IN THIS CHAPTER YOU WILL LEARN:

- Why falling birthrates mean that we are not likely to run out of natural resources.
- Why using a mix of energy sources is efficient, even if some of them are quite costly.
- Why running out of oil would not mean running out of energy.
- How the profit motive can encourage resource conservation.
- How to use property rights to prevent deforestation and fisheries extinctions.

Natural Resource and Energy Economics

People like to consume goods and services. But to produce those goods and services, natural resources must be used up. Some natural resources, such as solar energy, forests, and schools of fish, are renewable and can potentially be exploited indefinitely. Other resources, such as oil, iron ore, and coal, are in fixed supply and can be used only once. This chapter explores two issues in relation to our supplies of resources and energy. The first is whether we are likely to run out of resources in the near or even distant future and thereby face the possibility of either a drastic reduction in living standards or even, perhaps, the collapse of civilization as we know it. The second is how to best utilize and manage our resources so that we can maximize the benefits that we receive from them both now and in the future.

We begin the chapter by addressing the issue of whether we are about to run out of resources. We then turn to energy economics and natural resource economics, focusing on the incentive structures that help to promote conservation and sustainability.

Resource Supplies: Doom or Boom?

Since the beginning of the Industrial Revolution in the late 18th century, a historically unprecedented increase in both population and living standards has taken place. The world's population has increased from 1 billion people in 1800 to about 6.5 billion today, and the average person living in the United States enjoys a standard of living at least 12 times higher than that of the average American living in 1800. Stated slightly differently, many more people are alive today and levels of consumption per person are much higher. These two factors mean that human beings are now consuming vastly more resources than before the Industrial Revolution both in absolute terms and in per capita terms. This fact has led many observers to wonder if our current economic system and its high living standards are sustainable. In particular, will the availability of natural resources be sufficient to meet the growing demand for them?

A sensible response clearly involves looking at *both* resource demand and resource supply. We begin by examining human population growth, because larger populations mean greater demand for resources.

Population Growth

We can trace the debate over the sustainability of resources back to 1798, when an Anglican minister in England named Thomas Malthus published *An Essay on the Principle of Population.* In that essay, Malthus argued that human living standards could only temporarily rise above subsistence levels. Any temporary increase in living standards would cause people to have more children and thereby increase the population. With so many more people to feed, per capita living standards would be driven back down to subsistence levels.

Unfortunately for Malthus' theory—but fortunately for society—higher living standards have *not* produced higher birthrates. In fact, just the opposite has happened. Higher standards of living are associated with *lower* birthrates. Such rates are falling rapidly throughout the world and the majority of the world's population is now living in countries that have birthrates that are lower than the **replacement rate** necessary to keep their respective populations from falling over time.

Table 27W.1 lists the total fertility rates for 12 selected nations including the United States. The **total fertility rate** is the average number of children that a woman is expected to have during her lifetime. Taking into account infant and child mortality, a total fertility rate of about 2.1 births per woman per lifetime is necessary to keep the population constant, since 2.1 children equals 1 child to replace the mother, 1 child to replace the father, and .1 extra child who can be expected to die before becoming old enough to reproduce.

As you can see from Table 27W.1, total fertility rates in many nations are well below the 2.1 rate necessary to keep the population stable over time. As a result, populations are expected to fall rapidly in many countries over the next few decades, with, for instance, the population of Russia expected to fall by about one-third from its current level of 143 million people to fewer than 100 million in 2050. And Russia is not alone; 30 countries are expected to see their populations fall by at least 10 percent by 2050, and of these, 13 are expected to experience a decline of at least 20 percent by 2050.

TABLE 27W.1 **Total Fertility Rates for Selected Countries, 2005**

Country	Total Fertility Rate
Australia	1.76
Canada	1.61
China	1.73
France	1.84
Germany	1.39
Hong Kong	0.95
Italy	1.28
Japan	1.25
Russia	1.28
South Korea	1.08
Sweden	1.66
United States	2.09

Source: 2005 value for Korea from Korean National Statistical Office, **www.nso.go.kr/eng/;** 2005 value for Japan from the Japanese Ministry of Health, Labor, and Welfare, **www.mhlw.go.jp/english/index.html;** all other figures are 2006 estimates from *The World Factbook*, **www.cia.gov.**

Worldwide, the precipitous fall of birthrates means that many **demographers** (scientists who study human populations) now expect the world's population to reach a peak of 9 billion people or fewer sometime around the middle of this century before beginning to fall, perhaps quite rapidly. For instance, if the worldwide total fertility rate declines to 1 birth per woman per lifetime (which is higher than Hong Kong's current rate of .95 per woman per lifetime), then each generation will be only half as large as the previous one because there will be only one child on average for every two parents. And even a rate of 1.3 births per woman per lifetime will reduce a country's population by half in just under 45 years.

The world's population increased so rapidly from 1800 to the present day because the higher living standards that arrive when a country begins to modernize bring with them much lower death rates. Before modernization happens, death rates are typically so high that women have to give birth to more than six children per lifetime just to ensure that, on average, two will survive to adulthood. But once living standards begin to rise and modern medical care becomes available, death rates plummet so that nearly all children survive to adulthood. This causes a temporary population explosion because parents—initially unaware that such a revolutionary change in death rates has taken place—for a while keep having six or more children. The impression persists that they must have several children to ensure that at least two will survive to adulthood. The result is one or two generations of very rapid population growth until parents adjust to the new situation and reduce the number of children that they choose to have.

The overall world population is still increasing because many countries such as India and Indonesia began modernizing only relatively recently and are still in the transition phase where death rates have fallen but birthrates are still relatively high. Nevertheless, birthrates are falling rapidly nearly everywhere. This means that the end of rapid population growth is at hand. Furthermore, because fertility rates tend to fall below the replacement rate as countries modernize, we can also expect total world population to begin to decline during the twenty-first century. This is a critical fact to keep in mind when considering whether we are likely to ever face a resource crisis: Fewer people means fewer demands placed on society's scarce resources.

Demographers have been surprised, however, at just how low fertility rates have fallen and why they have fallen so far below the replacement rate in so many countries. The decline of fertility rates to such low levels is especially surprising given the fact that couples typically tell demographers that they would like to have *at least* two children. Because this implies that most couples would prefer higher total fertility rates than we actually observe, it seems probable that social or economic factors are constraining couples to have fewer children than they desire, thereby causing total fertility rates to fall so low. Demographers have not yet reached agreement on which factors are most important, but possible candidates include changing attitudes toward religion, the much wider career opportunities available to women in modern economies, and the expense of having children in modern societies. Indeed, children have been transformed from economic assets that could be

CONSIDER THIS . . .

Can Governments Raise Birthrates?

Low birthrates pose major problems for governments. The primary problem is that with very few children being born today, very few workers will be alive in a few decades to pay the large amounts of taxes that will be needed if governments are to keep their current promises regarding Social Security and other old-age pension programs. Too few young workers will be supporting too many elderly retirees. Another potential problem is a lack of soldiers. Consider Russia. With its population expected to fall by one-third by midcentury, defending its borders will be much harder.

As a response, Russian President Vladimir Putin announced a new policy in 2006 that would pay any Russian woman who chooses to have a second child a bounty worth 250,000 rubles ($9280). In addition, the Russian government promised to double monthly child benefits in an effort to make having children less financially burdensome for parents. Many other countries have experimented with similar policies. In 2004, France began offering its mothers a payment of €800 ($1040) for each child born and Italy began offering a €1000 ($1300) payment for second children.

As far as demographers can tell, however, these and other policies aimed at raising birthrates by offering maternity leave, free day care, or other subsidies to mothers or their children have not been able to generate any sustained increases in fertility levels in any country in which they have been attempted. Unless more effective policies are developed, fertility rates seem very likely to remain low and, as a result, the total demand placed on our limited supplies of natural resources may never again face the problem of a rapidly expanding population.

put to work at an early age in agricultural societies into economic liabilities that are very costly to raise in modern societies where child labor is illegal and where children must attend school until adulthood. The nearby Consider This vignette discusses current government efforts to raise birthrates by offering financial incentives to parents.

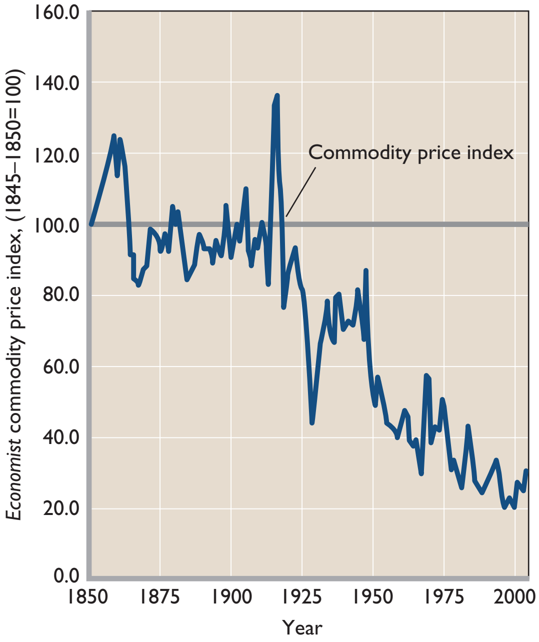
Resource Consumption per Person

Thomas Malthus' tradition of predicting a collapse in living standards has been carried on to this day by various individuals and groups. One well-reported prediction was made by Stanford University butterfly expert Paul Ehrlich. In his 1968 book, *The Population Bomb*, he made the Malthusian prediction that the population would soon outstrip resources so that "in the 1970s and 1980s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now." Contrary to this prediction, no famines approaching these magnitudes materialized then and none appear likely today.

One reason that Ehrlich's pessimism was not borne out was because the population growth rate slowed dramatically as living standards around the world rose. Another reason is that the long-run evidence indicates that the supply of productive resources available to be made into goods and services has been increasing faster than the demand for those resources for at least 150 years. This is best seen by looking at Figure 27W.1, which tracks *The Economist* magazine's commodity price index for the years 1850 to 2005. The index currently contains 25 important commodities including aluminum, copper, corn, rice, wheat, coffee, rubber, sugar, and soybeans. In earlier days, it included commodities such as candle wax, silk, and indigo, which were important at the time. The index also adjusts for inflation so that one can see how the real cost of commodities has evolved over time and it is standardized so that the real price of commodities during the years 1845 to 1850 is given a value of 100.

As Figure 27W.1 demonstrates, a dramatic long-run decline in real commodity prices has occurred. With the current value of the index at about 30, the real cost of buying commodities today is roughly 70 percent lower than it was in the initial 1845–1850 period. This means that commodity supplies have increased faster than commodity demands, since the only way that commodity prices could have fallen so much in the face of increasing demand is if the supply curve for commodities shifted to the right faster than the demand curve for commodities shifted to the right.

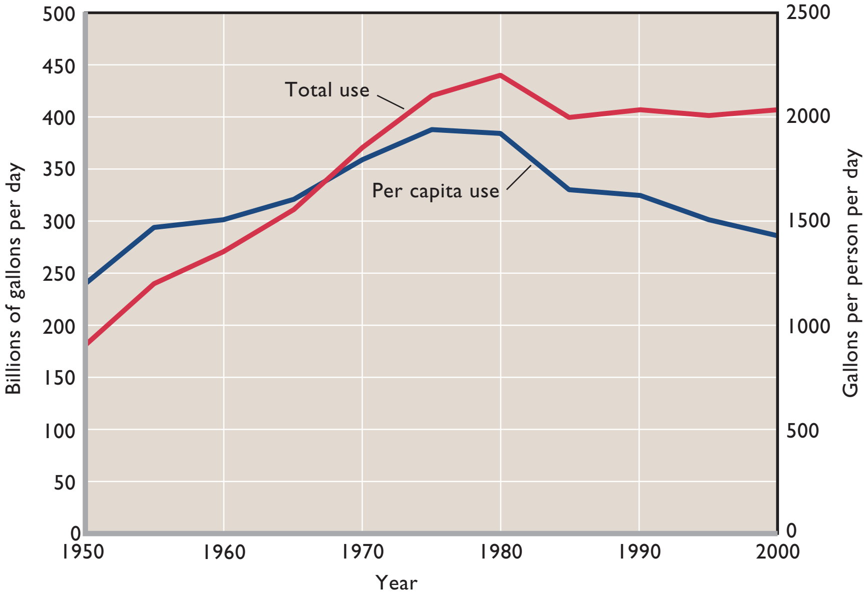
FIGURE 27W.1 ***The Economist*'s commodity price index, 1850–2005.** *The Economist* magazine's commodity price index attempts to keep track of the prices of the commodities most common in international trade. It is adjusted for inflation and scaled so that commodity prices in the years 1845–1850 are set to an index value of 100. The figure shows that real commodity prices are volatile (vary considerably from year to year) but are now 70 percent lower than they were in the mid-nineteenth century. This implies that commodity supplies have increased faster than commodity demands.



Source: The Economist, **www.economist.com.** Inflation adjustments made using the GDP deflator for the United States calculated by the Bureau of Economic Analysis, **www.bea.gov.**

A key point is that the long-run fall of commodity prices implies that commodity supplies have grown faster than the sum total of the two pressures that have acted over this time to increase commodity demands. The first is the huge rise in the total number of people alive and therefore consuming resources (since 1850, the world's population has risen from 1.25 billion to 6.5 billion). The second is the huge rise in the amount of consumption *per person*. That is, more people are alive today than in 1850, and each person alive today is on average consuming several times more than the average person alive in 1850. Still, the long-run fall in commodity prices confirms that supplies have managed to grow fast enough to overcome both these demand-increasing pressures.

But will supplies be able to overcome these two pressures in the future? Prospects are hopeful. First, the rapid and continuing decline in birthrates means that the huge population increases that occurred during the nineteenth and twentieth centuries are not likely to recur in the future. Indeed, we have seen that population decline has begun in several countries and it now seems likely that overall world population will begin to decline within this



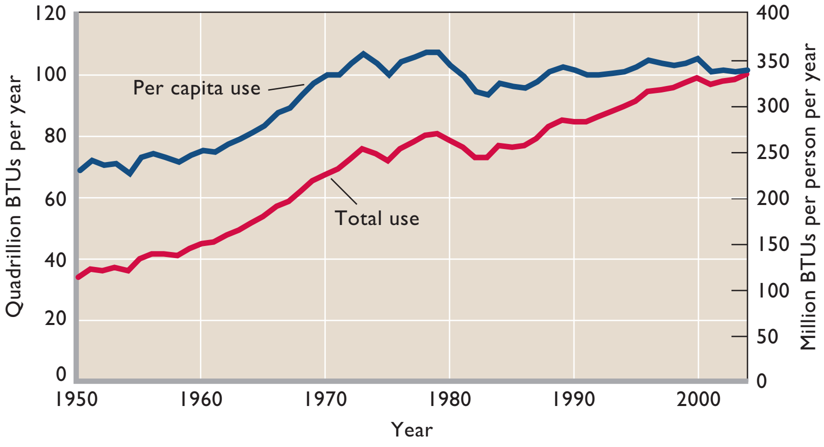
Source: United States Geologic Survey, **www.usgs.gov.**

FIGURE 27W.2 Total and per capita water use in the United States, 1950–2000. Average total water use in the United States peaked at 440 billion gallons per day in 1980 before declining to about 400 billion gallons per day in 1985, where it has remained through 2000, the last year for which data are available. Average per capita water consumption fell 28 percent from a peak of 1941 gallons per person per day in 1975 to only 1430 gallons per person per day in 2000.

century. This trend will moderate future increases in the total demand for goods and services. Second, resource consumption *per person* (as distinct from goods and services consumption per person) also has either leveled off or declined in the past decade or so in the richest countries, which currently consume the largest fraction of the world's resources.

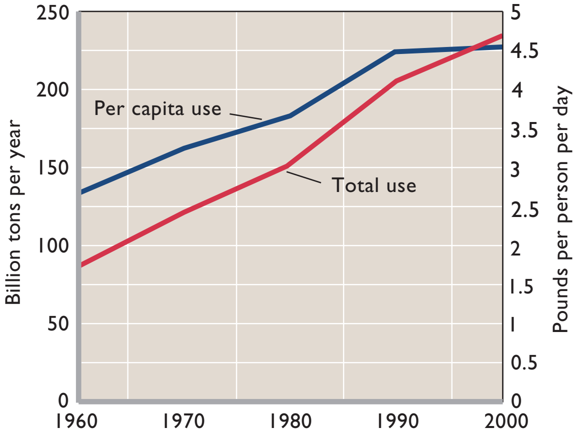
This can best be seen by looking at Figures 27W.2, 27W.3, and 27W.4, which show, respectively, how much water, energy, and other resources the United States has consumed on an annual basis both in total and per capita terms over the last few decades. The red lines in each figure show total annual use while the blue lines trace per capita annual use. To accommodate both sets of data, the units measuring total annual use are on the vertical scales on the left side of each figure while the units measuring per capita annual use are shown on the vertical scales on the right side of each figure.

The blue line in Figure 27W.2 shows that per capita water use in the United States peaked in 1975 at 1941 gallons per person per day. It then fell by over 28 percent to just 1430 gallons per person per day in 2000. The blue line in Figure 27W.3 shows that annual per capita energy use peaked at 360 million British thermal units per person



Source: United States Energy Information Administration, **www.eia.doe.gov.**

FIGURE 27W.3 Total and per capita energy consumption in the United States, 1950–2004. Per capita energy consumption in the United States peaked at 360 million British thermal units (BTUs) per person per day in 1979. It then fell over the following decade before stabilizing in the late 1980s at a value of about 340 million BTUs per person per day. Total energy consumption between 1950 and 2004 nearly tripled, increasing from 34.6 quadrillion BTUs in 1950 to 99.7 quadrillion BTUs in 2004. Since 1990, total energy consumption has increased by an average of only 1.2 percent per year.



Source: United States Environmental Protection Agency, **www.epa.gov.**

FIGURE 27W.4 Total and per capita trash generation in the United States, 1950–2000. The total annual amount of trash generated in the United States increased from 88.1 billion tons in 1960 to 234.0 billion tons in 2000. Per capita trash generation increased from an average of 2.67 pounds per person per day in 1960 to an average of 4.50 pounds per person per day in 1990, after which it leveled off so that per capita trash generation was 4.54 pounds per person per day in 2000. It has more recently fallen slightly to 4.47 pounds per person per day in 2003, the latest year for which data are available.

in 1979 before settling down to around 340 million BTUs per person after 1988. (A **British thermal unit,** or BTU, is the amount of energy required to raise the temperature of 1 pound of water by 1 degree Fahrenheit). Finally, Figure 27W.4 takes advantage of a fundamental principle of physics to show that the per capita use of other resources has also leveled off since 1990. This principle states that matter is neither created nor destroyed—only transformed—by the sorts of chemical reactions that take place as raw materials are turned into finished products and then consumed. As a result, we can measure how much use of solid objects like plastics, metals, and paper takes place by measuring how much trash is generated when they are thrown away. Consequently, since Figure 27W.4 shows that per capita trash generation has leveled off at about 4.5 pounds per person per day since 1990, we can conclude that per capita consumption of solids has also leveled off since that time.

These three figures give further cause for optimism on the availability of future resource supplies. We have already provided evidence that the number of people in the world is not likely to increase substantially. Figures 27W.2, 27W.3, and 27W.4 show that per capita consumption levels are also likely to either level off or decline. Together, these two facts suggest that the total demand for resources is likely to reach a peak in the relatively near future before falling over time as populations decline.

That being said, resource demand is likely to increase substantially for the next few decades as large parts of the world modernize and begin to consume as much per capita as the citizens of rich countries do today. For instance, per capita energy use in the United States in 2004 was 340 million BTUs per person. If every person in the world used that much energy, total annual energy demand would be 2210 quadrillion BTUs, or about 5 times the 2003 world production of 421 quadrillion BTUs. One of the world's great economic challenges over the coming decades will be to supply the resources that will be demanded as living standards in poorer countries rise to rich-country levels. But because population growth rates are slowing and because per capita resource uses in rich countries have leveled off, we can now foresee a maximum total demand for resources even if living standards all over the world rise to rich-country levels. Given the ongoing improvements in technology and productivity that characterize modern economies and which allow us to produce increasingly more from any given set of inputs, it consequently seems unlikely that we will run into a situation where the total demand for resources exhausts their overall supply.

Significant challenges, however, are still likely to appear in those places where local supplies of certain resources are extremely limited. Water, for instance, is a rare and precious commodity in many places, including the Middle East and the American Southwest. Governments will have to work hard to ensure that the limited supplies of water in such areas are used efficiently and that disputes over water rights are settled peacefully. Along the same lines, resources are often produced in certain areas but consumed in others with, for instance, one-quarter of the world's oil being produced in the Middle East but most of the demand for oil coming from Europe, North America, and East Asia. In such cases, institutions must be developed that can move such resources from the areas in which they originate to the areas in which they are used. If not, local shortages may develop in the areas that cannot produce these resources despite the fact that the resources in question may at the same time be in very plentiful supply in the areas in which they are produced.

QUICK REVIEW 27W.1

- Thomas Malthus and others have worried that increases in our demand for resources will outrun the supply of resources, but commodity prices have been falling for more than a century, indicating that supply has increased by more than demand.
- Because total fertility rates are very low and falling, population growth for the world will soon turn negative and thereby reduce the demand for natural resources.
- Per capita consumption of resources such as water, energy, and solids has either fallen or remained constant in the United States. If per capita consumption continues to stay the same or decrease while populations fall, total resource demand will fall—meaning that the demand for resources is unlikely to threaten to use up the available supply of resources.

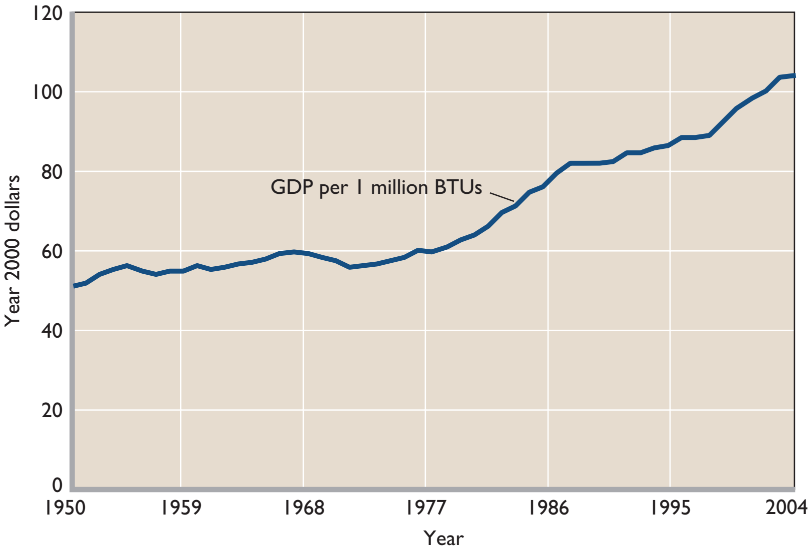
Energy Economics

Energy economics studies how people deal with energy scarcity. This involves both demand and supply. In terms of energy supply, people are interested in attempting to find and exploit low-cost energy sources. But since energy is only one input into a production process, often the best energy source to use in a given situation is, paradoxically, actually rather expensive—yet still the best choice when other costs are taken into account. The economy therefore develops and exploits many different energy sources, from fossil fuels to nuclear power.

In terms of energy demand, the most interesting fact is that per capita energy use has leveled off in recent years in developed countries, as we previously illustrated for the United States in Figure 27W.3. This fact implies that our economy has become increasingly efficient at using energy to produce goods and services. This is best seen by noting that while per capita energy inputs remained fixed at about 340 million BTUs per person per year between 1988 and 2005, real GDP per person rose during that time period by 32 percent, so that people were able to make and consume about one-third more goods and services per person despite using no more energy per person.

This increase in energy efficiency has been part of a long historical trend, as Figure 27W.5 makes quite clear. For the years 1950 through 2004, it shows the number of inflation-adjusted dollars of GDP that the U.S. economy has produced each year for every 1 million BTUs of energy consumed in the United States. The figure demonstrates that technological improvements greatly increased energy efficiency, so much so that although 1 million BTUs of energy yielded only $51.30 worth of goods and services in 1950, 1 million BTUs of energy yielded $108.70 worth of goods and services in 2004 (when the comparison is made using year 2000 dollars to account for inflation).

Keep this huge increase in energy efficiency in mind when considering the magnitude of future energy demands. Because better technology means that more output can be produced with the same amount of energy input, rising living standards in the future will not necessarily depend on using more energy. The behavior of the U.S. economy since 1988 bears this out since, as we just pointed out, real GDP per person increased by about one-third between 1988 and 2004 while per capita energy inputs



Source: United States Energy Information Administration, **www.eia.doe.gov.**

FIGURE 27W.5 Inflation adjusted GDP per million BTUs of energy consumption in the United States, 1950–2004. This figure shows the number of dollars worth of real GDP the U.S. economy produced per million BTUs of energy consumed in each year from 1950 through 2004 when annual GDP figures are converted to year 2000 dollars to account for inflation. Energy efficiency has more than doubled during this period, with real output per energy input rising from $51.30 worth of GDP per million BTUs in 1950 to $108.70 worth of GDP per million BTUs in 2004.

remained constant. Living standards can be raised without having to increase energy inputs.

Efficient Energy Use

We just saw that the United States has grown increasingly efficient at using energy. The same is true for other developed countries. An interesting fact about energy efficiency, however, is that it often involves using a mix of energy inputs, some of which are much more expensive than others. The best way to see why this is true is to examine electric power generation.

A typical electric plant has to serve tens of thousands of homes and businesses and is expected to deliver an uninterrupted supply of electricity 24 hours a day, 7 days a week. This task is not easy. The problem is that massive changes in energy demand occur over the course of a day. Demand is extremely low at night when people are sleeping, begins to rise rapidly in the morning as people wake up and turn on their lights, rises even more when they are at work, falls a bit as they commute home, rises back up a bit in the evening when they turn on their houselights to deal with the darkness and their televisions to deal with their boredom, and finally collapses as they turn out their lights and go to sleep.

The problem for electric companies as they try to minimize the costs of providing for such large variations in the demand for electricity is that the power plants that have the lowest operating costs also have the highest fixed costs in terms of construction. For instance, large coal-fired plants can produce energy at a cost of about 4 cents per kilowatt hour. But they can do this only if they are built large enough to exploit economies of scale and if they are then operated at full capacity. To see why this can be a problem, imagine that such a plant has a maximum generating capacity of 20 megawatts per hour but that its customers' peak afternoon demand for electricity is 25 megawatts per hour. One solution would be to build two 20-megawatt coal-fired plants. But that would be very wasteful because one would be operating at full capacity (and hence minimum cost), while the other would be producing only 5 megawatts of its 20-megawatt capacity. Given that such plants cost hundreds of millions of dollars to build, this would be very wasteful.

The solution that electric companies employ is to use a mix of different types of generation technology. This turns out to be optimal because even though some electricity generation plants have very high operating costs, they have low fixed costs (that is, they are very inexpensive to build). Thus, the power company in our example might build one large coal-fired plant to generate 20 of the required 25 megawatts of energy at 4 cents per kilowatt hour, but it would then build a small 5-megawatt natural gas generator to supply the rest. Such plants produce electricity at the much higher cost of 15 cents per kilowatt hour, but they are relatively inexpensive to build. As a result, this solution would save the electric company from having to build a second very expensive coal-fired plant that would wastefully operate well below its full capacity.

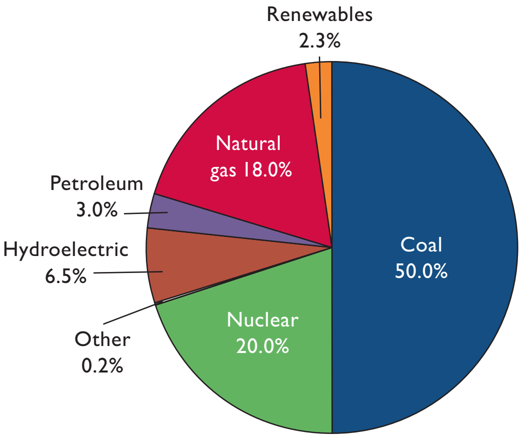
The result of this process of mixing generator technologies is that the United States currently generates electricity from a variety of energy sources, as we show in Figure 27W.6. Half of it is generated at large, low-cost coal-fired plants with the rest coming from a variety of sources including hydroelectric power, natural gas, and renewable energy sources such as geothermal, wind, and solar.

Running Out of Energy?

Some observers worry that we may soon run out of the energy needed to power our economy. Their fears are based largely on the possibility that the world will run out of oil sometime in the next century. It is the case, however, that there is no likelihood of running out of energy. If anything, running out of oil would not mean running out of energy—just running out of *cheap* energy.

This is best seen by looking at Table 27W.2, which compares oil prices with the prices at which other energy sources become economically viable. For instance, biodiesel, a type of diesel fuel made from decomposed plant wastes, is so expensive to produce that it becomes economically viable (that is, less costly to produce than oil) only if oil

FIGURE 27W.6 Percentages of U.S. electricity generated using various energy sources, 2004. About 50 percent of U.S. electricity was generated by coal-fired plants in 2004, with nuclear power and natural gas accounting together for a further 38 percent of the total.



Source: United States Energy Information Administration, **www.eia.doe.gov.**

TABLE 27W.2 **Oil Prices at Which Alternative Energy Sources Become Economically Viable**

Oil Price per Barrel at Which Alternative Is Economically Viable	Alternative Fuel
$80	Biodiesel
60	U.S. corn-based ethanol[*]
50	Shale oil
40	Tar sands; Brazilian sugar-cane-based ethanol; gas to liquids;[†] coal-to-liquids[‡]
20	Conventional oil

[*] Excludes tax credits.

[†] Gas to liquid is economically viable at $40 if natural gas price is $2.50 or less per million BTUs.

[‡] Coal to liquid is economically viable at $40 if coal price is $15 per ton or less.

Sources: Cambridge Energy Research Associates, **www.cera.com;** *The Economist,* April 22, 2006, **www.economist.com.**

costs $80 or more per barrel. On the other hand, ethanol made from corn in the United States costs less to produce and would be an economically viable alternative to oil even if the price of oil were only $60 per barrel.

The key point to gather from this table, however, is that even if we were to run out of oil, alternatives would quickly become available. At a price of $40 per barrel, vast reserves of energy derived from tar sands, the conversion of natural gas and coal to liquid petroleum, and even ethanol derived from cheap Brazilian sugar cane become economically viable alternatives. At $50 per barrel, shale oil becomes a viable alternative. At $60 per barrel, corn-based ethanol becomes viable. And at $80 per barrel, so does biodiesel.

In fact, these prices can be thought of as a giant supply curve for energy, with rising energy prices leading to increased energy production. The result is that even if the supply of oil begins to dry up and oil prices consequently rise, other energy supplies will quickly be brought on line to fill the energy gap created by the decline in the amount of oil available. Also, the alternative prices listed in Table 27W.2 are *current* alternative prices. As technologies improve, the costs of producing these alternatives are likely to fall and, as a result, the potential costs of replacing oil if it runs out will be even lower than suggested by the prices in the table. As a result, economists do not worry about running out of oil or, more generally, running out of energy. There is plenty of energy—the only question is price, and the impact of potentially increasing energy prices on the standard of living.

Finally, it should also be pointed out that energy sources differ not only with regard to their prices but also with regard to the different types and forms of externalities—especially pollution—that are generated when they are used. Burning coal, for instance, generates substantial air pollution that imposes costs on people far downwind. These externalities should be properly accounted for when comparing different potential energy sources, and natural resource economists do go to great lengths to account for externalities and to design policies that can mitigate the harm they cause. But in order to keep this chapter tightly focused on the fundamentals of natural resource and energy economics, we discuss externalities and the options available for society to deal with them separately in Chapter 28. **(Key Question 5)**

CONSIDER THIS . . .

Turning Entrails (and Nearly Anything Else) into Oil

Nature takes millions of years to apply the heat and pressure necessary to convert organic matter like dead plants and animals into oil. A company called Changing World Technologies can do the job in just 2 hours at a factory it opened in 2005 outside a turkey slaughterhouse in Carthage, Missouri.

Each day, 270 tons of discarded turkey parts (entrails, heads, feet, lungs, and so on) get converted into 500 barrels of fuel oil by means of a reaction tank that heats the debris to 500 degrees Fahrenheit while simultaneously pressurizing it to 600 pounds per square inch. The process replicates geologic pressures that normally take place in the earth's crust, pressures that break down the long chains of hydrocarbons found in plants and animals into the short chains of hydrocarbons that make up fossil fuels like methane, gasoline, and diesel. Even more amazing, the reaction tank can gulp down any sort of organic debris—used tires, Styrofoam cups, sewage water, plastic car parts—and turn it into a grade of fuel oil that can be immediately sold to utility companies for use in electric generators or which can be further refined into gasoline, diesel, and even hydrogen.

The current factory produces the oil at a cost of $80 per barrel, which is higher than the cost of buying similar oil produced the old fashioned way (that is, by pumping it out of the ground after nature does the dirty work). But with a Federal biofuel subsidy of $42 per barrel, the firm is able to make a modest profit and hopes that expanding the process to a much larger scale will allow it to drive the cost of the process down to only $30 per barrel, far less than the current market price of similar grades of oil produced naturally.

QUICK REVIEW 27W.2

- Energy efficiency has consistently improved so that more output can be produced for every unit of energy used by the economy.
- After taking the very different fixed costs of different electricity generating plants into account, utility companies find it efficient to use a variety of energy sources (coal, natural gas, nuclear) to deal with the large daily variations in energy demand with which they must cope.
- Even if we run out of oil, we will not run out of energy because many alternative sources of energy are available. These alternatives are, however, more costly than oil so that if we were to run out of oil, energy costs in the economy would most likely increase.

Natural Resource Economics

The major focus of natural resource economics is to design policies for extracting or harvesting a natural resource that will maximize the **net benefits** from doing so. The net benefits are simply the total dollar value of all benefits minus the total dollar value of all costs, so that a project's net benefit is equal to the dollar value of the gains or losses to be made. A key feature of such policies is that they take into account the fact that present and future decisions about how fast to extract or harvest a resource typically cannot be made independently. Taking more today means having less in the future and having more in the future is possible only by taking less today.

In applying this general rule, however, large differences between renewable natural resources and nonrenewable natural resources become apparent. **Renewable natural resources** include things like forests and wildlife, which are capable of growing back, or renewing themselves, if they are harvested at moderate rates. This leaves open the possibility of enjoying their benefits in perpetuity. Solar energy, the atmosphere, the oceans, and aquifers are also considered renewable natural resources either because they will continue providing us with their benefits no matter what we do (as is the case with solar energy) or because if we manage them well, we can continue to enjoy their benefits in perpetuity (as is the case with the atmosphere, the oceans, and aquifers.) **Nonrenewable natural resources** include things like oil, coal, and metals, which are either in actual fixed supply (like the metals found in the earth's crust) or which are renewed so slowly as to be in virtual fixed supply when viewed from a human time perspective (as is the case with fossil fuels like oil and coal, which take millions of years to form out of decaying plants and animals).

The key to optimally managing both renewable and nonrenewable resources is designing incentive structures that prompt decision makers to consider not only the net benefits to be made by using the resources under their control in the present but also the net benefits to be made by conserving the resources under their control in the present in order to be able to use more of them in the future. Once these incentive structures are in place, decision makers can weigh the costs and benefits of present use against the costs and benefits of future use in order to determine the optimal allocation of the resource between present and future uses. The key tool used in weighing these alternatives is present value, which allows decision makers to sensibly compare the net benefits of potential present uses with the net benefits of potential future uses.

Using Present Values to Evaluate Future Possibilities

Natural resource economics studies the optimal use of our limited supplies of resources. Decisions about optimal resource use typically involve choosing how resources will be exploited intertemporally, or over time. For instance, suppose that a poor country has just discovered that it possesses a small oil field. Should the country pump this oil today when it can make a profit of $50 per barrel, or should it wait 5 years to pump the oil given that it believes that in 5 years it will be able to make a profit of $60 per barrel due to lower production costs?

This question is difficult to answer immediately because $60 worth of money in 5 years is hard to compare with $50 worth of money today. Economists solve this problem by converting the future quantity of money (in this case $60) into a present-day equivalent measured in present-day money. That way the two quantities of money can be compared using the same unit of measurement, present-day dollars.

The formula for calculating the present-day equivalent, or **present value,** for any future sum of money (in this case, $60 in 5 years) is described in detail in Chapter 14W, but the intuition is simple. Suppose that the current market rate of interest is 5 percent per year. How much money would a person have to save and invest today at 5 percent interest in order to end up with exactly $60 in 5 years? The correct answer turns out to be $47.01 because if $47.01 is invested at an interest rate of 5 percent per year, it will grow into precisely $60 in 5 years. Stated slightly differently, $47.01 today can be thought of as being equivalent to $60 in 5 years because it is possible to transform $47.01 today into $60 in 5 years by simply investing it at the market rate of interest.

This fact is very important because it allows for a direct comparison of the benefits from the country's two possible courses of action. If it pumps its oil today, it will get $50 per barrel worth of present-day dollars. But if it pumps its oil in 5 years and gets $60 per barrel at that time, it will only get $47.01 per barrel worth of present-day dollars since the present value of $60 in 5 years is precisely $47.01 today. By measuring both possibilities in present-day dollars, the better choice of action becomes obvious: The country should pump its oil today, since $50 worth of present-day money is obviously greater than $47.01 worth of present-day money.

The ability to calculate present values also allows decision makers to use cost-benefit analysis in situations where the costs and benefits happen at different points in time. For instance, suppose that a forestry company is considering spending $1000 per acre to plant seedlings that it hopes will grow into trees that it will be able to harvest in 100 years. It expects that the wood from the trees will be worth $125,000 per acre in 100 years. Should it undertake this investment? The answer is *no* because at the current market interest rate of 5 percent per year, the present value of $125,000 in 100 years is only $950.56 today, which is less than the $1000 per acre that the firm would have to invest today to plant the seedlings. When both the benefits and costs of the project are measured in the same units (present-day dollars), it is clear that the project is a money loser and should be avoided.

More generally, the ability of policy makers to calculate present values and put present-day dollar values on future possibilities is vitally important because it helps to ensure that resources are allocated to their best possible uses over time. By enabling a decision maker to compare the costs and benefits of present use with the costs and benefits of future use, present value calculations help to ensure that a resource will be used at whatever point in time it will be most valuable.

This is especially important when it comes to conservation because there is always a temptation to use up a resource as fast as possible in the present rather than conserving some or all of it for future use. By putting a present-day dollar value on the net benefits to be gained by conservation and future use, present value calculations provide a financial incentive to make sure that resources will be conserved for future use whenever doing so will generate higher net benefits than using them in the present. Indeed, a large part of natural resource economics focuses on nothing more than ensuring that the net benefits that can be gained from conservation and future use are accounted for by the companies and individuals who are in charge of deciding when and how to use our limited supply of resources. When these future net benefits are properly accounted for, resource use tends to be conservative and sustainable, whereas when they are not properly accounted for, environmental devastation tends to take place, including, as we will discuss in detail below, deforestation and fisheries collapse.

Nonrenewable Resources

Nonrenewable resources like oil, coal, and metals must be mined or pumped from the ground before they can be used. Oil companies and mining companies specialize in the extraction of nonrenewable resources and attempt to make a profit from extracting and then selling the resources that they mine or pump out of the ground. But because extraction is costly and because the price that they will get on the market for their products is uncertain, profits are not guaranteed and such companies must plan their operations carefully if they hope to realize a profit.

We must note, however, that because an oil field or a mineral deposit is typically very large and will take many years to fully extract, an extraction company's goal of "maximizing profits" actually involves attempting to choose an extraction strategy that will maximize a *stream* of profits—potential profits today as well as potential profits in the future. There is, of course, a tradeoff. If the company extracts more today, its revenues will be larger today since it will have more product to sell today. On the other hand, more extraction today means that less of the resource will be left in the ground for future extraction and, consequently, future revenues will be smaller since future extraction will necessarily be reduced. Indeed, every bit of resource that is extracted and sold today comes at the cost of not being able to extract it and sell it in the future. Natural resource economists refer to this cost as the **user cost** of extraction because current extraction and use means lower future extraction and use.

Present Use versus Future Use

The concept of user cost is very helpful in showing how a resource extraction firm that is interested in maximizing its flow of profits over time will choose to behave in terms of how much it will choose to extract in the present as opposed to the future. To give a simple example, consider the case of a coal mining company called Black Rock whose mine will have to shut down in 2 years, when the company's lease expires. Because the mine will close in 2 years, the mine's production can be thought of as taking place either during the current year or next year. Black Rock's problem is to figure out how much to mine this year in order to maximize its stream of profits.

To see how Black Rock's managers might think about the problem, look at Figure 27W.7, which shows the situation facing the company during the first year. Begin by noticing *P*, the market price at which Black Rock can sell each and every ton of coal that it extracts. The firm's managers will obviously want to take this price into consideration when deciding how much output to produce.

Next, consider the company's production costs, which we will refer to as **extraction costs,** or *EC*, since this is an extraction company. The extraction costs include all costs associated with running the mine, digging out the coal, and preparing the coal for sale. Notice that the *EC* curve that represents extraction costs in Figure 27W.7 is upward sloping to reflect the fact that the company's marginal extraction costs increase the more the company extracts because faster extraction involves having to rent or buy more equipment and having to either hire more workers or pay overtime to existing workers. Rapid extraction is costly, and the *EC* curve slopes upward to reflect this fact.

Next, consider how much output the firm's managers will choose to produce if they fail to take user cost into account. If the firm's managers ignore user cost, then they will choose to extract and sell Q_0 tons of coal (given by where the horizontal *P* line crosses the upward-sloping *EC* line at point *A*). They will do this because for each and every ton of coal that is extracted up to Q_0, the market price at which it can be sold exceeds its extraction cost—making each of those tons of coal profitable to produce.

But this analysis considers only potential first-year profits. None of those tons of coal *has* to be mined this year. Each of them could be left in the ground and mined during the second year. The question that Black Rock's managers have to ask is whether the company's total stream of profits would be increased by leaving some or all of those tons of coal in the ground this year in order to be mined and sold next year.

This question can be answered by taking account of user cost. Specifically, the company's managers can put a dollar amount on how much future profits are reduced by current extraction and then take that dollar amount into account when determining the optimal amount to extract this year. This process is best understood by looking once again at Figure 27W.7. There, each ton of coal that is extracted this year is assumed to have a user cost of *UC* dollars per ton that is set equal to the present value of the profits that the firm would earn if the extraction and sale of each ton of coal were delayed until the second year. Taking this user cost into account results in a total cost curve, or *TC*, that is exactly *UC* dollars higher than the extraction cost curve at every extraction level. This parallel upward shift reflects the fact that once the company takes user cost into account, its total costs must be equal to the sum of extraction costs and user cost. That is, $TC = EC + UC$.

If the firm's managers take user cost into account in this fashion, then they will choose to produce less output. In fact, they will choose to extract only Q_1 units of coal (shown by where the horizontal *P* line crosses the upward-sloping *TC* line at point *B*). They will produce exactly this much coal because for each and every ton of coal that is extracted up to Q_1, the market price at which it can be sold exceeds its total cost—including not only the current extraction cost but also the cost of forgone future profits, *UC*.

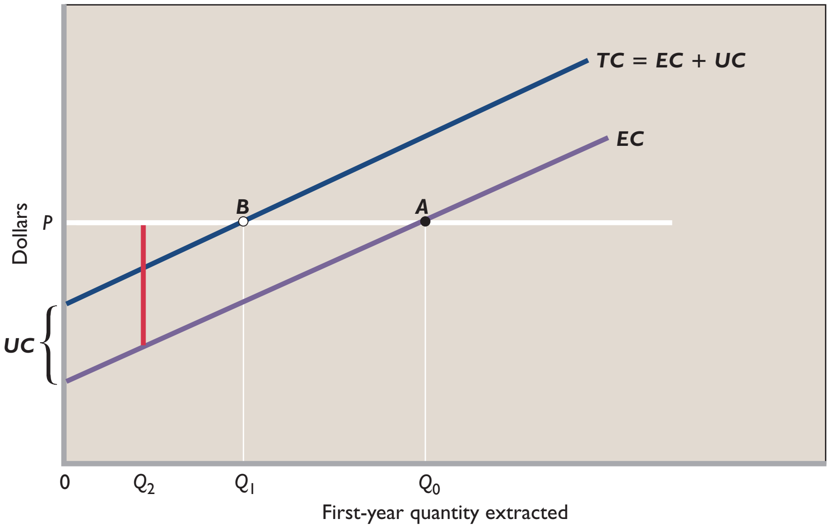


FIGURE 27W.7 Choosing the optimal extraction level. A firm that takes account only of current extraction costs, *EC*, will produce Q_0 units of output in the current period—that is, all units for which the market price *P* exceeds extraction costs, *EC*. If it also takes account of user cost, *UC*, and the fact that current output reduces future output, it will produce only Q_1 units of output—that is, only those units for which price exceeds the sum of extraction costs and user cost.

Another way to understand why Black Rock will limit its production to only Q_1 tons of coal is to realize that for every ton of coal up to Q_1, it is more profitable to extract during the current year than during the second year. This is best seen by looking at a particular ton of coal like Q_2. The profit that the firm can get by extracting Q_2 this year is equal to the difference between Q_2's extraction cost and the market price that it can fetch when it is sold. In terms of the figure, this first-year profit is equal to the length of the vertical red line that runs between the point on the *EC* curve above output level Q_2 and the horizontal *P* line.

Notice that the red line is longer than the vertical distance between the *EC* curve and the *TC* curve. This means that the first-year profit is greater than the present value of the second-year profit because the vertical distance between the *EC* curve and the *TC* curve is equal to *UC*, which is by definition the present value of the amount of profit that the company would get if it delayed producing Q_2 until the second year. It is therefore clear that if the firm wants to maximize its profit, it should produce Q_2 during the first year rather than during the second year since the profit to be made by current production exceeds the present value of the profit to be made by second-year production.

This is not true for the tons of coal between output levels Q_1 and Q_0. For these tons of coal, the first-year profit—which is, as before, equal to the vertical distance between the *EC* curve and the horizontal *P* line—is less than *UC*, the present value of the second-year profit that can be obtained by delaying production until the second year. Consequently, the extraction of these units should be delayed until the second year.

The model presented in Figure 27W.7 demonstrates that the goal of profit-maximizing extraction firms is not to simply mine coal or pump oil as fast as possible. Instead, they are interested in extracting resources at whatever rate will maximize their streams of profit over time. This incentive structure is very useful to society because it means that our limited supplies of nonrenewable resources will be conserved for future extraction and use if extraction firms expect that demand (and hence profits) in the future will be higher than they are today. This can be seen in Figure 27W.8, where user cost has increased in the current period from UC_0 to UC_1 to reflect an increase in expected future profits. This increase in user cost causes Black Rock's total cost curve to shift up from $TC_0 = EC + UC_0$ to $TC_1 = EC + UC_1$. This shift, in turn, reduces the optimal amount of current extraction from Q_0 tons of coal to only Q_1 tons of coal.

This reduction in the amount of coal currently extracted conserves coal for extraction and use in the future when it will be in higher demand. Indeed, Black Rock's profit motive has caused it to reallocate extraction in a way that serves the interests of its customers and their desire to consume more in the future. Since the supply of this nonrenewable resource is limited, more consumption in the future implies less consumption today and Black Rock has accommodated this constraint by reducing extraction this year in order to increase it next year.

More generally speaking, Black Rock's behavior in this case demonstrates that under the right institutional structure, profit-maximizing firms will extract resources efficiently over time, meaning that each unit of the resource will tend to be extracted when the gains from doing so are the greatest. **(Key Question 7)**

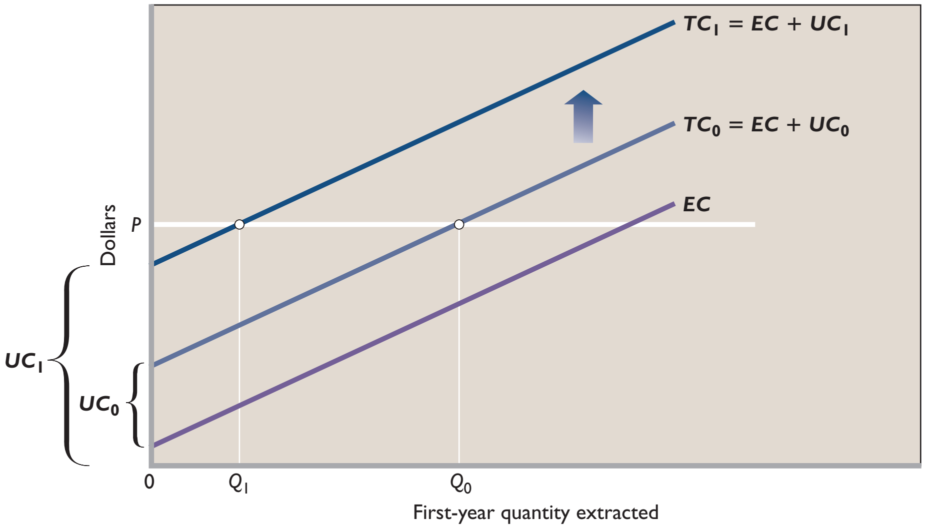


FIGURE 27W.8 An increase in expected future profits leads to less current extraction. An increase in future profitability increases user cost from UC_0 to UC_1, thereby raising the total cost curve from TC_0 to TC_1. The firm responds by reducing current production from Q_0 to Q_1 in order to be able to extract more in the future and take advantage of the increase in future profitability.

Market Failures Lead to Excessive Present Use

We just demonstrated that profit-maximizing extraction companies are very happy to decrease current extraction if they can benefit financially from doing so. In particular, they are willing to reduce current extraction if they have the ability to profit from the future extraction and sale of their product. Indeed, this type of a financial situation gives them the incentive to conserve any and all resources that would be more profitably extracted in the future.

This pleasant result breaks down completely if market failures such as weak or uncertain property rights do not allow extraction companies to profit from conserving resources for future use. For instance, look back at Figure 27W.7 and consider how much Black Rock would produce if it were suddenly told that its lease would expire at the end of this year rather than at the end of next year. This would be the equivalent of having a user cost equal to zero because there would be no way for the company to profit in the future by reducing current extraction. As a result, the firm will ignore user cost and take into account only current extraction costs, *EC*. The result will be that it will extract and sell Q_0 tons of coal, more than the Q_1 tons that it would extract if it had an opportunity to profit from conservation.

Applications

Resources tend to be extracted much too quickly if there is no way to profit from conservation. Let's examine two such situations.

Conflict Diamonds

The name **conflict diamonds** refers to diamonds that are mined by combatants in war zones in Africa in order to provide the hard currency that they need to finance their military activities. Most of these civil wars, however, are very unpredictable, so that control of the mines is tenuous, slipping from one army to another depending on the tide of war.

This fluidity has destroyed any incentive to conserve the resource since the only reason a person would reduce current extraction would be if he or she could benefit from that act of conservation by being able to extract more in the future. But because nobody can be sure of controlling a mine for more than a few months, extraction rates are always extremely high, with the only limit being extraction costs.

This behavior is very wasteful of the resource because once the war finally ends and money is needed to rebuild the country, whichever side wins will find precious few diamonds left to help pay for the reconstruction. Unfortunately, the incentive structures created by the uncertainty of war see to it that extraction takes place at far too rapid a pace, making no allowance for the possibility that future use would be better than present use.

Elephant Preservation

As with nonrenewable resources, renewable resources like wildlife also get used up much too fast if decision makers have no way of profiting from conservation—the only difference being that if a renewable wildlife resource is used too fast, it can become extinct. This was the situation facing elephants in Africa during the 1970s and 1980s when elephant populations in most parts of Africa declined drastically due to the illegal poaching of elephants for their ivory tusks. It was the case, however, that elephant populations in a few countries expanded considerably. The difference resulted from the fact that in certain countries like Botswana and Zimbabwe, property rights over elephants were given to local villagers, thereby giving them a strong financial incentive to preserve their local elephant populations. In particular, local villagers were allowed to keep the money that could be earned by taking foreign tourists on safari to see the elephants in their area as well as the money that could be made by selling hunting rights to foreign sports hunters. This gave them a strong incentive to prevent poaching, and villagers quickly organized very effective patrols to protect and conserve their valuable resource.

By contrast, elephants belonged to the state in other countries, meaning that locals had no personal stake in the long-term survival of their local elephant populations since any elephant tourism money flowed to the state and other outsiders. This created the perverse incentive that the only way for a local to benefit personally from an elephant was by killing it to get its ivory. Indeed, most of the poaching in these countries was done by locals who had been given no way to benefit from the long-term survival of their local elephant populations. As with nonrenewable resources, the inability to benefit from conservation and future use causes people to increase their present use of renewable resources.

QUICK REVIEW 27W.3

- Because nonrenewable resources are finite, it is very important to allocate their limited supply efficiently between present and future uses.
- If resource extraction companies can benefit from both present and future extraction, they will limit current extraction to only those units which are more profitable to extract in the present rather than in the future. This conserves resources for future use.
- If resource users have no way of benefiting from the conservation of a resource, they will use too much of it in the present and not save enough of it for future use—even if future use would be more beneficial than present use.

Renewable Resources

We just saw that under the right circumstances, extraction companies have a strong profit incentive to moderate their current extraction rates and conserve nonrenewable resources for future use. A similar incentive can also hold true for companies and individuals dealing with renewable resources like forests and wildlife. If property rights are structured properly, then decision makers will have an incentive to preserve resources and manage them on a sustainable basis, meaning that they will harvest the resources slowly enough that the resources can always replenish themselves.

On the other hand, if proper incentives are not in place, then high and nonsustainable harvest rates can quickly wipe out a renewable resource. Indeed, ecologists and natural resource economists can cite numerous examples of fish populations collapsing because of overfishing and of rainforests being wiped out because of overlogging. This section discusses the economics of renewable resources as well as policies that promote the sustainable use of renewable resources. To keep things concrete, we focus on forests and then fisheries.

Forest Management

Forests provide many benefits including wildlife habitat, erosion prevention, oxygen production, recreation, and, of course, wood. In 2005, just under 10 billion acres, or about 30 percent of the world's land area, was forested and about 555 million acres, or about 25 percent of the United States' land area, was forested. The amount of land covered by forests is, however, growing in some places but declining in others. This fact is apparent in Global Perspective 27W.1, which gives the average annual percentage change over the years 1990 to 2000 in the amount of forest-covered land in 12 selected countries as well as in the entire world.

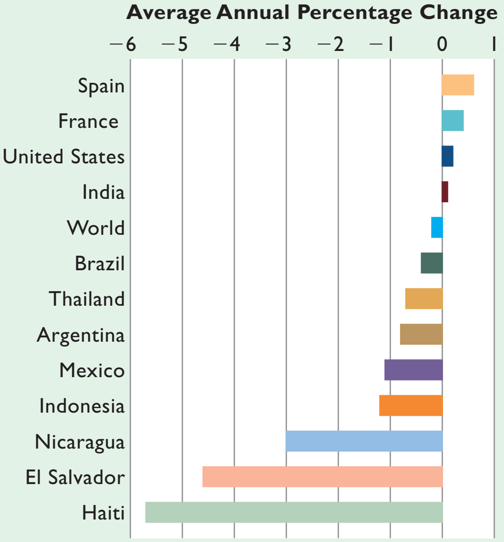
Economists believe that the large variation in growth rates seen in Global Perspective 27W.1 is largely the result of differences in property rights. In certain areas, including the United States and western Europe, forests are either private property or strictly regulated government property. In either case, individuals or institutions have an incentive to harvest their forests on a sustainable basis because they can benefit not just from cutting down the trees currently alive but also from keeping their forests going in order to reap the benefits that they will give off in the future if they are managed on a sustainable basis.

By contrast, deforestation is proceeding rapidly in countries where property rights over forests are poorly enforced or nonexistent. To see why this is true, consider the situation facing competing loggers if nobody owns the property rights to a given forest. In such a situation, whoever chops down the forest first will be able to reap economic benefits because, while nobody can have ownership or control over a living tree, anybody can establish a property right to it by chopping it down and bringing it to market. In such a situation, everybody has an incentive to chop down as many trees as fast as they can in order to get to them before anyone else can. Sadly, nobody has an incentive to preserve trees for future use because—without enforceable property rights—person A has no way to prevent person B from chopping down the trees that person A would like to preserve.

GLOBAL PERSPECTIVE 27W.1

Average Annual Percentage Change in the Amount of Land Covered by Forests, 1990–2000

Average annual percentage changes in the amount of land covered by forests vary greatly by nation, as indicated below.



Source: State of the World's Forests 2005, United Nations Food and Agriculture Organization, **www.fao.org.**

To reduce and hopefully eliminate nonsustainable logging, governments and international agencies have been taking increasingly strong steps to define and enforce property rights over forest areas. One major result is that in areas such as the United States and Europe where strong property rights over forests have been established, virtually all wood production is generated by commercially run forestry companies. These companies buy up large tracts of land on which they plant and harvest trees. Whenever a harvest takes place and the trees in a given area are chopped down, seedlings are planted to replace the felled trees, thereby replenishing the stock of trees. These companies are deeply concerned about the long-term sustainability of their operations and many often plant trees in the expectation that more than a century may pass before they are harvested.

Optimal Forest Harvesting

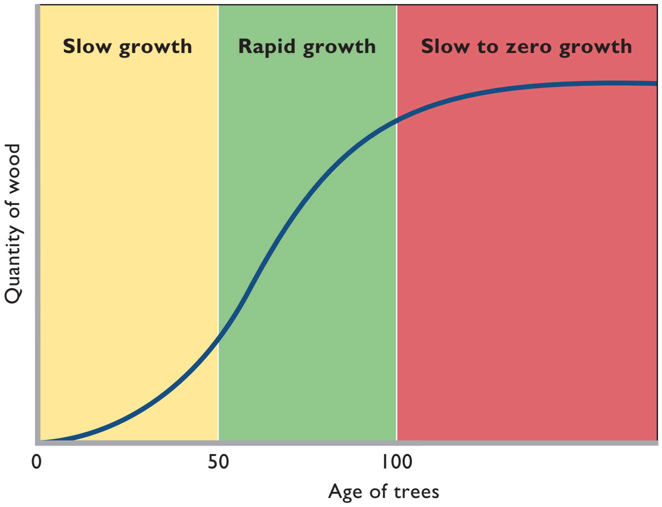
In cases where the property rights to a forest are clear and enforceable (as they are in the United States), forest owners have a strong incentive to manage their forests on a sustainable basis because they can reap the long-term benefits that derive from current acts of conservation. A key part of their long-term planning is deciding how often to harvest and then replant their trees.

This is an interesting problem because a commercial forestry company that grows trees for lumber or paper production must take into consideration the fact that trees grow at different rates over the course of their lifetimes. Indeed, Figure 27W.9 shows that if the company plants an acre of land with seedlings and lets those seedlings grow into mature trees, the amount of wood contained in the trees at first grows rather slowly as the seedlings slowly grow into saplings, then grows quite quickly as the saplings mature into adult trees, and then tapers off as the trees reach their maximum adult sizes.

This growth pattern means that forestry companies have to think very carefully about when to harvest their trees. If they harvest and replant the acre of land when the trees are only 50 years old, they will miss out on the most rapid years of growth. On the other hand, there is not much point in letting the trees get much more than 100 years old before harvesting and replanting since at that age very little growth is left in them. The result is that the forestry company will choose to harvest the trees and replant the land when the trees reach an age of somewhere between 50 and 100 years old. The precise age will be chosen to maximize firm profits and will be affected not only by the growth rate of trees but also by other factors including the cost of harvesting the trees and, of course, the market price of wood and how it is expected to vary over time.

The key point to keep in mind, however, is that forestry companies that have secure property rights over their trees do not harvest them as soon as possible. Instead, they shepherd their resource and harvest their trees only when replacing older, slow-growing trees with younger, fast-growing trees finally becomes more profitable. And, of course, it must also be emphasized that forestry companies *replant*. They do this because they know that they can benefit from the seedlings' eventual harvest, even if that is 50 or 100 years in the future. In countries where property rights are not secure, nobody replants after cutting down a forest because there is no way to prevent someone else from cutting down the new trees and stealing the harvest.

FIGURE 27W.9 **A forest's growth rate depends on its age.** Because trees do not reach their most rapid growth rates until middle age, forestry companies have an incentive not to harvest them too early. But because growth then tapers off as the trees reach their maximum adult sizes, there is an incentive to chop them down before they are fully mature in order to replant the area with faster growing young trees.



Optimal Fisheries Management

A **fishery** is a stock of fish or other marine animal that can be thought of as a logically distinct group. A fishery is typically identified by location and species—for example, Newfoundland cod, Pacific tuna, or Alaskan crab. Table 27W.3 lists the top 10 U.S. fisheries in terms of how much their respective catches were worth in 2004.

TABLE 27W.3 **Top 10 U.S. Fisheries in Dollar Terms, 2004**

Fishery	Market Value of Catch
Walleye pollock	$372,935,985
Lobster	366,006,019
Sea scallop	321,373,824
White shrimp	203,031,651
Pacific halibut	176,800,729
Brown shrimp	160,578,051
Sockeye salmon	156,970,037
Pacific cod	146,455,969
Blue crab	126,468,775
Dungeness crab	120,057,410

Source: National Marine Fisheries Service, National Oceanic and Atmospheric Administration, **www.nmfs.noaa.gov.**

The key difficulty with fishery management is that the only way to establish property rights over a fish swimming in the open ocean is to catch it and kill it. As long as the fish is alive and swimming in the open ocean, it belongs to nobody. But as soon as it is caught, it belongs to the person who catches it. This property rights system means that the only way to benefit economically from a fish is to catch it and thereby turn it into a private good.

This creates an incentive for fishers to be very aggressive and try to outfish each other, since the only way for them to benefit from a particular fish is to catch it before someone else does. The natural result of this perverse incentive has been tremendous overfishing, which has caused many fisheries to collapse and which threatens many others with collapse as well.

Two examples of fishery collapse are presented in Figure 27W.10, which shows the number of metric tons per year of Maine red hake and Atlantic tuna that were caught between 1973 and 2004 by U.S. fishers. A **fishery collapse** happens when a fishery's population is sent into a rapid decline because fish are being harvested faster than they can reproduce. The speed of the decline depends on how much faster harvesting is than reproduction. In the case of Maine red hake, the decline was very abrupt, with the annual catch falling from 190.3 million metric tons in 1986 down to only 4.1 million tons 5 years later. After making a minor resurgence in 1994, the fishery then totally collapsed, so that the catch has been less than 1 ton per year for most of the last decade despite the best efforts of fishers to catch more. The collapse of the Atlantic tuna fishery has been more gradual, presumably because the ratio of harvest to reproduction was not as extreme as it was for Maine red hake. But even when harvesting exceeds reproduction by only a small amount in a given year, the population declines. And if that pattern holds for many years, the population will be forced into collapse. This has been the case for Atlantic tuna, which has seen its annual catch collapse more gradually, from a peak of 248.9 million metric tons in 1984 down to only 4.1 million metric tons in 2004.

Overfishing and fishery collapse are now extremely common, so much so that worldwide stocks of large predatory fish like tuna, halibut, swordfish, and cod are believed to be 90 percent smaller than they were just 50 years ago. In addition, Table 27W.4 shows that just 3 percent of world fisheries in 2003 were estimated to be underexploited, whereas 76 percent were categorized as fully exploited, overexploited, depleted, or (hopefully) recovering from depletion.

TABLE 27W.4 Status of World's Fisheries in 2003

Status	Percentage
Underexploited	3%
Moderately exploited	21
Fully exploited	52
Overexploited	16
Depleted	7
Recovering from depletion	1

Source: United Nations Food and Agriculture Organization, **www.fao.org.**

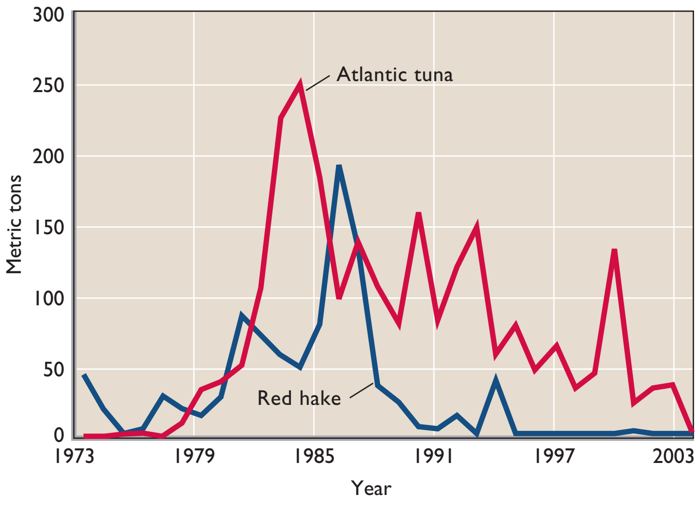


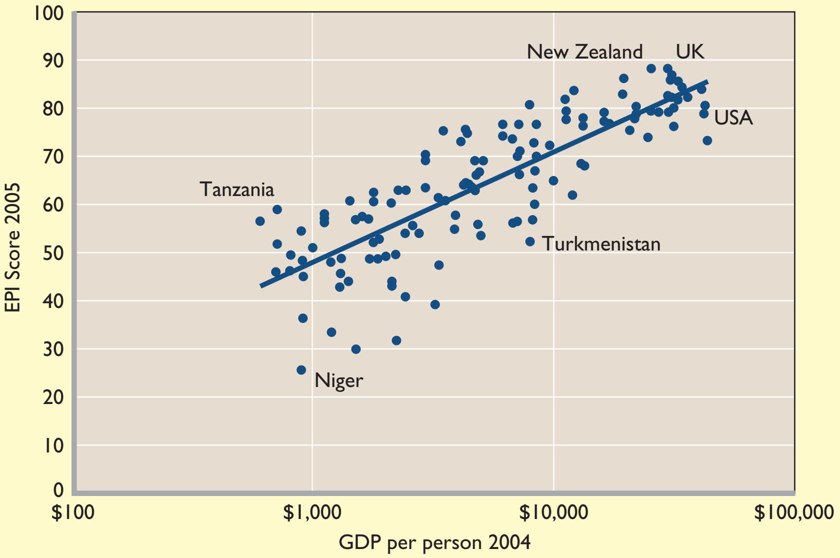
FIGURE 27W.10 The collapse of two fisheries, 1973–2004. This figure shows how many metric tons of Atlantic tuna and Maine red hake were caught by U.S. fishing boats each year from 1973 to 2004. Overfishing has caused the population of both species to collapse, Maine red hake very abruptly and Atlantic tuna more slowly.

Source: National Marine Fisheries Service, National Oceanic and Atmospheric Administration, **www.nmfs.noaa.gov.**

Last Word

Is Economic Growth Bad for the Environment?

Measures of environmental quality are higher in richer countries.



Many people are deeply concerned that environmental degradation is an inevitable consequence of economic growth. Their concern is lent credence by sensational media events like oil and chemical spills and by the indisputable fact that modern chemistry and industry have created and released into the environment many toxic chemicals and substances that human beings did not even know how to make a couple of centuries ago.

Economists, however, tend to be rather positive about economic growth and its consequences for the environment. They feel this way because significant evidence indicates that richer societies spend much more money on keeping their respective environments healthy than do poorer societies. Viewed from this perspective, economic growth and rising living standards are good for the environment because as societies get richer, they tend to spend more on things like reducing emissions from smokestacks, preventing the dumping of toxic chemicals, and insisting that sewage be purified before its water is returned to the environment. They also tend to institute better protections for sensitive ecosystems and engage in greater amounts of habitat preservation for endangered species.

But are these increasing expenditures on environmentally beneficial goods and services enough to overcome the massive increases in environmental harm that seem likely to accompany the enormous amounts of production and consumption in which rich societies engage? The empirical record suggests that the answer is yes.

Policies to Limit Catch Sizes

Governments have tried several different polices to limit the number of fish that are caught each year in order to prevent fisheries from collapsing. They also hope to lower annual catch sizes down to sustainable levels, where the size of the catch does not exceed the fishery's ability to regenerate. Unfortunately, many of these policies not only fail to reduce catch sizes but also create perverse incentives that raise fishing costs because they do not stop the free-for-all nature of fishing, whereby each fisher tries to catch as many fish as possible as fast as possible before anyone else can get to them.

For example, some policies attempt to reduce catch sizes by limiting the number of days per year that a certain species can be caught. For instance, the duration of the legal crabbing season in Alaska was once cut down from several months to just 4 days. Unfortunately, this policy failed to reduce catch sizes because crabbers compensated for the short legal crabbing season by buying massive boats that could harvest in 4 days the same amount of crab that they had previously needed months to gather.

Fishers bought the new, massive boats because while the new policy limited the number of days over which crabbers were allowed to compete, it did not lessen their incentive to try to catch as many crabs as possible before anyone else could get to them. Indeed, the massive new boats were a sort of arms race, with each fisher trying to buy a bigger, faster, more powerful boat than his competitors in order to be able to capture more of the available crabs during the limited 4-day season. The result, however, was a stalemate because if everybody is buying bigger, faster, more powerful boats, then nobody gains an advantage. Consequently, the policy actually made the situation worse. Not only did it fail to reduce catch size; it

The best evidence for this is given by the accompanying figure, in which each of 133 countries is represented by a point that indicates both its GDP per capita (measured on the horizontal axis using a logarithmic scale) and its year 2005 score on the Environmental Performance Index, or EPI.

This index, produced by researchers at Yale University, compares countries based on how well they are doing in terms of 16 environmental indicators, including atmospheric carbon emissions, measures of air and water quality, the degree of wilderness protection, energy efficiency, and measures of whether a country's fisheries and forests are being overexploited. Out of a maximum possible EPI score of 100, New Zealand and Sweden received the highest scores of, respectively, 88.0 and 87.8. The United States was ranked 28th with a score of 78.5 while the lowest-ranked country, Niger, received a score of 25.7.

When EPI scores are combined with measures of GDP per person in the figure, an extremely strong pattern emerges: Richer countries have higher EPI scores. In fact, the relationship between the two variables is so strong that 70 percent of the differences between countries in terms of EPI scores are explained by their differences in GDP per person. In addition, the logarithmic scale used on the horizontal axis allows us to look at the best-fit line drawn through the data and conclude that a 10-fold increase in GDP per capita (from, for instance, $1000 to $10,000) is associated with a 20-point increase in EPI. The figure is therefore clear confirmation that economic growth can not only go together with a healthy environment, but that economic growth actually promotes a healthy environment by making people rich enough to pay for pollution-reduction technologies that people living in poorer countries cannot afford.

Looking to the future, many economists are hopeful that economic growth and rising living standards will pay for the invention and implementation of new technologies that could make for an even cleaner environment. If the current pattern continues to hold, increased standards of living will lead to better environmental outcomes.

Note: The horizontal axis is measured using a logarithmic scale, so that each successive horizontal unit represents a 10-fold increase in GDP per person. This is useful because it happens to be the case that the relationship between EPI and GDP per person is such that a 10-fold increase in GDP per person is associated with a 20-point increase in EPI. Graphing the data using a logarithmic scale makes this relationship obvious.

Sources: The EPI data are from the Yale Center for Environmental Law and Policy, **www.yale.edu/epi.** The data on real GDP per person (at purchasing power parity) in 2004 are from ***The World Factbook*****, www.cia.gov.**

also drove up fishing costs. This was an especially pernicious result because the policy had been designed to help fishers by preserving the resource upon which their livelihoods depended.

Another failed policy attempted to limit catch size by limiting the number of fishing boats allowed to fish in a specific area. This policy failed because fishers compensated for the limit on the number of boats by operating bigger boats. That is, many small boats that could each catch only a few tons of fish were replaced by a few large boats that could each catch many tons of fish. Once again, catch sizes did not fall.

A policy that does work to reduce catch size goes by the acronym **TAC,** which stands for **total allowable catch.** Under this system, biologists determine the TAC for a given fishery, for instance, 100,000 tons per year. Fishers can then fish until a total of 100,000 tons have been brought to shore. At that point, fishing is halted for the year.

This policy has the benefit of actually limiting the size of the catch to sustainable levels. But it still encourages an arms race between the fishers because each fisher wants to try to catch as many fish as possible before the TAC limit is reached. The result is that even under TACs, fishing costs rise because fishers buy bigger, faster boats as each one tries to fulfill as much of the overall TAC catch limit as possible.

The catch-limiting system that economists prefer not only limits the total catch size but also eliminates the arms race between fishers that drives up costs. The system is based on the issuance of **individual transferable quotas,** or **ITQs,** which are individual catch size limits that specify that the holder of an ITQ has the right to harvest a given quantity of a particular species during a given time period, for instance, 1000 tons of Alaskan king crab during the year 2007.

The individual catch sizes of all the ITQs that are issued for a given fishery during a specific year add up to the fishery's overall TAC for the year so that they put a sustainable limit on the overall catch size. This preserves the fishery from overexploitation. But the fact that the ITQ quotas are *individual* also eliminates the need for an arms race. Because each fisherman knows that he can take as long as he wants to catch his individual quota, he does not need a superexpensive, technologically sophisticated boat that is capable of hauling in massive amounts of fish in only a few days in order to beat his competitors to the punch. Instead, he can use smaller, less expensive, and simpler boats since he knows that he can fish slowly—perhaps year round if it suits him.

This move toward smaller boats and more leisurely fishing greatly reduces fishing costs. But ITQs offer one more cost-saving benefit. They encourage all of the fishing to be done by the lowest-cost, most-efficient fishing vessels. This is true because ITQs are *tradable* fishing quotas, meaning that they can be sold and thereby traded to other fishers. As we will explain, market pressures will cause them to be sold to the fishers who can catch fish most efficiently, at the lowest possible cost.

To see how this works, imagine a situation in which the market price of tuna is $10 per ton but in which a fisherman named Sven can barely make a profit because his old, slow boat is so expensive that it costs him $9 per ton to catch tuna. At that cost, if he does his own fishing and uses his ITQ quota of 1000 tons himself, he will make a profit of only $1000. At the same time, one of his neighbors, Tammy, has just bought a new, superefficient ship that can harvest fish at the very low cost of $6 per ton. This difference in costs means that Sven and Tammy will both find it advantageous to negotiate the sale of Sven's ITQ to Tammy. Sven, for his part, would be happy to accept any price higher than $1000 since $1000 is the most that he can make if he does his own fishing. Suppose that they agree on a price of $2 per ton, or $2000 total. In such a case, both are better off. Sven is happy because he gets $2000 rather than the $1000 that he would have earned if he had done his own fishing. And Tammy is happy because she is about to make a tidy profit. The 1000 tons of tuna that she can now catch will bring $10,000 in revenues when they are sold at the market price of $10 per ton, while her costs of bringing in that catch will be only $8000 since it costs $6000 in fishing costs at $6 per ton to bring in the catch plus the $2000 that she pays to Sven for the right to use his 1000-ton ITQ.

Notice, though, that society also benefits. If Sven had used his ITQ himself, he would have run up fishing costs of $9000 harvesting the 1000 pounds of tuna that his quota allows. But because the permit was sold to Tammy, only $6000 in fishing costs are actually incurred. The tradable nature of ITQs promotes overall economic efficiency by creating an incentive structure that tends to move production toward the producers who have the lowest production costs.

It remains to be seen, however, if ITQs and other catch-reduction policies will be enough to save the world's fisheries. Since current international law allows countries to enforce ITQs and other conservation measures only within 200 miles of their shores, most of the world's oceans are fishing free-for-alls. Unless this changes and incentive structures are put in place to limit catch sizes in these areas, economic theory suggests that the fisheries there will continue to decline as fishers compete to catch as many fish as possible as fast as possible before anyone else can get to them. **(Key Question 11)**

Summary

1. Per capita living standards in the United States are at least 12 times higher than they were in 1800. This increase in living standards has entailed using much larger amounts of resources to produce the much larger amounts of goods and services that are currently consumed. The increase in resource use can be attributed to two factors. First, there has been a large increase in resource use per person. Second, there are now many more people alive and consuming resources than at any previous time.
2. The large increase in total resource use has led to a spirited debate about whether our high and rising living standards are sustainable. In particular, will our demand for resources soon outstrip the supply of resources? A proper answer to this question involves examining the demand for resources as well as the supply of resources.
3. A good way to examine the demand for resources is to think of total resource demand as being the product of the amount of resources used per person times the number of people alive. Thomas Malthus famously predicted that higher living standards would tend to lead to higher birthrates. The opposite, however, has held true. Higher living standards have led to lower birthrates and the majority of the world's population now lives in countries where the total fertility rate is less than the replacement rate of 2.1 births per woman per lifetime necessary to keep a country's population stable over time.

4. The result is that world population growth is not only slowing but is actually turning negative in many countries. What is more, the effect of low birthrates is so strong that many demographers believe that the world's population will reach a maximum of fewer than 9 billion people in the next 50 years before beginning to decline quite rapidly. That implies substantially reduced resource demand.
5. The evidence from the United States and other rich countries is that resource use per person has either fallen or leveled off during the past several decades. For instance, per capita water use in the United States fell 28 percent between 1975 and 2000. Per capita energy use has been stable since the late 1980s. And because the per capita generation of trash has been stable since 1990, we can infer that the per capita use of solid objects like metals, paper, and plastics has been stable since that time as well.
6. Combined with the expected decline in population levels, the fact that per capita resource use has either fallen or leveled off implies that the total demand for resources is likely to reach a peak in the relatively near future before falling over time as populations decline.
7. Natural resource economists predict that resource supplies are likely to grow faster than resource demands in the future. This confidence is based on the fact that since 1850 the real (inflation-adjusted) prices of resources have fallen by about 70 percent. Because this decline in prices happened at the same time that total resource use was increasing dramatically, it seems likely that resource supplies will continue to grow faster than resource demands since, going forward, resource use should grow less quickly than it has in the past because population growth has slowed (and is expected to turn negative) and because per capita resource use in recent decades has leveled off or turned negative.
8. Living standards can continue to rise without consuming more energy thanks to more efficient productive technologies, which can produce more output using the same amount of energy input. Indeed, real GDP per person in the United States increased by about one-third between 1988 and 2005 despite the fact that annual per capita energy consumption remained constant per person during those years.
9. Differences in fixed costs mean that a wide variety of energy sources are used in the economy despite the fact that some of these energy sources are much more costly than others. For instance, coal-fired electric generating plants use low-cost coal, but are extremely expensive to build so that they are used only in situations where very large generating capacities are required. By contrast, when smaller amounts of electricity are required, it often makes more sense to employ other generating technologies such as natural gas despite the fact that they use more expensive fuel.
10. We are not running out of energy. Even if we run out of oil, there are plenty of other energy sources including biodiesel, ethanol made from corn or sugar cane, and oil made from organic waste products. The only question is cost. Currently, oil is relatively inexpensive compared to other energy sources so that if we run out of oil and have to turn to alternatives, the cost of energy is likely to rise.
11. Renewable natural resources like forests and fisheries as well as nonrenewable natural resources like oil and coal tend to be overused in the present unless there are institutions created that provide resource users with a way to benefit from conservation. Governments can ensure this benefit by strictly defining and enforcing property rights so that users know that if they conserve a resource today, they will be able to use it in the future.
12. Encouraging conservation is especially difficult in the open ocean where it is impossible to either define or enforce property rights over fish because, by international law, nobody owns the open ocean and so anyone can fish there as much as they want. This lack of property rights leads to severe overfishing and an eventual collapse of the fishery.
13. Closer to shore, however, governments can define property rights within their sovereign waters and impose limits on fishing. The best system involves combining total allowable catch (TAC) limits for a given fishery with individual transferable quota (ITQ) limits for individual fishers.

Terms and Concepts

replacement rate
total fertility rate
demographer
British thermal unit (BTU)
net benefits
renewable natural resources
nonrenewable natural resources
present value
user cost
extraction cost
conflict diamonds
fishery
fishery collapse
total allowable catch (TAC)
individual transferable quota (ITQ)

Study Questions

1. Describe Thomas Malthus' theory of human reproduction. Does it make sense for some species—say bacteria or rabbits? What do you think makes humans different?
2. Suppose that the current (first) generation consists of 1 million people, half of whom are women. If the total fertility rate is 1.3 and the only way people die is of old age, how big will the fourth generation (the great-grandchildren) be? How much smaller (in percentage terms) is each generation than the previous generation? How much smaller (in percentage terms) is the fourth generation than the first generation? Are you surprised by how quickly the population declines?
3. Demographers have been very surprised that total fertility rates have fallen below 2.0, especially because most people in most countries tell pollsters that they would like to have two children. Can you think of any possible economic factors that may be causing women in so many countries to average fewer than two children per lifetime? What about other social or political changes?
4. Resource consumption per person in the United States is either flat or falling, depending on the resource. Yet living standards are rising due to improvements in technology that allow more output to be produced for every unit of input used in production. What does this say about the likelihood of our running out of resources? Could we possibly maintain or improve our living standards even if the population were expected to rise in the future rather than fall?
5. **KEY QUESTION** Suppose that you hear two people arguing about energy. One says that we are running out of energy. The other counters that we are running out of cheap energy. Explain which person is correct and why.
6. A community has a nighttime energy demand of 50 megawatts, but a peak daytime demand of 75 megawatts. It has the chance to build a 90-megawatt coal-fired plant that could easily supply all of its energy uses even at peak daytime demand. Should it necessarily proceed? Could there be lower-cost options? Explain.
7. **KEY QUESTION** Recall the model of nonrenewable resource extraction presented in Figure 27W.7. Suppose that a technological breakthrough means that extraction costs will fall in the future (but not in the present). What will this do to future profits and, therefore, to current user cost? Will current extraction increase or decrease? Compare this to a situation where future extraction costs remain unchanged but current extraction costs fall. In this situation, does current extraction increase or decrease? Does the firm's behavior make sense in both situations? That is, does its response to the changes in production costs in each case maximize the firm's stream of profits over time?
8. If the current market price rises, does current extraction increase or decrease? What if the future market price rises? Do these changes in current extraction help to ensure that the resource is extracted and used when it is most valuable?
9. **ADVANCED ANALYSIS** Suppose that a government wants to reduce its economy's dependence on coal and decides as a result to tax coal mining companies $1 per ton for every ton of coal that they mine. Assuming that coal mining companies treat this tax as an increase in extraction costs this year, what effect will the tax have on current extraction in the model used in Figure 27W.7? Now, think one step ahead. Suppose that the tax will be in place forever, so that it will also affect extraction costs in the future. Will the tax increase or decrease user cost? Does this effect increase or decrease the change in current extraction caused by the shift of the EC curve? Given what you found, should environmental taxes be temporary?
10. **ADVANCED ANALYSIS** User cost is equal to the present value of future profits in the model presented in Figure 27W.7. Will the optimal quantity to mine in the present year increase or decrease if the market rate of interest rises? Does your result make any intuitive sense? (Hint: If interest rates are up, would you want to have more or less money right now to invest at the market rate of interest?)
11. **KEY QUESTION** Various cultures have come up with their own methods to limit catch size and prevent fishery collapse. In old Hawaii, certain fishing grounds near shore could be used only by certain individuals. And among lobstermen in Maine, strict territorial rights are handed out so that only certain people can harvest lobsters in certain waters. Discuss specifically how these systems provide incentives for conservation. Then think about the enforcement of these property rights. Do you think similar systems could be successfully enforced for deep sea fishing, far off shore?
12. Aquaculture is the growing of fish, shrimp, and other seafood in enclosed cages or ponds. The cages and ponds not only keep the seafood from swimming away but also provide aquaculturalists with strong property rights over their animals. Does this provide a good incentive for low-cost production as compared with fishing in the open seas where there are few if any property rights?
13. **LAST WORD** The figure in the Last Word section shows that a 10-fold increase in a country's GDP per person is associated with about a 20-point increase in EPI. Do you think that this pattern can be extrapolated out into the future? That is, could the United States (which currently has an EPI of 78.5) gain another 20 points if it increased its GDP per person by a factor of 10 from its current level? (Hint: Consider diminishing returns.)

Web-Based Questions

1. **U.S. ENERGY SOURCES AND USES** The Energy Information Agency **(www.eia.gov)** of the United States government contains a treasure trove of data about both U.S. and international energy generation and consumption. Go to the Historical Data Overview page at **www.eia.doe.gov/overview_hd.html** and notice the Energy Flow diagram that appears at the upper right. Click on the diagram to expand it and then look it over. The diagram gives energy consumption and usage for the United States for the most recent year for which data is available. Is the United States totally dependent on oil imports? What fraction of its oil consumption does it have to import? Is it strange that even though the country is a net importer of petroleum, it exports some petroleum, too? What about the overall energy situation? What percentage of its overall energy consumption can it fulfill with domestically produced energy? What fraction of domestic production comes from renewable energy sources? Is this higher or lower than you were expecting?
2. **CARBON DIOXIDE EMISSIONS—RISING OR FALLING?** We presented evidence earlier that per capita consumption of water, energy, and solid objects like plastics and metals has been constant or falling in recent decades. The consumption of fossil fuels, however, is of special concern because of worries about global warming caused by the emission into the atmosphere of carbon dioxide and other so-called greenhouse gasses. Go to the Energy Information Agency's Environment page, **www.eia.doe.gov/environment.html.** Scan the International Emissions Data links and click on the one that says Per Capita Emissions in order to open up an Excel spreadsheet that contains per capita carbon dioxide emissions for almost all countries for each of the previous 20 years or so. Have per capita carbon dioxide emissions in the United States, Japan, and France grown, stayed about the same, or fallen over the past couple of decades? Does is surprise you to learn that over this time period France has moved to generate more than 80 percent of its electricity from nuclear power, which emits no carbon dioxide? What about emissions in China, Indonesia, and India? Why have emissions risen so much (in percentage terms) in these countries? (Hint: They are not as poor as they used to be.) If current trends in these countries continue, should we be worried? And could defining property rights over the atmosphere solve the problem?