# 20 Economics and Ecology

Whole classes of animals are mysteriously declining in population and possibly headed to extinction. Take frogs, for example. The Global Amphibian Assessment found in 2004 that, due to mass die-offs and loss of habitat, about a third of all species of frogs, toads and salamanders could soon disappear. That the problem could be worldwide, affecting these creatures in Canada and Madagascar, is particularly disturbing. Recent evidence points to an outbreak of skin fungus as an important factor, itself possibly linked to global climate change, but researchers admit the problem—if it is one problem and not a combination of many problems—is still only dimly understood.

More immediately worrisome for humans is the disappearance of bees. More than a quarter of all bee colonies in the United States have collapsed in the space of a few years, and similar trends have occurred in Europe and Latin America. Bees play an indispensable role in pollinating many of the fruit and vegetable crops that make up a large part of the human diet, so the potential impact on agriculture could be enormous. Pesticides and the outbreak of a deadly virus are possible causes put forward by researchers, but at the moment specialists are far from a consensus on the issue.

These stories exemplify several ominous trends in humanity's changing relationship with nature. Large and potentially very harmful alterations are occurring in the environment. The scale is large, even global. The causes are not fully known, and we have every reason to expect there will be more unpleasant surprises as our knowledge increases. In some areas, like climate change, a huge research effort has clarified the mechanisms that are at work and the tasks that have to be accomplished to avoid greater harm. In many others, however, the complexity of ecological interrelationships leaves us with far more questions than answers.

In this chapter we will look at the uneasy relationship between economics and ecology. The main themes have already been foreshadowed: we will consider the problem that many essentials for life, like bees, frogs and other animal species, have an uncertain status in the modern economy, that the effects of human activities on the environment are often not taken into account, that economies need to be

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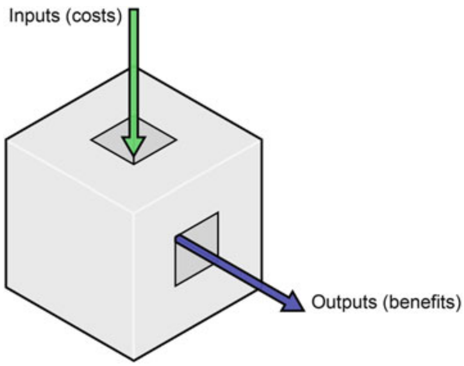


**Fig. 20.1** The economy as a machine that transforms inputs into outputs. The economy is seen as taking in inputs such as labor, raw materials and equipment and producing outputs (goods and services) of benefit to consumers

restructured if they are to become sustainable, and that managing complexity and uncertainty will be a large part of the solution.

## 20.1 Ecology: A Big Omission

Chapter 4 presented the Big Story as traditionally understood by economists. On the first page there appeared Fig. 20.1:

The goal of the economy is to generate net benefits, a value of outputs in excess of the value of inputs, and Fig. 20.1 is intended to express this.

But the Big Story has a Big Hole: where does the input arrow come from, and where does the output arrow go? As presented in the picture, the inputs appear as if by magic, and the outputs disappear in more or less the same way. To be complete, we should pencil in the additional boxes and pipes from which the economy gets its resources and which absorb its products. Much of this would represent what we commonly call "the environment", the physical planet we live on, its web of chemical nutrients and energy, and its vast complexity of plant and animal life. Also on the input side we should recognize the physical and social processes by which human beings are reproduced, raised and cared for, most of which are outside the market economy. Finally, our accumulated social and cultural heritage, including our languages, customs and artistic and scientific insights, are essential contributors to economic progress, and these too ought to be represented in a complete model. While most of this chapter will focus on the natural environment, much of it applies as well to the social and cultural environments within which any economy must function.

## 20.2 The Environment as a Commons

The words "economics" and "ecology" come from the same Greek root, oikos, which refers to a household, with a further connotation of provision and sustenance. Throughout history thinkers have compared the activities of animals and plants to acquire their nutrients, reproduce themselves and survive as a species to similar human preoccupations. By the same token, we might imagine the economy as we have described it in this book as humanity's use of and adaptation to the environment, seen up close and from the inside. (A bird, if it could write, might produce a textbook on "birdonomics".) Yet this view falls apart in one fundamental respect. The components of the natural environment that have entered our analysis up to this point represent only a tiny fraction of what is actually out there and necessary for our survival. We have considered people and their various abilities ("labor") and land (primarily as space) and certain useful minerals and organisms ("raw materials"), but the vast majority of the environment has made no appearance at all. Where is the energy radiating from the sun, or the atmosphere, the oceans, the global cycles of chemical flows or the genetic resources we call biodiversity? Where, for that matter, are languages, the intellectual legacies passed on through science and literature, and the slowly acquired understanding of how human beings can live and work together, expressed in our cultures through songs, stories and sayings? All of these things are indispensable, but thus far we have simply taken them for granted. Yet, as we saw with the frogs and bees, and as we are learning with climate change, it is all too possible for human economies to undermine the environment we need in order to prosper; there is also reason to think that aspects of our cultural inheritance could be at risk.

At the most basic level, the problem is that modern economies privilege those items, whether they are produced goods or services or natural resources, that are privately owned, but most of the things and systems we depend on aren't. They make up what is often called **the commons**, the set of resources used by human economies which are shared, rather than owned in the conventional sense. A commons may be local, like the fish who make their home in a small stream, or it may be global, like the world's climate system, or it may exist at any level in between. For this reason, it might be more accurate to envision human societies as inhabiting many overlapping commons, adding to the complexity of this already difficult-to-describe dimension of our place in the world.

**Box 20.1: "All of Arizona Is Owned by Someone"**

Many years ago, I was traveling with my family through a remote part of the Sonoran Desert in Arizona. We drove down small roads until it seemed we had left most traces of civilization behind. On all sides were long vistas of saguaro and other cactuses backed by primitive-looking sandstone formations, a mosaic of brown, green and orange against the bluest of western skies. There were no buildings, no power lines, no farms. Yet suddenly we saw a sign which announced, in stern letters, "Remember, All of Arizona Is Owned by Someone".

On one level, this is certainly true. Every bit of land is legally held either by a private landowner, a tribe or some agency of government, and the sign

(continued)

**Box 20.1** (continued)
reminds us that this ownership puts legal restrictions on what visitors, like my family, are permitted to do as we pass through. Yet surely Arizona is more than just an expanse of land. What about the hydrological cycle (the movement of water through precipitation, evaporation and surface and underground flows), which is crucial to the well-being of this hot, dry region? What about the wildlife, like the insects that pollinate the cactuses when they bloom in the spring? What about the history of this state, with its conflicts and accommodation between native peoples and Mexican and Anglo settlers? These too are part of Arizona, but who owns them?

Rather than trying to define a concept like the commons precisely, it is more helpful to look at the sorts of entities people use this term to refer to. Some commons are things, with physical dimensions, like the world's oceans or the continent of Antarctica. We could, if we wanted, put a fence around them, along with a sign like the one I saw in Arizona. Others are physical but take the form of systems, like the global climate system or the genetic diversity of amphibians. Still others are intangible resources like language and other forms of knowledge and culture, or like the broadcast spectrum, a waveform frequency "space" which is occupied by communications systems—radio and television, cellular telephones and other transmissions. Because the elements that would make up a complete list of possible commons is so diverse, it is difficult to say what, if anything, they all have in common. Instead, we can describe some of the features that are typical, but which might not characterize all of them:

1. Absence of private or public ownership. In general, the commons is not owned in the conventional sense of private or public ownership. There is no piece of paper giving a particular individual or organization the right to restrict access, capture the benefits or transfer title to other buyers. Sometimes, however, governments act as if they were owners, by setting rules similar to the ones owners might put in place. For instance, governments do not own the populations of fish that inhabit the coastline, but they often place restrictions on how many fish can be caught in order to prevent these populations from being decimated. Similarly, regulations that prohibit pollution of the water and air can be thought of as the sorts of policies governments might adopt if they were owners of these resources. Nevertheless, government policies tend to be inconsistent in these domains, exactly because governments are not motivated the way true owners would be by threats to the value of their property. (Governments usually take greater care of graffiti on the walls of public buildings than the dumping of toxic substances into lakes and rivers.) We will see later, however, that alternative forms of ownership, neither public nor private in the conventional sense, can have a place in the commons; this is an important frontier of economic institution-building.

2. Unsuitability of private or public ownership. Not only are most commons unowned, they would be difficult to place in conventional ownership. As we have seen, many do not have identifiable boundaries. How could anyone own the hydrological cycle? Everywhere there is water or water vapor, the cycle is present. Every living organism takes in and emits water. If the owner of the hydrological cycle decides to put up a fence, what would be outside it? Another problem is that, even if the resource could be owned, it may be so essential to life and devoid of alternatives that the resulting monopoly power would be too great to bear. It is technically possible for someone to own arithmetic, in the same way that patents are granted for drug formulas. The owner of the arithmetic patent could demand to be paid every time someone performs one of the basic operations (addition, subtraction. . .), and it could be enforced by taking violators to court. Indeed, some higher mathematical algorithms, not different in kind from basic arithmetic functions, *are* patented, and users do have to pay a royalty. There is a debate over whether and to what extent the techniques of mathematics and other scientific fields should be privatized, but all sides agree that the most necessary and widely-used methods ought to remain in the commons.
3. Indispensable services. In 1997 a team of researchers led by Robert Costanza published an estimate of the economic value of the world's ecosystems and other natural resources, which came to about $33 trillion. This sounds like, and is, a lot of money, but it was not much more than the value of the world's total economic production at the time. In other words, according to this study the loss of all of nature would require us to somewhat more than double our human-produced output in order to maintain the same level of overall economic well-being. For all the cleverness these researchers employed in their calculations, their conclusion is clearly false. *There is no substitute for the environment as a whole*. We can damage it a bit more or less, but as an entire system we cannot survive without it. This judgment applies to most individual commons as well. We cannot make do without any of the major nutrient cycles or the hydrological cycle; we cannot function as human beings without our languages and other bases in shared culture; nearly the entire edifice of modern economies rests on the accumulated knowledge of generations of scientists and other scholars. The commons is priceless.
4. Self-reproduction. Most commons survive and prosper to the extent that they are *not* interfered with by human actions. Over timespans that are relevant to human history, the oceans and atmosphere have maintained themselves quite well without human intervention to keep them going. Biodiversity is renewed by the ceaseless pressure of natural selection against a gradually changing natural environment. Languages generally develop and become more sophisticated without the need for official organizations to control how they are spoken and written—although organizations exist in some countries to influence how languages evolve, and on occasion (particularly in the adoption of written scripts) conscious intervention can play a crucial role. It is true that in some of the cultural commons, like science, an infusion of economic resources can propel the rate of growth, and governments and financial interests can influence

which questions scientists investigate, but efforts to prevent scientists from following their research leads or communicating their results ultimate destroy the basis for scientific work altogether. In the great majority of cases, preserving the commons means allowing its intrinsic forces to operate without outside interference. The corollary to this principle is that, if we keep such interference to a minimum, the commons we pass on to future generations will be at least as valuable to them as the commons we inherited from our ancestors was to us, and in the case of the cultural commons, even more so.

The economic analysis of the commons became a matter of great public interest with the publication of the article "The Tragedy of the Commons" by biologist Garrett Hardin in 1968. This short, powerfully argued study presents the exploitation of the commons in a form corresponding to the prisoner's dilemma that has already made several appearances in this book. Consider, proposes Hardin, a community of shepherds who share a common grazing area. (We will take some liberties with his original presentation, but the idea is the same.) This pasture is not owned by anyone, individually or collectively. It provides food for any sheep who graze on it, but too many sheep will destroy its productivity. Even at their most profligate, it would take the sheep of many shepherds to accomplish this. Suppose there are two choices facing each shepherd, to use the pasture with restraint, so that, if all do this, its productivity will be maintained, or to use it excessively, so that, again if all do the same, the pasture will become barren. This first choice can be called cooperation and the second defection. Using our device of referring to any particular shepherd as A and all the others taken together as B, we can set up the payoff matrix on the following page (Fig. 20.2).

To simplify, we express the outcomes for each shepherd with the numbers 1–4, corresponding to how they would be valued by them. The best outcome is 1. In this case, since all the other shepherds are behaving sustainably, and since the overuse by just one shepherd is not enough to destroy the pasture, the sole defector gets the best of both worlds, continuing use of the pasture and the advantage of being able to feed more sheep from it. Second-best is 2. Once again the pasture is maintained, which is of great value to all shepherds, but, compared to the first-best outcome, the individual shepherd takes less advantage from it. Much worse is 3, since now the pasture is destroyed, but even worse than this is 4, since, not only is the pasture useless in the future, the shepherd even loses the temporary benefit of having his sheep overgraze it for a season or two.

As we know from previous encounters with the prisoner's dilemma, there is a strong case that the shepherds will follow the individually rational strategy of choosing D and allowing the pasture to be ruined. They may deeply regret this result, but it is not in any one person's interest to break from the pattern. If this is truly the model that best predicts how a commons, like a common pasturage, will be treated, we are all in a lot of trouble. Hardin felt that there were only two solutions: either establish ownership rights to the pasture so that someone will have the personal incentive to enforce restrictions on access (for instance by charging a fee), or institute government regulations to prevent the shepherds from engaging in overexploitation. The **tragedy of the commons** is the inevitable destruction of

| | | Shepherd B: C | Shepherd B: D |
|---|---|---|---|
| Shepherd A | C | A:2, B:2 | A:4, B:1 |
| | D | A:1, B:4 | A:3, B:3 |

**Fig. 20.2** Payoff matrix for the exploitation of an unowned sheep pasture. If *C* represents sustainable grazing by a shepherd and *D* unsustainable grazing, there is an individual incentive to choose *D*, and the unowned common pasture falls victim to the collective irrationality of a prisoner's dilemma

unowned resources that will occur without these interventions, based on the logic of the prisoner's dilemma.

In 1990, however, political scientist and future Nobel economics prize-winner Elinor Ostrom replied with her influential book, *Governing the Commons*: *The Evolution of Institutions for Collective Action*. Ostrom points out that, in many instances, real-world herders, such as communities of Swiss farmers sharing common Alpine pastures, managed to avoid the disastrous result predicted by Hardin. The reason, she argued, was that the problem is better understood as a repeated prisoner's dilemma, along the lines we examined in Chap. 10. As we saw, when the game is played a large (and indefinite) number of times, incentives emerge for the players to initiate cooperation and to defect only if others defect. If the rewards to cooperation are large enough (which in the case of a fragile commons they normally would be), and if the players' time horizon is long enough (if their discount rate is low enough), then mutual cooperation rather than mutual defection would be the expected result.

The effect of this argument was to generate new respect for the commons as an economic institution. While private ownership and government regulation both have roles to play, the commons, and the cooperative customs and attitudes that evolve to support it, could be seen as a third basis for human economies. To emphasize this new legitimacy, those who adopt this view often use the phrase **common property resources** to describe what was formerly seen as simply unowned. In most cases, the use of the term "property" in this expression is metaphorical, since property rights in the formal sense do not exist. Nevertheless, the idea is that communities can develop ways of respecting these resources as if they were actually owned in common. The term is also used to make the point that a commons does not have to be defenseless against those who would abuse it. Instead, those commons that are not protected by cooperative institutions are singled out as **open access resources**. Much is made of the argument that common property does not necessarily mean open access. To put this another way, making such a distinction implies that, where we find open access resources, which anyone can exploit without limit, we should try to establish the sorts of cooperative governance measures that characterize better-regulated common property resources.

To some extent, the dispute between these two ways of thinking about the commons is artificial. In many instances the tragedy of the commons is real and urgent, and formal ownership or public regulation offer the only solutions. In others we see just the sort of cooperative arrangements that advocates of common property resources prefer, or at least the possibility of helping them become established. Sometimes all of these factors are in play: cooperation does some of the job but needs to be supplemented by other forms of control. The real world does not conform to any single academic model.

Preserving the commons normally means containing the reach of the private market. A community of shepherds that respects the biological limits of its common pasturage will probably have fewer sheep, or will have to redirect its economy toward other activities that will enable it to purchase more feed from other sources. And these other sources might become more limited or expensive if the common property resources they depend on are respected as well. Ultimately, like our hypothetical shepherds, the overall size and growth of our own economy, as well as the types of activities it extends into, may come into conflict with our need to maintain the various commons whose health is important to us.

This generalization is clear enough when we consider issues like climate change and biodiversity (which requires that many plant and animal habitats be left in a natural state), but a particular flashpoint has been the cultural commons. In recent years there has been a change in the laws governing patents and copyrights, together referred to as **intellectual property rights**. On the one hand, permitting companies and individuals to own a wider range of ideas, like phrases, genetic structures (for life forms) or scientific insights, can serve as a spur to investment in their creation. (We briefly considered the debate over intellectual property rights in Chap. 13.) On the other, each extension of these property rights is also a reduction in the space given to intellectual common property. When scientific ideas are privately owned they are no longer the common heritage of society. When songs and fictional characters remain private property long after they have permeated the general culture, they cannot as easily serve as the raw material for new cultural creation. The broadcast spectrum, which is of enormous economic value, has only recently begun to be auctioned to private companies which earn profits from its use. Just where the line should be drawn between common and private property is a matter for debate, but there is reason to think that, in a world in which private property is widespread and generates powerful incentives for its owners to expand their access to all available resources, and where common property is generally unowned and incentives to safeguard it are weaker, there will probably be a bias in the direction of excessive privatization.

This insight has led to new efforts to develop and institutionalize property forms for common property resources—to turn metaphor into reality. How could communities come to exercise common ownership of at least some portion of the commons? We have already seen, in Chap. 15, how communities with a tie to a particular resource can be given de facto ownership, so that access can be rationed through a market; the example of Japanese coastal regulation illustrates this. Another approach is the creation of trusts which hold formal title to resources and whose statutes legally obligate them to protect their continued value. In many countries there has been a rapid increase in the number of land trusts, for instance. These bodies own parcels of land, but not for purposes of private gain. They are required to ensure that the ecological values of these lands are preserved for future generations and can use them to earn income or provide other benefits only if this primary mission is fulfilled. Other trusts have been established to safeguard cultural treasures, like ancient buildings or the homes of celebrated artists, writers or political leaders.

The question is whether this type of institution can be adapted to provide protection for the most urgently at-risk resources, like the atmosphere (with its concentration of greenhouse gases) and biodiversity. Moving in this direction will require that such trusts operate on a much larger scale, at least national and perhaps international. If common property owners charge for access to their resources (such as carbon fees), a lot of money will be at stake. This suggests that trusts or similar entities may have to be carefully designed and regulated to prevent some combination of large financial temptation and distended organizational structure from undermining their fidelity to the primary mission of resource preservation.

## 20.3 Natural Resources as Economic Inputs

Up to this point our focus has been on commons as realms to be protected from exploitation, but much of their value, of course, depends on the economic uses they are put to. In this section we will shift the spotlight to the way natural resources ought be used if economies are to make the most of them.

In very broad strokes, we can distinguish between three types of resources, renewable, depletable and nonaugmentable. The first two of these have been the subject of a vast amount of economic theorizing; the third is something of a hybrid.

1. **Renewable resources**. An excellent example of this type of resource is topsoil, the basis for agricultural productivity. The economics of agricultural land were first systematically explored by the brilliant economist David Ricardo at the beginning of the nineteenth century. Ricardo wrote of what he called “the original and indestructible powers of the soil”, but he was a city boy (Amsterdam and London, although he later purchased a country estate in England). As any real farmer knows, soil can be built up or eroded away. Good practices leave as much or more productive soil in place for the next season, and bad practices cause erosion and the loss of this valuable natural resource.

Ricardo’s theory of land rents was based on the assumption that the productivity of agricultural land is fixed, so that landowners can raise their prices based on the scarcity of land relative to the demand for food. In particular, he examined the consequences if there are differences in productivity across land, or if more labor or other inputs have to be provided in some farms in order to produce enough food to meet the needs of consumers. More recent theories take into account the possibility that land (soil) and other renewable resources can either be drawn down or built up.

The simplest version of the theory puts it this way: a profit-maximizing resource owner will compare the return on investments in a renewable resource to other investments available in the economy, as reflected in the going rate of interest on bonds or other financial assets. For instance, if it will cost extra money to farm in a way that preserves topsoil, the "rational" farmer will compare the return on this cost—more productive land next year—to what could be obtained by putting the extra money into an average investment account. The same analysis, in the opposite direction, applies to cutting production costs and allowing the soil to deplete.

The process can be seen most vividly in another such resource, timber. Consider the situation of a profit-maximizing owner of a timber stand. Suppose her trees grow at a certain rate per year, say 5 %. This means that, by letting the trees stand, she can have 5 % more wood the following year. But she can also cut down the trees, sell them, and invest the proceeds. If the expected return on this financial investment, again approximated by the prevailing interest rate, exceeds 5 %, it is more profitable to cut the trees. In other words, not cutting the trees is equivalent to investing in them and earns a return equal to the growth rate of the trees. Our profit-maximizing timber owner compares this return to the one she could make on her money if she cuts the trees and buys a financial asset. Her choice is determined by whichever return is greater. Since trees grow more slowly as they age, it is typical that, for a period of time there is more money to be made by letting them continue to grow, and then at some point this incentive ends and the trees should be "liquidated" so that they can be replaced by a more profitable asset. Of course, it is also possible for interest rates to change. Very generally, one can say that, as interest rates in the economy rise, it becomes more profitable to draw down the stock of renewable resources like timber and topsoil, and vice versa. This generalization applies to other renewable resources, like harvestable fish.

2. **Depletable resources**. Some extremely important natural resources, like oil and other minerals, are in fixed supply. There is a certain amount available in the earth's crust and that's it. Of course, improvements in technology can make it possible to extract some portion of this resource that was previously unavailable, but there are ultimate limits to how much can be made available to the economy. The original theory of the efficient extraction of such depletable (or nonrenewable) resources was developed by Harold Hotelling, a British mathematician and economist, during the 1920s, and it has been embellished considerably since then.

In the simplest version of Hotelling's model, it is assumed that the resource has a single, profit-maximizing owner. The total amount available for extraction is known with complete certainty, and so also are future demands and interest rates. Finally, it is assumed that there is some other resource or technology which provides a perfect substitute, called a backstop, but at a higher price. If there are no costs of exploration or production, the price of the depletable resource should be exactly equal to that of the backstop at the moment it is exhausted, and it should rise to this level over time at exactly the rate of interest. The reasons are not difficult to fathom. The backstop price should prevail at the moment when the change from one resource to the other occurs, since this would permit the owner of the resource being depleted to sell the very last bit at the highest possible price. The price should rise at the interest rate because otherwise it would be profitable to either extract and sell the resource more quickly (putting the money into an interest-bearing fund) or leave it in the ground (where its price would rise faster than alternative investments), depending on whether the price growth is below or above the interest rate. Finally, if we know where the price has to end up, and if we know how quickly it must rise from one year to the next, and if we also know the demand for the resource—the relationship between price and quantity demanded—as well as how much of the resource lies in the ground to be extracted, we can calculate both the starting price today and the number of years before complete resource exhaustion occurs. In other words, if we feed in enough information, the model can compute the future time path of both prices and production levels right up to the last barrel or ton.

This is an ideal model in some respects, but it relies on many assumptions that have little basis in reality. All the crucial variables—the total amount of the resource to be extracted, future demands, future interest rates, future backstops—are generally unknown. This is the case with oil, for instance. There is tremendous debate over how much oil awaits development, and whether it will be economically feasible to make use of deposits with very high costs of extraction. Some geologists think we are already approaching **peak oil**, where the rate of production reaches its highest possible level, only to decline thereafter; others think the peak still decades away. There is enormous uncertainty over future demand, especially in the context of efforts to stem global climate change. At this point no one can say just which technologies will take the place of oil in transportation and the other uses in which its high energy density is particularly valued.

From a political perspective, the Hotelling analysis also misses an important aspect of the real world: most owners of depletable resources like oil deposits are not profit-maximizing businesses but governments with other objectives and much shorter time horizons. There is no indication that any government of an oil-producing country actually performs a Hotelling-like calculation to decide the rate of extraction, and there is no reason to expect, when all the oil is used up at some future date, that historians looking backward will find that the production decisions along the way had anything to do with maximizing returns. At best, Hotelling's theory provides a normative benchmark for what resource policies should look like, not a prediction of what they will actually be.

One important corollary of the Hotelling model does turn out to be useful, however. In principle, if we leave out the role of production costs, the steady increase in the resource price should reflect its increasing long-run scarcity as deposits are depleted. If production costs also rise over the course of depletion, it is the difference between the price and the cost that reflects scarcity. This difference is what economists refer to as "rent". Suppose one of our social goals is that no generation exploit any later generation for economic gain—that we do not profit at the expense of our children or grandchildren. This would seem to be violated automatically if depletable resources are extracted, because it leaves less for the future. But if the rent portion of the resource price reflects the scarcity that results from depletion, we can set things right by putting this portion aside and saving (investing) it for the benefit of the future. This requirement that rents not be consumed but placed in reserve to make up for our consumption of depletable resources is the **Hartwick Rule**. The clearest example of a country following this rule is Norway, which puts all of its rental earnings from the North Sea oil it sells into a special investment fund. This fund is for the benefit of future generations who will inherit a Norway without these lucrative oil deposits.

Note that the ideal Hotelling and Hartwick visions still involve the complete depletion of all economically useful mineral deposits. Whether this is such a good idea is a question we will return to later in this chapter.

3. **Nonaugmental resources**. Certain natural resources have some of the characteristics of renewable resources and some more typical of depletable resources. Take the case of biodiversity. Like soil and trees, the genetic resources of our planet can be used over and over without causing them to disappear. As long as we harvest species at a rate that permits them to continue to survive, and as long as we maintain sufficient habitat of sufficient quality, we will not suffer a loss of biodiversity. (We could even permit some species to become extinct as long as the rate of extinction does not exceed the rate at which new species are being evolved.) A similar story could be told about wilderness, which is valued for its recreational, spiritual, scientific and cultural attributes. We exploit wilderness by visiting it and trampling it underfoot to some extent, but so long as we don't overdue it we can have the same wilderness to enjoy year after year. On the other hand, if we exploit resources like biodiversity and wilderness too intensively, they decline irreversibly (at least within relevant human time frames). In this second respect they are subject to depletion like mineral deposits.

Economically, the question is whether it is ever appropriate to allow nonaugmentable resources to become depleted. The general answer is yes, since they may not yet be scarce enough to generate rents that offset the economic advantages of heavy exploitation. The problem with this answer, however, is that to have any confidence in it, we would have to be fairly confident of our knowledge of future demands for the resource. If we clearcut or pave over a wilderness area today, for instance, we should not only take into account the current value placed on it but also the value that future generations are likely to express, since these actions are largely irreversible. In practice, most economists are reluctant to see our stock of nonaugmentable resources diminish, mainly because of this uncertainty.

One point that is common to all three types of resources we have considered is that today's uses affect tomorrow's availability. When we measure our economy, the value of goods and services we produce each month or year, too often we fail to take account of the effects our choices have on future supplies of natural resources. If you read in the newspaper that economic growth was 3 % last year, for example, it is highly unlikely that this number was adjusted for the depletion of resource stocks, or possibly the accumulation of new stocks of renewable resources. There is widespread agreement among economists that these adjustments ought to be made, although the technical problems with calculating the changing value of natural resources are demanding. Partial measures of the depreciation of "natural capital" can be found in the World Banks's World Development Indicators, however—possibly a harbinger of still more accurate accounting methods to come.

## 20.4 Pollution

In Chap. 15 we looked at the theory of externalities, which is the main tool economists use to study pollution. We will briefly review it here in preparation for a larger discussion of the effectiveness of economic analysis in light of the structure of ecological systems.

Recall that the theory takes as its starting point the Market Welfare Model, whose conditions are that the demand curve for goods represents the marginal benefit they provide to society, the supply curve represents the marginal cost to society, and there is a single, market-clearing equilibrium. In this happy state the market price would register both the marginal cost and the marginal benefit to society of producing and consuming one additional unit, and the equilibrium level of production will also maximize the net benefits attainable by society. Into this Eden the snake of externality is introduced. Now (since our interest is pollution) the supply curve can no longer represents social cost; instead, some of the cost is unpaid, and the supply curve is lower than it should be. This situation is summarized in Fig. 20.3 on the next page.

If the market is left to work on its own, it would arrive at the equilibrium quantity $Q_e$, and the price charged would be $P_e$. Both of these distort true benefits and costs. At $Q_e$ the level of production is excessive, since some units are being produced whose true social cost, measured by the MSC curve, exceed their social benefit (measured by D). Similarly, $P_e$ does not reflect the true social cost of the last unit produced at $Q_e$; the amount is understated to the extent of E, which represents the cost of the externality (pollution). An example of this situation might be the burning of coal to generate electricity. There are large effects on the environment from this process that are not included in market costs. The extraction of coal, especially in surface mines, harms land and water resources; burning it pollutes the air, with consequences for human health, acid precipitation and climate change. These externalities are not paid for by coal companies, electricity generating companies or consumers of electrical power. The price per kilowatt-hour does not reflect the true cost of producing this energy, and we have too many power plants burning too much coal.

If Fig. 20.3 is our guide, and if we have perfect information regarding marginal social costs and benefits, two options immediately suggest themselves. First, we could place a tax of E on each unit being produced (assuming E is the marginal cost

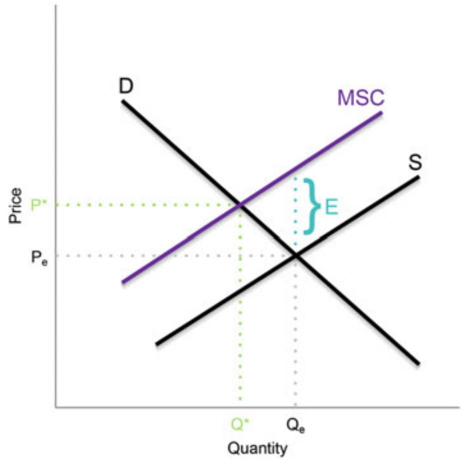


**Fig. 20.3** An external cost of production. The Market Welfare Model is assumed to apply to demand but not supply. $Q_e$ is the quantity sold at price $P_e$ in the market equilibrium, but Q*, sold at P*, would maximize net benefits to society. At $Q_e$ the marginal social cost curve MSC is above the market supply curve by the vertical distance E, which represents the external social cost

of the externality at all levels of production). In this way, the supply curve would shift upward and superimpose itself on the MSC curve; $Q_e$ would fall to Q*, $P_e$ would rise to P*, and all would be as it should be. Or a public authority could announce that only the amount of pollution at Q* will be permitted. This amount could be divided into many individual permits, and these permits could be placed on a market. The price of the permit would rise to the point where the total cost of production at Q* was equal to P*, since this is what market demand will support—but no more. Thus, the government can either set a price for pollution and allow the market to determine the quantity (approach 1), or it can set a quantity and allow the market to determine the price (approach 2). In a world of perfect information these are essentially equivalent.

In the real world, of course, information is far from perfect. In the case of coal, for instance, uncertainties include the amount of pollution from different extraction and combustion technologies, the true cost of this pollution, the potential for competing technologies, such as wind generators, to emerge, and the future trend in the demand for electricity—for instance, as other pressures increase for greater conservation and efficiency. The choice between the two approaches then boils down to a question of which risk one would rather take, unpredictable prices or unpredictable quantities. If we set a fixed pollution price, and if this price has long-run credibility, firms have the advantage being able to plan ahead, knowing exactly how much they will have to pay for the polluting production methods. The risk of uncertainty falls on the environment, which may have to absorb less pollution or more, depending on how developments unfold. If we set a fixed quantity of pollution the impact on the environment is more certain, but now producers cannot know in advance what their costs will be. The choice between these two options largely comes down to which risk is more acceptable to those in a position to decide.

Let's take a closer look at the second option. To simplify to some extent, we can say there are also two ways to fix the total amount of pollution through the use of pollution permits. First, these permits can be auctioned off to the highest bidder. If this happens, each firm that wants to buy a permit to produce a good or service will have to pay the market price, which is determined by the number of permits sold and the market demand for the things firms produce. The second approach is to give these permits away to the firms and then let the firms trade amongst each other. Those with more permits than they need will sell to those who have fewer. The market price should once again rise to level of the external cost. There is a big difference between these two approaches. If the permits are sold, firms as a group must pay to pollute; money goes to the government (or perhaps an environmental fund), which can then be spent on another purpose or rebated to the public. This is the idea behind **green taxes**, for instance, which use revenues from selling pollution permits to replace existing taxes, like those on income. If permits are given away and then traded, firms as a group neither lose nor gain, provided other factors remain constant. There is no net revenue for the public. In addition, it is not clear on what basis an initial distribution of permits should be made. Should those who polluted most in the past get the biggest allotment? This is usually how it's done, and it rewards those with the poorest pollution track record. Most economists believe there is a strong case for auctioning pollution permits, but, given the clout businesses have in the political process, it is much easier to pass legislation that gives them away.

Up to this point, we have followed the overall logic of Fig. 20.3, which is based on an adjustment to the Market Welfare Model. The three conditions of this model are assumed to hold except only for the single externality of pollution. In most real-world cases, however, we cannot be so confident of this. There are, after all, many uncompensated externalities, public goods, instances of asymmetric information, less-than-perfect competition and other assumption-violating aspects to economic life. Thus, even if we were to put exactly the right price on the externality in front of us, the result may be far from optimal—including the amount of pollution itself. If the demand curve overstates true social benefit, for instance, then perhaps even less pollution in meeting that demand should be tolerated. Even more troubling is the fundamental doubt that has arisen over the entire approach of the Market Welfare Model due to advances in behavioral economics. As we have seen in previous chapters, the analysis that links choices in the marketplace to the well-being of workers and consumers (and people in their other social roles) has retreated in the face of evidence that people do not act according to the assumptions of economic rationality, and that improvements in human well-being (happiness) do not fit to the rational economic model in any case. Economics is in a state of transition: some economists feel the time has come to jettison the normative apparatus of welfare economics; most, however, are reluctant to give it up. To the extent that one doubts the welfare approach, one also doubts whether it provides a useful basis for deciding how much pollution should continue to be allowed.

So let's follow this second train of thought. In Fig. 20.3 the optimal level of production Q* was determined according to the assumptions that demand represents marginal social benefit and that a proper adjustment to the supply curve would convert it into a measurement of marginal social cost. Suppose we decide that the whole approach is unwarranted, what then? One alternative that is increasingly being employed is to allow pollution limits to be determined by the analyses of public health or ecological scientists rather than economists. For instance, if the main problem with the pollution under consideration is that it harms human health, policy-makers might agree on a maximum health risk the public would be asked to face. The level of pollution that gives us that risk would be the level allowed. Or ecologists might determine that a particular concentration of a pollutant in surface waters would destroy essential fish or other habitat, and the total amount of pollution would be capped so that this concentration is not reached. In either case, we would determine the allowable amount of pollution and the resulting Q* with little or no regard to market demand and supply conditions. The use of permits or pollution taxes would be tailored to achieving this Q*; that is, market mechanisms would be employed to achieve goals that are not market-determined. Of course, in nearly every policy debate, market factors do enter in; consideration is given to the costs to producers and consumers and not only to health or habitat. Nevertheless, in principle the types of pollution control processes we have sketched in this section could be put at the service of goals determined by professionals in other fields.

In Chap. 15 it was pointed out that, rather than trying to regulate the price or quantity of pollution, public policy could take the form of carving out property rights so that a new market in pollution would emerge, and the externality would cease to exist. This is based on Coase's insight that an externality is due simply to the absence of a market in something that should have one. If water pollution is an externality, it is because no one owns the water being polluted or has a clear legal basis to charge a fee to the polluter. We are now in the position to connect a pair of dots, since earlier in this chapter we raised the issue of strengthening property rights in common property resources. It should be clear that this could have an important bearing on pollution policy. If more components of the commons can be vested in institutions whose mission is to preserve them, the burden of determining prices and quantities of pollution can shift from government to a new set of markets. The main advantage of this shift would be political: governments have many motives, and controlling pollution is only one of them. Common property institutions would, in principle, have only the motive of protecting the commons and would decide how much pollution to allow accordingly. Of course, political problems never disappear entirely; in a sense, the problem would shift from how to get governments to value the commons to how to ensure that those charged with exercising common property rights actually adhere to their mission.

## 20.5 Sustainability

"Sustainable" seems to be a word that makes people feel good. We have sustainable coffee, sustainable furniture and sustainable investing. Sustainability has connotations of solidity, far-sightedness and moral virtue. The closer one looks at the concept, however, the more questions arise: there is no single standard for what constitutes sustainability, nor how it should be measured.

The core idea is straightforward—sort of. Sustainability is based on the underlying value of **intergenerational equity**, the principle that no human generation should spend its accumulated inheritance at such a rate that subsequent generations would be worse off than them. Our children and grandchildren should live at least as well as we do, and the minimum ethical principle is that we should not live without regard for them. Actually, in the wealthier countries the trend has been the opposite: each succeeding generation has lived somewhat better, so the current interest in sustainability indicates that many now fear this trend may be reversed. The reason is that ecological damage is taking place much more rapidly and on a much wider scale than in the past, to the point that it is at least conceivable that the world we will leave our heirs will be severely impoverished.

The main difficulty with sustainability is that it has been given two fundamentally different interpretations, one based on traditional economics, the other on the view that environmental values supercede all others.

The economic interpretation is that living standards should not fall over time, where living standards are seen as the result of both economic wealth and the quality of the environment. This means that deterioration of the environment and the stock of natural resources is entirely compatible with sustainability, provided that increases in human-produced wealth at least compensate. For instance, if we chop down a forest for timber, and invest the earnings in better schools and roads, future generations will be at least as well off as we are if the loss of this forest is made up by the benefit from better schooling and transportation. In the traditional economic view, there is nothing magic about the natural environment: it is one aspect of our overall wealth (natural capital), but so is produced wealth. It is the sum of all wealth, natural and produced, that should matter.

The implication of the economic approach to sustainability is that any exploitation of natural resources, whether by drawing down renewable resources, using up depletable or nonaugmentable ones, or by polluting the environmental commons, that earns its way in financial terms is permissible. If the economic value of pumping oil from the ground and burning it to move cars along highways is greater than the value of leaving the oil in place, it is consistent with sustainability that we pump the oil. Presumably rational decision-makers can be relied on to make this choice where resources are owned; using economically justified regulations to control exploitation is still the remedy where ownership is missing or insufficient.

But one further stipulation must be met to achieve **economic sustainability**: any permanent loss in natural capital has to be offset by a corresponding investment in some other form, whether physical (buildings, machines, infrastructure) or human (education, health). That is, we cannot simply take the revenues from pumping oil and have bigger parties; this would leave future generations with nothing to compensate them for the loss of this valuable resource. Instead, we should sequester the money corresponding to the increased scarcity of oil (due to our pumping it) and make sure it is invested. Since this scarcity is reflected in the portion of the price attributable to rent (the difference between the selling price and the production cost), it is this amount that must be saved. If your short-term memory is in good shape, you will recognize this as the Hartwick Rule, from the section on depletable resources. So the lesson from economic sustainability is this: to be sustainable is simply to do what one should in order to be efficient in general, but also to see to it that all resource rents are funneled into productive investments.

According to the “strong” environmental view of sustainability, the economic approach is a recipe for disaster. It is a mistake, these proponents say, to believe that human-produced capital can take the place of the natural environment. Hydrocarbons like oil, natural gas and coal, for example, also provide the raw material for plastics. The earth’s supply took hundreds of millions of years to create and cannot be renewed within a humanly meaningful time frame. If we burn them up for transportation, heating and electricity and leave nothing for our descendants, they will not be able to make use of plastics and other materials, some of which may not yet be invented, that are based on hydrocarbons. No amount of bridges and skyscrapers will compensate them for this. Moreoever, as much as we may worry about completely exhausting the earth’s supply of minerals, this is likely to be far less consequential than the potentially catastrophic effect of uncontrolled climate change or other disruptions in the earth’s ecological systems. For instance, if our production of greenhouse gases today makes it inevitable that sea levels rise by 25 ft or more over the next century, as they would under some scenarios, then the loss of thousands of years of human habitation and investment along the world’s coastlines would dwarf any conceivable capital fund we might set aside as an offset.

If this so-called **strong sustainability** position is adopted, what are the implications for environmental and resource policies? Strictly speaking, they are incapable of being met. They tell us that no human activities should be permitted to damage natural capital: that all renewable resources be maintained at their current levels, that there be no extraction of any depletable resources, and that no nonaugmentable resources, such as wilderness areas and endangered species, be lost to the future. They also imply that no pollution should be permitted if it causes damage that cannot be reversed before future generations appear. This would mean, among other things, that all further emission of greenhouse gases should cease immediately.

Advocates of strong sustainability recognize that, taken literally, this program is out of reach, but they suggest that it can still provide helpful guidelines for policy. Thus, according to this view, we should try as far as we are able to reduce our dependence on depletable mineral resources as soon as possible, and we should place a similar priority on reducing, eventually to zero, our emissions of persistent forms of pollution, like atmospheric carbon. The economic feasibility of these goals has to be taken into account, they say, but the purpose is not economic but ecological, and success should be measured by environmental and resource criteria, not economics.

To some extent, these two positions, economic and strong sustainability, are separated by different value systems; in this sense they can’t be bridged. On a practical level, however, much of the disagreement comes down to a single question: how substitutable are natural and human-produced capital? Is it true, as the economic-oriented advocates say, that in nearly every case more of the produced kind can take the place of less of the natural kind? Would we be as happy living in a town with a theater for cultural events instead of a nearby pond that served as a watering hole for migratory birds? (Maybe we drained the pond and sold the land to raise money for the theater, and maybe people in the theater can watch movies about bird migrations.) Or is it the case that such substitution is more the exception than the rule, and that the less visible, but just as significant results of our loss of natural capital, like the larger ecological effects of disrupting bird migrations, are impossible to compensate?

It is impossible to answer such questions at this level of generality. (Attempts to do this are more likely to lead to shouting matches than reasoned discussions.) It may be, however, that the extent of substitution and compensation can be analyzed for particular resources, so that we might choose different criteria for different situations. Climate change probably does not allow for much substitution; perhaps following the Hartwick Rule is sufficient for many of our scarce mineral resources.

One final complication arises from the fact that we have introduced a new form of equity, between generations, but the other, between different people within our own generation, is still a concern. We have seen that living standards are dramatically uneven around the world and within our individual countries. Billions still live in poverty. Do the demands of intergenerational equity come into conflict with those of present-day social justice?

Most advocates of sustainability, whether of the economic or strong variety, are willing to attach a rider to their proposals under which some sort of commitment to present-day equality is affirmed. The problem is that this elides the difficult question of how to proceed if there is a tradeoff between these two types of equity. One solution that has been proposed goes like this: (1) First, calculate the total amount of worldwide resource use that would be consistent with meeting our sustainability goals. This would have to be done individually for each major type of resource. (2) Set a date for achieving sustainability. (3) Estimate the future population of the planet at the time determined in (2). (4) Divide each resource use in (1) by the number of people in (3). The result is a resource use target for each person or, adding them up, each community of persons. This has been called each individual's **equitable sustainable share**. Very roughly, adoption of this approach would require about a 90 % reduction in the use of most natural resources (including via pollution) on the part of the citizens of the wealthy countries if a target date in the mid-twenty-first century is selected.

The attractive aspect of this calculation is that it accommodates the generally accepted philosophical standard of universalism (as laid out by, among others, Kant), that all human beings be treated equally. The world's poorest people are given the same amount of resources to improve their living standards as the world's richest are to sustain them. The approach may be criticized, however, for being based on the assumption that every person will be in a position to actually make use of these resources within the time frame of the calculation. If millions remain in poverty and are cut off from access to resources, the others could conceivably have more than their share. Those who take inspiration from the potential Pareto principle (see Chap. 6) might also argue that giving the most productive societies more access to resources, and then mandating that they share the spoils, might improve the lot of the poorest countries more than a perfectly equal division. But who would make them share? And who would arrange to have resource use limits correspond to equitable sustainable shares?

## 20.6 Complexity and Uncertainty

Throughout this chapter we have been referring to ecology, but we haven't really said what it is. Since few readers of this book are likely to be familiar with this large and fast-developing field, it is important to say a few words about it.

**Ecology** is the study of the interrelationships among organisms and between them and their physical environments that determine how they survive and reproduce. It draws on chemistry, biology, geology and other sciences to develop models of the linkages between the living and nonliving components of an ecosystem. The central concepts involve cyclical flows:

- energy flows from sunlight to photosynthesis to food chains to reradiation of heat back into space;
- nutrient flows, such as carbon, nitrogen and phosphorus, between living and nonliving elements;
- the hydrological cycle, which provides water to organisms, draws it from organisms (evapotranspiration) and moves it between atmosphere, land and ocean.

At a more detailed level, ecologists study how particular species or communities of species (like a marsh) function within these flows; for instance, how nutrient flows support or result from the growth and decay of a particular type of marsh grass. Such interrelationships are complicated by the distinctive life histories of organisms—for instance, the role of seed dispersal. Most research in ecology operates between the two levels of specific organisms, which can be collected in the field and analyzed in the laboratory, and the system-level processes within which these organisms function.

At a deep level, ecology is at odds with economics. Economics is about a world of self-contained things and people. The goods and services that trade in markets have thick lines around them, so to speak, establishing a clear distinction between what is owned and what is not. If I buy a chair from you, and we take it from your living room and put it in mine, both of us know quite well what has changed and what has stayed the same. It is not as though some part of the chair has remained behind in its old quarters; what I see in your house is what I get in mine. And we don't expect that your other furniture will suddenly become less stable because they miss their former roommate. The separateness of the chair is what makes it "work" as an item of exchange. Ecology, by training us to see the connectedness of the things it studies, makes us less sure that ownership and exchange are always useful notions.

The problem of complex interaction, which is the subject matter of ecology, can be seen by looking at one example, maintaining spawning habitat for salmon. First the context: salmon are remarkable fish. They are born mostly in the small streams of the colder coastal regions. After feeding in fresh water for a period of time, they swim downstream and enter the ocean, somehow making the adjustment to a saltwater world. For between one and four years, depending on the species, they patrol the oceans, making journeys of hundreds of miles; here they find more food to sustain them, and also sometimes end up as food themselves. Finally they experience an urge to return to their native stream. Salmon have the ability to identify the "taste" of their native water, even though their stream might have been a minor tributary of another minor tributary; and, remarkably, they can do this from their migration route in the ocean, far from the stream they somehow remember. A concentration of native water of no more than a few parts per billion of ocean water is enough to tell them where to go. The salmon then make the reverse adjustment back to fresh water, head up the stream to where they were born (often leaping over rapids so tourists can take pictures of them) and search for a mate. The females dig nests in shallow gravel bottoms by throwing and twisting their bodies; the fish mate and die, leaving the newborn to renew the cycle.

As tremendously competent as these fish are in their age-old tasks, their lifecycle is vulnerable to disruption at many points. Dams or other obstructions can prevent the fish from moving up or downriver; the water may be too warm for salmon to live in; currents may be too swift or too slow, and the eddies may not be right for spawning spots; riverbanks may be stripped of vegetation, denying cover to the fish and removing habitat for the creatures they feed on early in life; gravel beds may be washed away; river flow may be too great or too small or may not match the needs of the fish at different times of the year; competing species may be introduced into salmon streams. This is not even a complete list of hazards, but it gives us the general idea.

What then is the economics of salmon habitat restoration or preservation? There are multiple requirements that have to be met if salmon are to flourish on a particular stream—are these like the "goods" we observe in human economies, except that they are good for fish? If they were, we could put a weight (price) on each one, which would tell us how much more of one requirement, like vegetative cover, is worth how much less of another, like stream flow. But this is not how the fish economy works. First, requirements are not like goods. Below a certain level life cannot be sustained; above a somewhat higher level there is no additional benefit and maybe even a lethal cost. Economic goods are valued from less to more, biological requirements as either within a suitable range (both minimum and maximum levels) or outside it. The second difference is even more difficult to manage: the value of each biological requirement depends on the value of all the others. Stream flow, water temperature, vegetative cover—these all interact to produce a habitat that can or cannot sustain salmon. None can be properly valued in isolation from the rest. By way of contrast, the market value of a chair sitting in your living room does not depend on what other furniture you have. True, its value to you does depend on this, but if it falls below the market price you can sell it, and the chair can find a new owner who values it for at least this amount. (And the chair does not change when you deliver it if you are careful....)

In practical terms, the significance of this discussion is that it is not possible to put an economic price on any particular feature of a functioning salmon stream. Even if we could put a price on the fish themselves (there is debate over whether this is meaningful), we could not say what portion of this value is conferred by planting trees along the bank or preventing dredging at a sensitive part of the river. Economic tools simply don't work for this problem, since we cannot compare the marginal cost of any particular habitat intervention with its marginal benefit. What we can do, however, is estimate the economic cost of providing an entire set of habitat conditions, and we can compare this to the benefits we can expect from doing this. Producing studies like this is useful and important, but it abandons the attempt to put prices on individual activities or their impacts, which is what economics normally tries to do. Of course, one further implication of this insight is that markets in ecological "goods", even if we could fashion them, would not maintain functioning ecosystems, since individual exchanges would fail to incorporate all the complex interrelationships that are responsible for their true value. This is a problem we will return to in the final chapter.

An additional source of complexity in ecosystems stems from their ability, under the right conditions, to recover from stress. A forest can be cut down and turned into farmland; then, generations later, the farms can be abandoned and the same sort of forest will gradually take over. Changes in a streambed might make it impossible for salmon to survive for a few seasons, but restoration of this habitat might enable the salmon to return. Ecologists call this property of ecosystems **resilience**, and it plays a crucial role in our impact on the natural world. Unfortunately, resilience cannot be assumed. If a lake suffers eutrophication (excessive nutrient loading, leading to oxygen-choking algae blooms) beyond a certain point, the organisms necessary to maintaining the interrelationships characteristic of a living lake may disappear, and stopping the harmful inflows may not lead to recovery. The problem is, what is the critical level of stress, such as the nutrient loading that might be caused by fertilizer runoff, at which resilience fails? This is difficult to determine in small, relatively well-understood systems like marshes and ponds, but it is impossible to determine with much confidence on larger scales, such as the earth's climate system.

From our survey of sustainability, it should be clear that knowing how far we can push natural systems before they lose their resilience is a key aspect of achieving a sustainable economy. If we go past the tipping point and leave to future generations an environment that is compromised beyond repair, we have failed the test, particularly if the systems we have ruined are so important that other forms of capital cannot compensate for them. Yet in few cases can we say with certainty just where the tipping point lies. This is a crucial issue in environmental policy, faced across a wide range of problems, from setting allowable concentrations of persistent organic pollutants (like many industrial and agricultural chemicals that have toxic effects and remain in the environment for decades or centuries) to establishing targets for the buildup of carbon in the atmosphere.

Because of the complexity of ecosystems and the difficulty of establishing the limits to resilience, we simply don't understand them very well. There are too many connections to trace, and understanding each individual connection can be someone's life work. Moreover, what one researcher discovers about a small piece of ecosystem functioning can force us to revise what we thought we knew about the other pieces. At this point, what we don't know about ecological processes vastly outweighs what we do. With each new bit of understanding come new surprises. It is a fair generalization to say that, on average, we continue to learn that the linkages between human beings and the rest of the natural world are wider, deeper and tighter than we had previously thought. This is why those who study ecology closely tend to be concerned that what we call "ecological problems" today comprise only a portion of the challenges we will have to face in the future.

These two factors, deep uncertainty about how ecological systems work and suspicion that what we don't know would (if we did) make us take ecological risks even more seriously, have led to attempts to set more stringent rules governing human impacts on the environment. These have crystallized in a set of ideas grouped together as **the precautionary principle**. Originally introduced into German chemical regulation, the precautionary principle has been invoked in a wide variety of environmental laws and treaties, from local ordinances to global agreements. Nevertheless, the term is used rather loosely and means different things to different people. Some of the possible elements of precaution include:

- Standards of evidence. We should not wait until scientists have produced evidence of harm at the level of certainty required in scholarly research. A reasonable suspicion of harm should be sufficient basis for taking action.
- Burden of proof. It should not fall on those worried about environmental impacts to demonstrate the risk of harm; rather, those who want to benefit from activities that threaten the environment should have the burden of demonstrating that the risk is below the level of concern.
- Extent of risk. It is unfair to make those with no say in the matter, such as future generations, bear *any* risk of significant, irreversible harm. Therefore these risks should be reduced to zero as quickly and completely as possible.
- Forward-looking risk assessment. Evaluation of environmental risks should be based, not only on what we know today (which is often very little), but, as far as possible, on what we can reasonably expect to know in the future, as evidence accumulates. In this we can be guided by the historical bias of new discovery: if certain risks have consistently gained in seriousness as we learned more about them, we should assume that they will be seen as even more serious in the future. Environmental policies that have been repeatedly made more stringent as new information appeared were too lenient in the past, before being changed, and are probably too lenient today. (Corresponding to the efficient market hypothesis presented in Chap. 17 is an efficient regulation hypothesis: a regulation that uses information efficiently should have an equal likelihood of being made more or less stringent as new information becomes available.)

The precautionary principle has many detractors, however. Most economists and many other policy analysts regard it as too fuzzy at best and restrictive to the point of paralysis at worst. How would we know whether we are being precautionary or not—what exactly is the test? For instance, in the first element, concerning standards of evidence, we know what scholarly research protocols are for statistical significance; typically they require 95 % confidence with the ready possibility of replication. (See Box 11.2 in Chap. 11.) Advocates of precaution want a lower standard, but what should it be? (One solution is the use of the expected utility formula introduced in Chap. 3: accept any likelihood of harm, however small, that emerges from research, and multiply this likelihood by the estimated amount of harm.) The burden of proof requirement of precaution can be criticized for placing so many barriers in front of businesses and governments that valuable goods and services would never be produced. Demanding that some risks should be reduced to zero would shut down large portions of the world's economy. As for future orientation, maybe the expectation that future knowledge will lead us to put more value on the environment has no basis other than the emotional commitment of environmental scientists and activists to nature—a personal bias no more worthy than someone else's commitment to TV sets and sports cars.

This debate has echoed in international policy disputes, especially over climate change and the role of environmental standards in international trade. For instance, one longstanding disagreement has pitted the United States against Europe on the question of growth hormones in cattle feed. The Europeans think these hormones should be banned under the precautionary principle, and they not only prohibit their own farmers from using them but also ban imports of hormone-laden American beef. The US government has argued that there is no conclusive scientific evidence demonstrating that these hormones are dangerous, and that the European policy is a violation of trade agreements established under the World Trade Organization. In this way a theoretical dispute over precaution has mushroomed into a multi-billion dollar conflict over trade, public health and the environment. Currently there is a temporary agreement under which a limited quantity of US beef, registered as hormone-free, is permitted to be sold in the EU—but this is a truce, not a solution.

### The Main Points

1. Seeing the economy as a self-enclosed system is misleading. There are also critical relationships with the natural and social environment: natural resources, ecological processes that sustain life, and the social and cultural mechanisms on which human beings and their abilities depend.
2. Many crucial ecological and cultural resources take the form of a commons, meaning that they are shared in general rather than being owned by any individual or organization. Typically, a commons is unsuitable for formal ownership: it is difficult to delimit and would be very costly to charge access to. Most resources of this type are self-reproducing—not only do they not need economic inputs the way most economic goods do, they maintain themselves best when not interfered with.
3. Exploitation of a commons can generate a "tragedy of the commons". This happens when individual users have an incentive to use up shared resources even though the group as a whole would be better off if the resource were maintained. It is possible to model this process as a prisoner's dilemma. If the community sharing a commons interacts over time, however, it is possible for a

cooperative solution to emerge; in that case economists use the expression "common property resource" to indicate that the shared good is managed in common.

4. An important issue is whether society would be better off if a particular commons is privatized. This can provide an incentive for maintaining the resource in question, but in many circumstances it can degrade it by disrupting the process by which it is sustained. This is a point of dispute in the current debate over intellectual property rights: when does private ownership of an idea or cultural attribute help stimulate more and better culture, and when does it stifle the cultural basis for creative work?
5. It is difficult to find an appropriate institutional form for a commons. One possibility is a trust, an organization whose explicit mission is the preservation of a portion of the shared heritage, like a historical monument or ecologically significant habitat. There are many unresolved issues in the organizational design of trusts.
6. Some natural resources are renewable: they can be replenished indefinitely, but the amount available in the future depends on the amount used today—fisheries, timber resources and topsoil are all examples. Profit-maximizing owners of such resources will compare their rate of growth if not harvested to the interest rate on money earned by harvesting and selling. Thus lower interest rates imply greater conservation.
7. Depletable natural resources have an approximately fixed stock, so any use today comes at the expense of less availability in the future; minerals provide the primary example. (The usable stock of minerals can change as the technology for exploiting them is developed, however.) Ideally, societies that draw down their stock of such resources should compensate future generations by earmarking rents (the difference between selling price and production cost) for investment projects.
8. A third type of natural resource, nonaugmentable, combines elements of the other two. These can be replenished, but if exploited beyond some threshold will be unavailable to future generations; examples include wilderness areas and biodiversity. In principle it may be warranted to use up some nonaugmentable resources if there are large enough gains in doing so, but uncertainty over their future value, and the irreversibility of such decisions, should make us cautious.
9. Pollution is normally analyzed as an external cost of economic activity. This suggests two approaches to policy, setting a price on damages that polluters are required to pay and mandating limits to polluting activities. The first is preferable when we are relatively certain of the marginal cost of pollution: this enables us to put the "right" price on it, and then market responses can determine how this translates into environmental outcomes. The second is preferable when we are relatively more certain what limits need to be respected on environmental damages: we can impose these limits and let the market determine how prices will adjust. To put it differently, priced-based approaches like pollution taxes determine the cost of the policy but accept uncertainty in its

environmental effects, while quantity-based approaches, like pollution permits, determine environmental outcomes but accept uncertainty in the costs individuals and businesses will have to pay.

10. Two meanings have been given to the concept of sustainability. "Strong" sustainability requires that we use natural resources today in such a way that future generations inherit at least as large (or valuable) a stock of such resources in the future. This calls for significant constraints on our harvesting of renewable and nonaugmentable resources and the least possible use of nonrenewable resources. "Economic" sustainability requires that any reduction in the availability of natural resources to future generations be compensated in the form of equally valued increases in produced resources, like infrastructure, equipment, innovations and human capital.
11. Ecosystems are extremely complex and not well understood; the problem of uncertainty is such that in many cases it is not possible to fine-tune regulations or pollution taxes to maximize the net benefits to society. In such situations some economists and environmental advocates would invoke the precautionary principle; this calls for a bias against permitting uncertain environmental or public health damages—in effect, a buffer between the policies that would appear optimal based on current knowledge and the policies we should actually implement. Although widely used, this principle remains controversial among economists.

## Terms to Discuss

Common property resources
Commons
Depletable resources
Ecology
Economic sustainability
Equitable sustainable share
Green taxes
Hartwick Rule
Intellectual property rights
Intergenerational equity
Nonaugmentable resources
Open access resources
Peak oil
Precautionary principle
Renewable resources
Resilience
Strong sustainability
Tragedy of the commons

**Questions to Consider**

1. What types of commons have played a role in the creation of this textbook? Does the book "use up" any of these common property resources? If you are reading this book as part of a class, is your classroom a commons? If so, are there any actions which have the potential to reduce its value to you and other students?
2. You and I are the recipients of a gift from previous generations, an environmental and cultural commons we can all freely take advantage of. Does this obligate us to make a comparable gift to our descendants?
3. Does global climate change represent a tragedy of the commons? Can you construct a payoff matrix that expresses it as a prisoner's dilemma? Who are the players, and what choices do cooperation and defection represent? Is there any evidence that common management is evolving along the lines predicted by Ostrom?
4. Are you familiar with any trusts along the lines discussed in this chapter? If so, what resources do they protect and how well do they protect them? What methods are used to ensure that they remain loyal to their main purpose?
5. Based on the analyses of renewable and depletable resources, some argue that environmentalists should generally be in favor of lower interest rates. Why would they make this claim? Do you agree? Can you think of any counterarguments, even considering only environmental impacts?
6. Most of the discussion concerning how to minimize climate change has centered on reducing the emission of carbon-containing gases into the atmosphere. Do you favor restricting the total amount of carbon that can be released, by issuing a fixed number of permits, and allowing the price to fluctuate, or setting a price for carbon and allowing the amount of carbon released to fluctuate? Why? If you prefer permits, should these be auctioned or distributed freely?
7. In 1967 the US government abandoned its plan to build a dam that would flood a portion of the Grand Canyon for hydroelectric power and water supply control. Was this decision in the interest of sustainability, against sustainability, or unlikely to matter much one way or the other? In your answer be as precise as possible about the criteria you are using for sustainability, and in particular whether they fall closer to the economic or strong versions of this concept.
8. Do you think that it should be an objective of economic and ecological policy to aim toward an equitable sustainable share of resource use for all people? Why or why not? Are there conditions under which the adoption of these targets would be politically feasible? What are the implications of your answer for sustainability policy?
9. As mentioned at the beginning of the chapter, one of the suspected causes of the decline of bee populations is a class of commonly used pesticides. Studies of the effects of these agricultural chemicals have been inconclusive one way or the other. Would you support invoking the precautionary principle to ban these chemicals while further studies are done? Does your answer depend on the economic benefits farmers get from using them? Does it depend on the balance between studies supporting and failing to find a negative effect on bees? What criteria are you using to answer these questions?