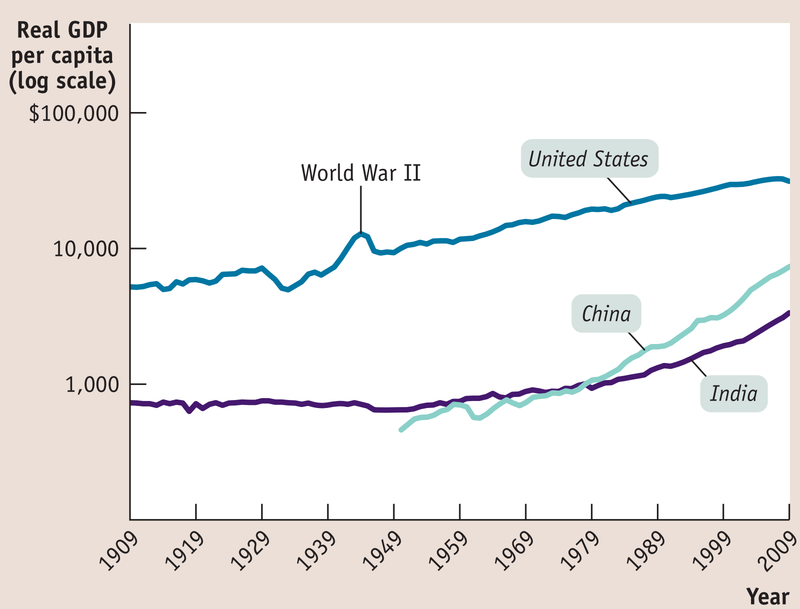
Although we also learned in Chapter 11 that growth in real GDP per capita should not be a policy goal in and of itself, it does serve as a very useful summary measure of a country's economic progress over time. Figure 13-1 shows real GDP per capita for the United States, India, and China, measured in 1990 dollars, from 1909 to 2009.

FIGURE 13-1

Economic Growth in the United States, India, and China over the Past Century

Real GDP per capita from 1909 to 2009, measured in 1990 dollars, is shown for the United States, India, and China. Equal percent changes in real GDP per capita are drawn the same size. India and China currently have a much higher growth rate than the United States. However, China has only just attained the standard of living achieved in the United States in 1909, while India is still poorer than the United States was in 1909.

Source: Angus Maddison, *Statistics on World Population, GDP, and Per Capita GDP, 1–2008AD,* http://www.ggdc.net/maddison; International Monetary Fund.



The vertical axis is drawn on a logarithmic scale so that equal percent changes in real GDP per capita across countries are the same size in the graph.

To give a sense of how much the U.S. economy grew during the last century, Table 13-1 shows real GDP per capita at 20-year intervals, expressed two ways: as a percentage of the 1909 level and as a percentage of the 2009 level. (We'll talk about India and China in a moment.) In 1929, the U.S. economy already produced 137% as much per person as it did in 1909. In 2009, it produced 608% as much per person as it did in 1909. Alternatively, in 1909 the U.S. economy produced only 16% as much per person as it did in 2009.

The income of the typical family normally grows more or less in proportion to per capita income. For example, a 1% increase in real GDP per capita corresponds, roughly, to a 1% increase in the income of the median or typical family—a family at the center of the income distribution. In 2009, the median American household had an income of about $50,000. Since Table 13-1 tells us that real GDP per capita in 1909 was only 16% of its 2009 level, a typical family in 1909 probably had a purchasing power only 16% as large as the purchasing power of a typical family in 2009. That's around $8,000 in today's dollars, representing a standard of living that we would now consider severe poverty. Today's typical American family, if transported back to the United States of 1909, would feel quite a lot of deprivation.

Yet many people in the world have a standard of living equal to or lower than that of the United States a century ago. That's the message about China and India in Figure 13-1: despite dramatic economic growth in China over the last three decades and the less dramatic acceleration of economic growth in India, China has only just attained the standard of living that the United States enjoyed in 1909, while India is still poorer than the United States was in 1909. And much of the world today is poorer than China or India.

You can get a sense of how poor much of the world remains by looking at Figure 13-2, a map of the world in which countries are classified according to their 2008 levels of

TABLE 13-1

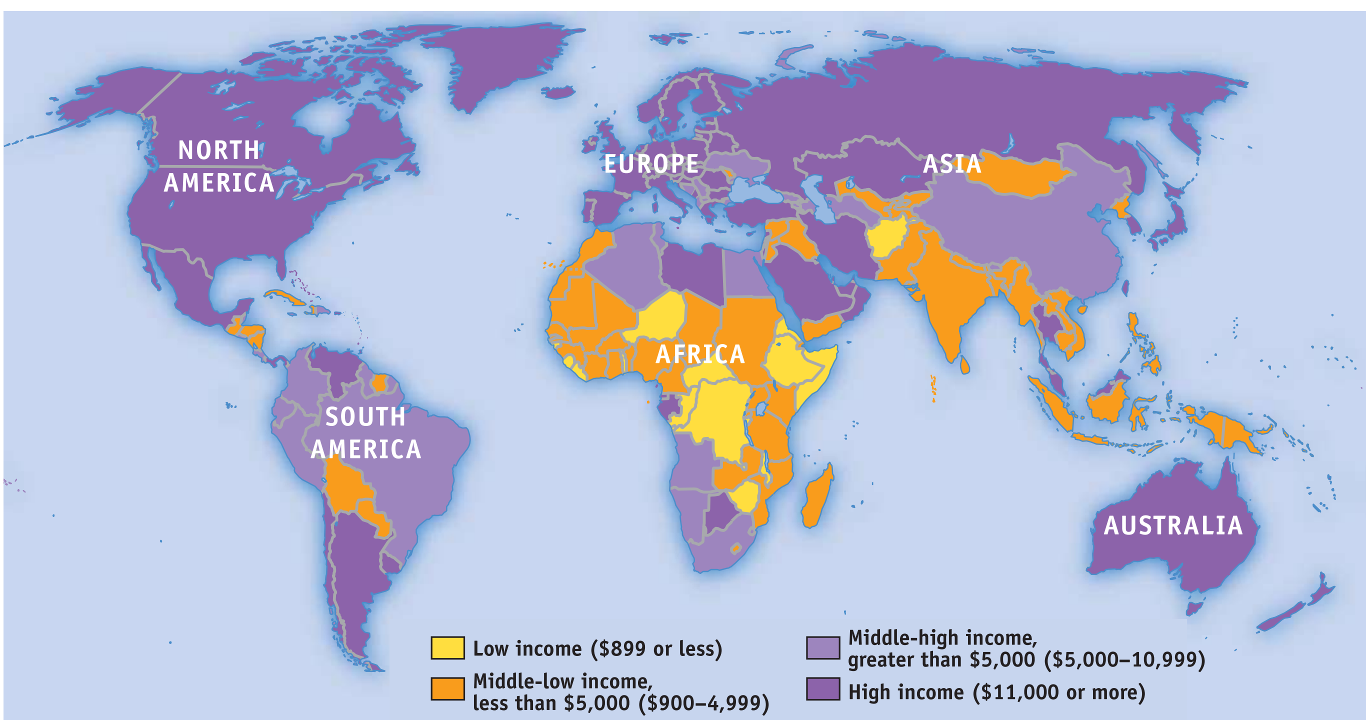
U.S. Real GDP per Capita

Year	Percentage of 1909 real GDP per capita	Percentage of 2009 real GDP per capita
1909	100%	16%
1929	137	23
1949	178	30
1969	303	50
1989	460	77
2009	600	100

Source: Angus Maddison, *Statistics on World Population, GDP, and Per Capita GDP, 1–2008AD,* http://www.ggdc.net/maddison; Bureau of Economic Analysis.

FIGURE 13-2 Incomes Around the World, 2008 Although the countries of Europe and North America—along with a few in the Pacific—have high incomes, much of the world is still very poor. Today, more than 50% of the world's population lives in countries with a lower standard of living than the United States had a century ago.

Source: International Monetary Fund.



The **Rule of 70** tells us that the time it takes a variable that grows gradually over time to double is approximately 70 divided by that variable's annual growth rate.

PITFALLS

CHANGE IN LEVELS VERSUS RATE OF CHANGE

When studying economic growth, it's vitally important to understand the difference between a change in level and a rate of change. When we say that real GDP "grew," we mean that the level of real GDP increased. For example, we might say that U.S. real GDP grew during 2008 by $58 billion.

If we knew the level of U.S. real GDP in 2007, we could also represent the amount of 2008 growth in terms of a rate of change. For example, if U.S. real GDP in 2007 was $13,254 billion, then U.S. real GDP in 2008 was $13,254 billion + $58 billion = $13,312 billion. We could calculate the rate of change, or the growth rate, of U.S. real GDP during 2008 as: (($13,312 billion − $13,254 billion)/$13,254 billion) × 100 = ($58 billion/$13,254 billion) × 100 = 0.44%. Statements about economic growth over a period of years almost always refer to changes in the growth rate.

When talking about growth or growth rates, economists often use phrases that appear to mix the two concepts and so can be confusing. For example, when we say that "U.S. growth fell during the 1970s," we are really saying that the U.S. growth rate of real GDP was lower in the 1970s in comparison to the 1960s. When we say that "growth accelerated during the early 1990s," we are saying that the growth rate increased year after year in the early 1990s—for example, going from 3% to 3.5% to 4%.

GDP per capita, in U.S. dollars. As you can see, large parts of the world have very low incomes. Generally speaking, the countries of Europe and North America, as well as a few in the Pacific, have high incomes. The rest of the world, containing most of its population, is dominated by countries with GDP less than $5,000 per capita—and often much less. In fact, today more than 50% of the world's people live in countries with a lower standard of living than the United States had a century ago.

Growth Rates

How did the United States manage to produce six times more per person in 2009 than in 1909? A little bit at a time. Long-run economic growth is normally a gradual process in which real GDP per capita grows at most a few percent per year. Over the past century, real GDP per capita in the United States increased an average of 1.8% each year.

To have a sense of the relationship between the annual growth rate of real GDP per capita and the long-run change in real GDP per capita, it's helpful to keep in mind the **Rule of 70,** *a mathematical formula that tells us how long it takes real GDP per capita, or any other variable that grows gradually over time, to double. The approximate answer is:*

(13-1) $$\text{Number of years for variable to double} = \frac{70}{\text{Annual growth rate of variable}}$$

(Note that the Rule of 70 can only be applied to a positive growth rate.) So if real GDP per capita grows at 1% per year, it will take 70 years to double. If it grows at 2% per year, it will take only 35 years to double. In fact, U.S. real GDP per capita rose on average 1.8% per year over the last century. Applying the Rule of 70 to this information implies that it should have taken 39 years for real GDP per capita to double; it would have taken 117 years—three periods of 39 years each—for U.S. real GDP per capita to double three times. That is, the Rule of 70 implies that over the course of 117 years, U.S. real GDP per capita should have increased by a factor of 2 × 2 × 2 = 8. And this does turn out to be a pretty good approximation of reality. Between 1890 and 2009—a period of 118 years—real GDP per capita rose just about eightfold.

FIGURE 13-3

Comparing Recent Growth Rates

Here the average annual rate of growth of real GDP per capita from 1980 to 2009 is shown for selected countries. China and, to a lesser extent, India and Ireland have achieved impressive growth. The United States and France have had moderate growth. Despite having once been considered an economically advanced country, Argentina has had sluggish growth. Still others, such as Zimbabwe, have slid backward.

Source: International Monetary Fund.

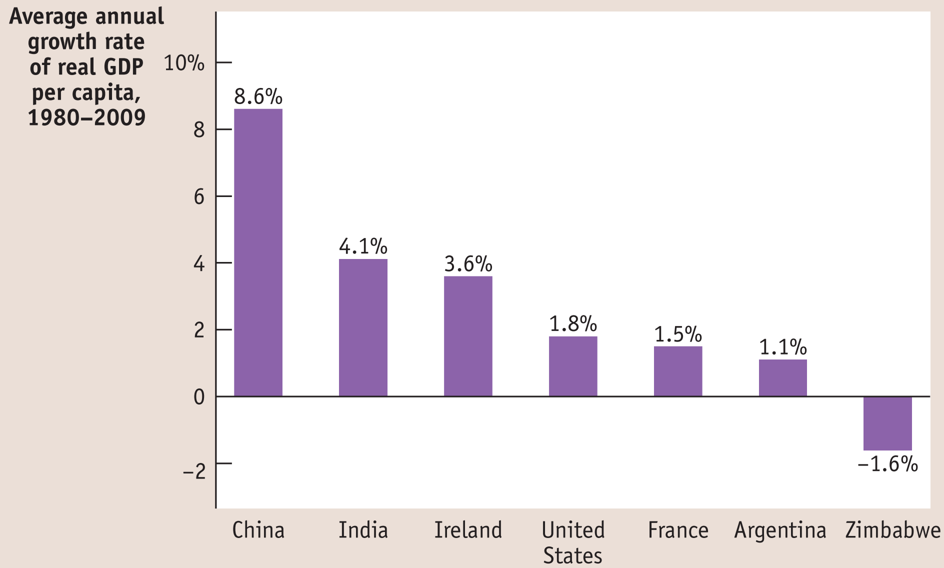


Figure 13-3 shows the average annual rate of growth of real GDP per capita for selected countries from 1980 to 2009. Some countries were notable success stories: for example, China, though still quite a poor country, has made spectacular progress. India, although not matching China's performance, has also achieved impressive growth, as discussed in the following Economics in Action.

Some countries, though, have had very disappointing growth. Argentina was once considered a wealthy nation. In the early years of the twentieth century, it was in the same league as the United States and Canada. But since then it has lagged far behind more dynamic economies. And still others, like Zimbabwe, have slid backward.

What explains these differences in growth rates? To answer that question, we need to examine the sources of long-run growth.

➤ECONOMICS IN ACTION

India Takes Off

India achieved independence from Great Britain in 1947, becoming the world's most populous democracy—a status it has maintained to this day. For more than three decades after independence, however, this happy political story was partly overshadowed by economic disappointment. Despite ambitious economic development plans, India's performance was consistently sluggish. In 1980, India's real GDP per capita was only about 50% higher than it had been in 1947; the gap between Indian living standards and those in wealthy countries like the United States had been growing rather than shrinking.

Since then, however, India has done much better. As Figure 13-3 shows, real GDP per capita has grown at an average rate of 4.1% a year, tripling between 1980 and 2009. India now has a large and rapidly growing middle class. And yes, the well-fed children of that middle class are much taller than their parents.

What went right in India after 1980? Many economists point to policy reforms. For decades after independence, India had a tightly controlled, highly regulated economy. Today, things are very different: a series of reforms opened the economy to international trade and freed up domestic competition. Some economists, however, argue that this can't be the main story, because the big policy reforms weren't adopted until 1991, yet growth accelerated around 1980.

Verity Steel/Alamy

India's high rate of economic growth since 1980 has raised living standards and led to the emergence of a rapidly growing middle class.

>> QUICK REVIEW

- Economic growth is measured using real GDP per capita.
- In the United States, real GDP per capita increased over fivefold during the twentieth century, resulting in a large increase in living standards.
- Many countries have real GDP per capita much lower than that of the United States. More than half of the world's population has living standards worse than those existing in the United States in the early 1900s.
- The long-term rise in real GDP per capita is the result of gradual growth. The **Rule of 70** tells us how many years of growth at a given annual rate it takes to double real GDP per capita.
- Growth rates of real GDP per capita differ substantially among nations.

Regardless of the explanation, India's economic rise has transformed it into a major new economic power—and allowed hundreds of millions of people to have a much better life, better than their grandparents could have dreamed. ▲

CHECK YOUR UNDERSTANDING 13-1

1. Why do economists use real GDP per capita to measure economic progress rather than some other measure, such as nominal GDP per capita or real GDP?
2. Apply the Rule of 70 to the data in Figure 13-3 to determine how long it will take each of the countries listed there to double its real GDP per capita. Would India's real GDP per capita exceed that of the United States in the future if growth rates remain the same? Why or why not?
3. Although China and India currently have growth rates much higher than the U.S. growth rate, the typical Chinese or Indian household is far poorer than the typical American household. Explain why.

Solutions appear at back of book.

The Sources of Long-Run Growth

Long-run economic growth depends almost entirely on one ingredient: rising *productivity*. However, a number of factors affect the growth of productivity. Let's look first at why productivity is the key ingredient and then examine what affects it.

The Crucial Importance of Productivity

Sustained economic growth occurs only when the amount of output produced by the average worker increases steadily. The term **labor productivity,** or **productivity** for short, is used to refer either to output per worker or, in some cases, to output per hour (the number of hours worked by an average worker differs to some extent across countries, although this isn't an important factor in the difference between living standards in, say, India and the United States). In this book we'll focus on output per worker. For the economy as a whole, productivity—output per worker—is simply real GDP divided by the number of people working.

You might wonder why we say that higher productivity is the only source of long-run growth. Can't an economy also increase its real GDP per capita by putting more of the population to work? The answer is, yes, but . . . . For short periods of time, an economy can experience a burst of growth in output per capita by putting a higher percentage of the population to work. That happened in the United States during World War II, when millions of women who previously worked only in the home entered the paid workforce. The percentage of adult civilians employed outside the home rose from 50% in 1941 to 58% in 1944, and you can see the resulting bump in real GDP per capita during those years in Figure 13-1.

Over the longer run, however, the rate of employment growth is never very different from the rate of population growth. Over the course of the twentieth century, for example, the population of the United States rose at an average rate of 1.3% per year and employment rose 1.5% per year. Real GDP per capita rose about 1.8% per year; of that, about 1.7%—that is, about 90% of the total—was the result of rising productivity. In general, overall real GDP can grow because of population growth, but any large increase in real GDP *per capita* must be the result of increased output *per worker.* That is, it must be due to higher productivity.

So increased productivity is the key to long-run economic growth. But what leads to higher productivity?

Labor productivity, often referred to simply as **productivity,** is output per worker.

Explaining Growth in Productivity

There are three main reasons why the average U.S. worker today produces far more than his or her counterpart a century ago. First, the modern worker has far more *physical capital,* such as machinery and office space, to work with. Second, the modern worker is much better educated and so possesses much more *human capital.* Finally, modern firms have the advantage of a century's accumulation of technical advancements reflecting a great deal of *technological progress.*

Let's look at each of these factors in turn.

Physical capital consists of human-made resources such as buildings and machines.

Human capital is the improvement in labor created by the education and knowledge embodied in the workforce.

Technology is the technical means for the production of goods and services.

The **aggregate production function** is a hypothetical function that shows how productivity (real GDP per worker) depends on the quantities of physical capital per worker and human capital per worker as well as the state of technology.

Physical Capital

Economists define **physical capital** as manufactured resources such as buildings and machines. Physical capital makes workers more productive. For example, a worker operating a backhoe can dig a lot more feet of trench per day than one equipped only with a shovel.

The average U.S. private-sector worker today is backed up by around $130,000 worth of physical capital—far more than a U.S. worker had 100 years ago and far more than the average worker in most other countries has today.

Human Capital

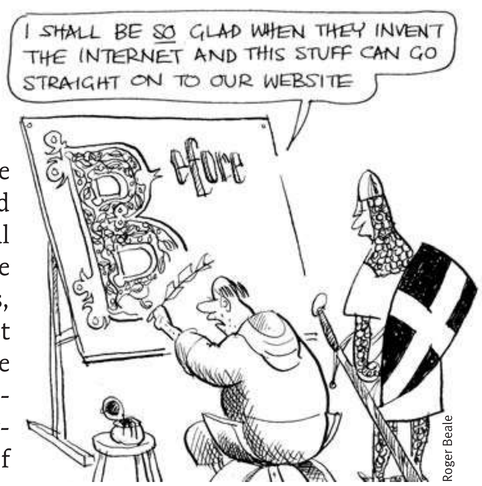
It's not enough for a worker to have good equipment—he or she must also know what to do with it. **Human capital** refers to the improvement in labor created by the education and knowledge embodied in the workforce.

The human capital of the United States has increased dramatically over the past century. A century ago, although most Americans were able to read and write, very few had an extensive education. In 1910, only 13.5% of Americans over 25 had graduated from high school and only 3% had four-year college degrees. By 2008, the percentages were 86% and 27%, respectively. It would be impossible to run today's economy with a population as poorly educated as that of a century ago.

Analyses based on *growth accounting,* described later in this chapter, suggest that education—and its effect on productivity—is an even more important determinant of growth than increases in physical capital.

Technology

Probably the most important driver of productivity growth is progress in **technology,** which is broadly defined as the technical means for the production of goods and services. We'll see shortly how economists measure the impact of technology on growth.



Roger Beale

Workers today are able to produce more than those in the past, even with the same amount of physical and human capital, because technology has advanced over time. It's important to realize that economically important technological progress need not be flashy or rely on cutting-edge science. Historians have noted that past economic growth has been driven not only by major inventions, such as the railroad or the semiconductor chip, but also by thousands of modest innovations, such as the flat-bottomed paper bag, patented in 1870, which made packing groceries and many other goods much easier, and the Post-it® note, introduced in 1981, which has had surprisingly large benefits for office productivity. As the upcoming For Inquiring Minds points out, experts attribute much of the productivity surge that took place in the United States late in the twentieth century to new technology adopted by retail companies like Wal-Mart rather than to high-technology companies.

Accounting for Growth: The Aggregate Production Function

Productivity is higher, other things equal, when workers are equipped with more physical capital, more human capital, better technology, or any combination of the three. But can we put numbers to these effects? To do this, economists make use of estimates of the **aggregate production function,** which shows how productivity depends on

An aggregate production function exhibits **diminishing returns to physical capital** when, holding the amount of human capital per worker and the state of technology fixed, each successive increase in the amount of physical capital per worker leads to a smaller increase in productivity.

the quantities of physical capital per worker and human capital per worker as well as the state of technology. In general, all three factors tend to rise over time, as workers are equipped with more machinery, receive more education, and benefit from technological advances. What the aggregate production function does is allow economists to disentangle the effects of these three factors on overall productivity.

A recent example of an aggregate production function applied to real data comes from a comparative study of Chinese and Indian economic growth by the economists Barry Bosworth and Susan Collins of the Brookings Institution. They used the following aggregate production function:

$$\text{GDP per worker} = T \times (\text{Physical capital per worker})^{0.4} \times (\text{Human capital per worker})^{0.6}$$

where T represented an estimate of the level of technology and they assumed that each year of education raises workers' human capital by 7%. Using this function, they tried to explain why China grew faster than India between 1978 and 2004. About half the difference, they found, was due to China's higher levels of investment spending, which raised its level of physical capital per worker faster than India's. The other half was due to faster Chinese technological progress.

In analyzing historical economic growth, economists have discovered a crucial fact about the estimated aggregate production function: it exhibits **diminishing returns to physical capital.** That is, when the amount of human capital per worker and the state of technology are held fixed, each successive increase in the amount of physical capital per worker leads to a smaller increase in productivity. Table 13-2 gives a hypothetical example of how the level of physical capital per worker might affect the level of real GDP per worker, holding human capital per worker and the state of technology fixed. In this example, we measure the quantity of physical capital in dollars.

As you can see from the table, there is a big payoff for the first $15,000 of physical capital: real GDP per worker rises by $30,000. The second $15,000 of physical capital also raises productivity, but not by as much: real GDP per worker goes up by only $15,000. The third $15,000 of physical capital raises real GDP per worker by only $10,000.

To see why the relationship between physical capital per worker and productivity exhibits diminishing returns, think about how having farm equipment affects the productivity of farmworkers. A little bit of equipment makes a big difference: a worker equipped with a tractor can do much more than a worker without one. And a worker using more expensive equipment will, other things equal, be more productive: a worker with a $30,000 tractor will normally be able to cultivate more farmland in a given amount of time than a worker with a $15,000 tractor because the more expensive machine will be more powerful, perform more tasks, or both.

But will a worker with a $30,000 tractor, holding human capital and technology constant, be twice as productive as a worker with a $15,000 tractor? Probably not: there's a huge difference between not having a tractor at all and having even an inexpensive tractor; there's much less difference between having an inexpensive tractor

TABLE 13-2

A Hypothetical Example: How Physical Capital per Worker Affects Productivity, Holding Human Capital and Technology Fixed

Physical capital per worker	Real GDP per worker
$0	$0
15,000	30,000
30,000	45,000
45,000	55,000

FOR INQUIRING MINDS

The Wal-Mart Effect

After 20 years of being sluggish, U.S. productivity growth accelerated sharply in the late 1990s. That is, starting in the late 1990s productivity grew at a much faster rate. What caused that acceleration? Was it the rise of the Internet?

Not according to analysts at McKinsey and Co., the famous business consulting firm. They found that a major source of productivity improvement after 1995 was a surge in output per worker in retailing—stores were selling much more merchandise per worker. And why did productivity surge in retailing in the United States? "The reason can be explained in just two syllables: Wal-Mart," wrote McKinsey.

Wal-Mart has been a pioneer in using modern technology to improve productivity. For example, it was one of the first companies to use computers to track inventory, to use bar-code scanners, to establish direct electronic links with suppliers, and so on. It continued to set the pace in the 1990s, but, increasingly, other companies have imitated Wal-Mart's business practices.

There are two lessons from the "Wal-Mart effect," as McKinsey calls it. One is that how you apply a technology makes all the difference: everyone in the retail business knew about computers, but Wal-Mart figured out what to do with them. The other is that a lot of economic growth comes from everyday improvements rather than glamorous new technologies.

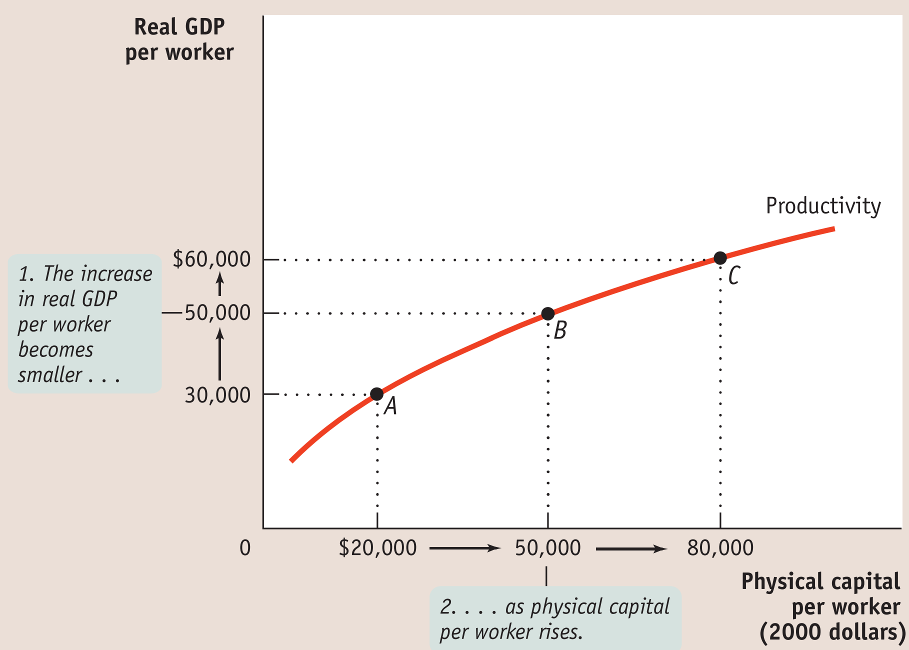
and having a better tractor. And we can be sure that a worker with a $150,000 tractor won't be 10 times as productive: a tractor can be improved only so much. Because the same is true of other kinds of equipment, the aggregate production function shows diminishing returns to physical capital.

Diminishing returns to physical capital imply a relationship between physical capital per worker and output per worker like the one shown in Figure 13-4. As the curve illustrates, more physical capital per worker leads to more output per worker. But each $30,000 increment in physical capital per worker adds less to productivity. By comparing points *A*, *B*, and *C*, you can also see that as physical capital per worker rises, output per worker also rises—but at a diminishing rate. Going from point *A* to point *B*, representing a $30,000 increase in physical capital per worker, leads to an increase of $20,000 in real GDP per worker. Going from point *B* to point *C*, a second $30,000 increase in physical capital per worker, leads to an increase of only $10,000 in real GDP per worker.

FIGURE 13-4

Physical Capital and Productivity

Other things equal, a greater quantity of physical capital per worker leads to higher real GDP per worker but is subject to diminishing returns: each successive addition to physical capital per worker produces a smaller increase in productivity. Starting at point *A*, with $20,000 in physical capital per worker, a $30,000 increase in physical capital per worker leads to an increase of $20,000 in real GDP per worker. At point *B*, with $50,000 in physical capital per worker, a $30,000 increase in physical capital per worker leads to an increase of only $10,000 in real GDP per worker.



PITFALLS

IT MAY BE DIMINISHED . . . BUT IT'S STILL POSITIVE

It's important to understand what diminishing returns to physical capital means and what it doesn't mean. As we've already explained, it's an "other things equal" statement: holding the amount of human capital per worker and the technology fixed, each successive increase in the amount of physical capital per worker results in a smaller increase in real GDP per worker. But this doesn't mean that real GDP per worker eventually falls as more and more physical capital is added. It's just that the *increase* in real GDP per worker gets smaller and smaller, albeit remaining at or above zero. So an increase in physical capital per worker will never reduce productivity. But due to diminishing returns, at some point increasing the amount of physical capital per worker no longer produces an economic payoff: at some point the increase in output is so small that it is not worth the cost of the additional physical capital.

It's important to realize that diminishing returns to physical capital is an "other things equal" phenomenon: additional amounts of physical capital are less productive *when the amount of human capital per worker and the technology are held fixed.* Diminishing returns may disappear if we increase the amount of human capital per worker, or improve the technology, or both at the same time the amount of physical capital per worker is increased. For example, a worker with a $30,000 tractor who has also been trained in the most advanced cultivation techniques may in fact be more than twice as productive as a worker with only a $15,000 tractor and no additional human capital. But diminishing returns to any one input—regardless of whether it is physical capital, human capital, or number of workers—is a pervasive characteristic of production. Typical estimates suggest that in practice a 1% increase in the quantity of physical capital per worker increases output per worker by only one-third of 1%, or 0.33%.

In practice, all the factors contributing to higher productivity rise during the course of economic growth: both physical capital and human capital per worker increase, and technology advances as well. To disentangle the effects of these factors, economists use **growth accounting,** which estimates the contribution of each major factor in the aggregate production function to economic growth. For example, suppose the following are true:

- The amount of physical capital per worker grows 3% a year.
- According to estimates of the aggregate production function, each 1% rise in physical capital per worker, holding human capital and technology constant, raises output per worker by one-third of 1%, or 0.33%.

In that case, we would estimate that growing physical capital per worker is responsible for $3\% \times 0.33 = 1$ percentage point of productivity growth per year. A similar but more complex procedure is used to estimate the effects of growing human capital. The procedure is more complex because there aren't simple dollar measures of the quantity of human capital.

Growth accounting allows us to calculate the effects of greater physical and human capital on economic growth. But how can we estimate the effects of technological progress? We do so by estimating what is left over after the effects of physical and human capital have been taken into account. For example, let's imagine that there was no increase in human capital per worker so that we can focus on changes in physical capital and in technology. In Figure 13-5, the lower curve shows the same hypothetical relationship between physical capital per worker and output per worker shown in Figure 13-4. Let's assume that this was the relationship given the technology available in 1939. The upper curve also shows a relationship between physical capital per worker and productivity, but this time given the technology available in 2009. (We've chosen a 70-year stretch to allow us to use the Rule of 70.) The 2009 curve is shifted up compared to the 1939 curve because technologies developed over the previous 70 years make it possible to produce more output for a given amount of physical capital per worker than was possible with the technology available in 1939. (Note that the two curves are measured in constant dollars.)

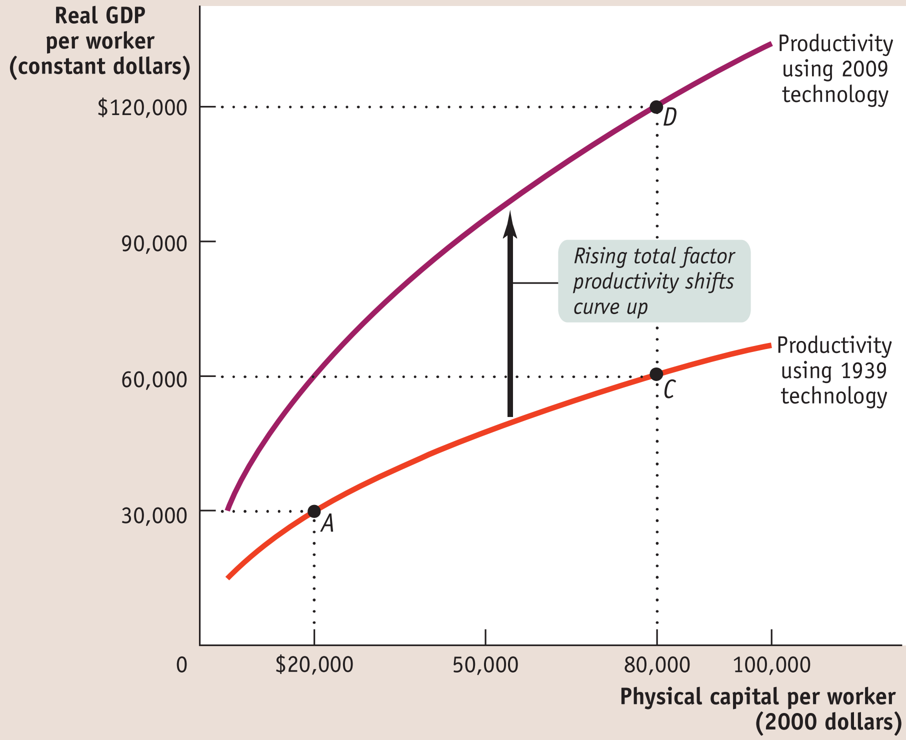
Let's assume that between 1939 and 2009 the amount of physical capital per worker rose from $20,000 to $80,000. If this increase in physical capital per worker had taken place without any technological progress, the economy would have moved from *A* to *C:* output per worker would have risen, but only from $30,000 to $60,000, or 1% per year (using the Rule of 70 tells us that a 1% growth rate over 70 years doubles output). In fact, however, the economy moved from *A* to *D:* output rose from $30,000 to $120,000, or 2% per year. There was an increase in both physical capital per worker and technological progress, which shifted the aggregate production function.

Growth accounting estimates the contribution of each major factor in the aggregate production function to economic growth.

FIGURE 13-5

Technological Progress and Productivity Growth

Technological progress shifts the productivity curve upward. Here we hold human capital per worker fixed. We assume that the lower curve (the same curve as in Figure 13-4) reflects technology in 1939 and the upper curve reflects technology in 2009. Holding technology and human capital fixed, quadrupling physical capital per worker from \$20,000 to \$80,000 leads to a doubling of real GDP per worker, from \$30,000 to \$60,000. This is shown by the movement from point *A* to point *C,* reflecting an approximately 1% per year rise in real GDP per worker. In reality, technological progress shifted the productivity curve upward and the actual rise in real GDP per worker is shown by the movement from point *A* to point *D*. Real GDP per worker grew 2% per year, leading to a quadrupling during the period. The extra 1% in growth of real GDP per worker is due to higher total factor productivity.



In this case, 50% of the annual 2% increase in productivity—that is, 1% in annual productivity growth—is due to higher **total factor productivity,** the amount of output that can be produced with a given amount of factor inputs. So when total factor productivity increases, the economy can produce more output with the same quantity of physical capital, human capital, and labor.

Most estimates find that increases in total factor productivity are central to a country's economic growth. We believe that observed increases in total factor productivity in fact measure the economic effects of technological progress. All of this implies that technological change is crucial to economic growth. The Bureau of Labor Statistics estimates the growth rate of both labor productivity and total factor productivity for nonfarm business in the United States. According to the Bureau's estimates, over the period from 1948 to 2008 American labor productivity rose 2.6% per year. Only 46% of that rise is explained by increases in physical and human capital per worker; the rest is explained by rising total factor productivity—that is, by technological progress.

What About Natural Resources?

In our discussion so far, we haven't mentioned natural resources, which certainly have an effect on productivity. Other things equal, countries that are abundant in valuable natural resources, such as highly fertile land or rich mineral deposits, have higher real GDP per capita than less fortunate countries. The most obvious modern example is the Middle East, where enormous oil deposits have made a few sparsely populated countries very rich. For example, Kuwait has about the same level of real GDP per capita as South Korea, but Kuwait's wealth is based on oil, not manufacturing, the source of South Korea's high output per worker.

Total factor productivity is the amount of output that can be achieved with a given amount of factor inputs.

But other things are often not equal. In the modern world, natural resources are a much less important determinant of productivity than human or physical capital for the great majority of countries. For example, some nations with very high real GDP per capita, such as Japan, have very few natural resources. Some resource-rich nations, such as Nigeria (which has sizable oil deposits), are very poor.

Historically, natural resources played a much more prominent role in determining productivity. In the nineteenth century, the countries with the highest real GDP per capita were those abundant in rich farmland and mineral deposits: the United States, Canada, Argentina, and Australia. As a consequence, natural resources figured prominently in the development of economic thought. In a famous book published in 1798, *An Essay on the Principle of Population,* the English economist Thomas Malthus made the fixed quantity of land in the world the basis of a pessimistic prediction about future productivity. As population grew, he pointed out, the amount of land per worker would decline. And this, other things equal, would cause productivity to fall. His view, in fact, was that improvements in technology or increases in physical capital would lead only to temporary improvements in productivity because they would always be offset by the pressure of rising population and more workers on the supply of land. In the long run, he concluded, the great majority of people were condemned to living on the edge of starvation. Only then would death rates be high enough and birth rates low enough to prevent rapid population growth from outstripping productivity growth.

It hasn't turned out that way, although many historians believe that Malthus's prediction of falling or stagnant productivity was valid for much of human history. Population pressure probably did prevent large productivity increases until the eighteenth century. But in the time since Malthus wrote his book, any negative effects on productivity from population growth have been far outweighed by other, positive factors—advances in technology, increases in human and physical capital, and the opening up of enormous amounts of cultivatable land in the New World.

It remains true, however, that we live on a finite planet, with limited supplies of resources such as oil and limited ability to absorb environmental damage. We address the concerns these limitations pose for economic growth in the final section of this chapter.

➤ECONOMICS IN ACTION

The Information Technology Paradox

From the early 1970s through the mid-1990s, the United States went through a slump in total factor productivity growth. Figure 13-6 shows Bureau of Labor Statistics estimates of annual total factor productivity growth since 1949. As you can see, there was a large fall in the productivity growth rate beginning in the early 1970s. Because higher total factor productivity plays such a key role in long-run growth, the economy's overall growth was also disappointing, leading to a widespread sense that economic progress had ground to a halt.

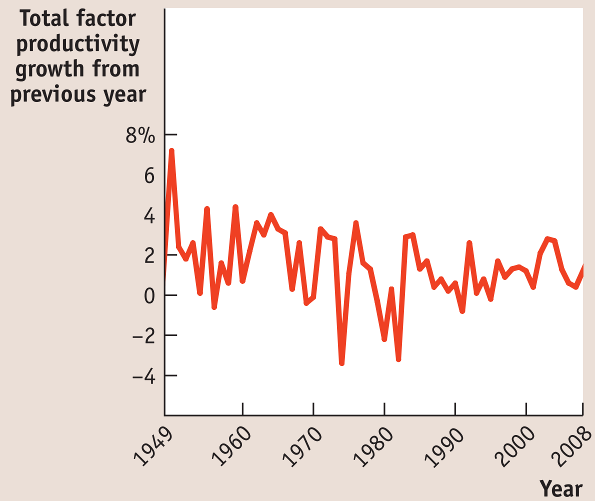
Many economists were puzzled by the slowdown in total factor productivity growth after 1973, since in other ways the era seemed to be one of rapid technological progress. Modern information technology really began with the development of the first microprocessor—a computer on a chip—in 1971. In the 25 years that followed, a series of inventions that seemed revolutionary became standard equipment in the business world: fax machines, desktop computers, cell phones, and e-mail. Yet the rate of growth of productivity remained stagnant. In a famous remark, MIT economics professor and Nobel laureate Robert Solow, a pioneer in the analysis of economic growth, declared that the information technology revolution could be seen everywhere except in the economic statistics.

FIGURE 13-6

The U.S. Productivity Growth Slowdown and Recovery

These estimates of U.S. total factor productivity growth show that the United States experienced a large fall in its total factor productivity growth rate beginning in the early 1970s and lasting through the mid-1990s. Many economists were puzzled because the fall occurred during a time of rapid technological progress. However, the likely explanation was that growth would accelerate only once people changed their way of doing business in order to take advantage of the new technology—an explanation consistent with the fact that U.S. productivity growth had a significant recovery during the second half of the 1990s.

Source: Bureau of Labor Statistics.



Why didn't information technology show large rewards? Paul David, a Stanford University economic historian, offered a theory and a prediction. He pointed out that 100 years earlier another miracle technology—electric power—had spread through the economy, again with surprisingly little impact on productivity growth at first. The reason, he suggested, was that a new technology doesn't yield its full potential if you use it in old ways.

For example, a traditional factory around 1900 was a multistory building, with the machinery tightly crowded together and designed to be powered by a steam engine in the basement. This design had problems: it was very difficult to move people and materials around. Yet owners who electrified their factories initially maintained the multistory, tightly packed layout. Only with the switch to spread-out, one-story factories that took advantage of the flexibility of electric power—most famously Henry Ford's auto assembly line—did productivity take off.

David suggested that the same phenomenon was happening with information technology. Productivity, he predicted, would take off when people really changed their way of doing business to take advantage of the new technology—such as replacing letters and phone calls with e-mail. Sure enough, productivity growth accelerated dramatically in the second half of the 1990s. And, as a For Inquiring Minds earlier in the chapter suggested, a lot of that may have been due to the discovery by companies like Wal-Mart of how to effectively use information technology. ▲

➤ CHECK YOUR UNDERSTANDING 13-2

1. Explain the effect of each of the following events on the growth rate of productivity.
   a. The amounts of physical and human capital per worker are unchanged, but there is significant technological progress.
   b. The amount of physical capital per worker grows, but the level of human capital per worker and technology are unchanged.
2. The economy of Erewhon has grown 3% per year over the past 30 years. The labor force has grown at 1% per year, and the quantity of physical capital has grown at 4% per year. The average education level hasn't changed. Estimates by economists say that each 1% increase in physical capital per worker, other things equal, raises productivity by 0.3%.
   a. How fast has productivity in Erewhon grown?
   b. How fast has physical capital per worker grown?

➤➤ QUICK REVIEW

- Long-run increases in living standards arise almost entirely from growing **labor productivity,** often simply referred to as **productivity.**
- An increase in **physical capital** is one source of higher productivity, but it is subject to **diminishing returns to physical capital.**
- **Human capital** and new **technology** are also sources of increases in productivity.
- The **aggregate production function** is used to estimate the sources of increases in productivity. **Growth accounting** has shown that rising **total factor productivity,** interpreted as the effect of technological progress, is central to long-run economic growth.
- Natural resources are less important today than physical and human capital as sources of productivity growth in most economies.