CHAPTER 4

The Nature of Resources and the Resources of Nature

The economic system is a subsystem of the global ecosystem, and one of the major goals of ecological economics is to determine when the benefits of continued growth in the economic subsystem are outweighed by the increasing opportunity costs of encroaching on the sustaining ecosystem. Achieving this goal demands a clear understanding of how the global ecosystem sustains the economy and how economic growth affects the sustaining ecosystem. In addition to determining when economic growth becomes uneconomic, ecological economists must provide the policies necessary to keep the economy within its "optimal" size range. Currently, the dominant tool for determining economic optimality is the market. However, markets only function effectively with goods and services that have certain specific attributes, and they really do not function at all with goods that cannot be exclusively owned. Developing effective policies requires a clear understanding of the specific attributes of goods and services that the economic system must allocate among alternative ends. In this chapter, we introduce you to several concepts that will be useful for understanding scarce resources. These include the difference between stock-flow and fund-service resources, and the concepts of rivalness and excludability. We will also consider further the laws of the thermodynamics.

Chapters 5 and 6 will apply these concepts to the abiotic and biotic scarce resources upon which our economy depends. Chapters 9 and 10 will explain why these concepts are so important to policy analysis.

A FINITE PLANET

With the exception of inconsequential bits of material arriving from space, there is only so much water, so much land, and so much atmosphere to our planet. We have finite supplies of soils, minerals, and fossil fuels. Even if we argue that natural processes make more soil and fossil fuels, the rate at which they do so is not only finite; it is exceedingly slow from a human perspective. Fortunately, we are blessed with a steady influx of solar energy that will undoubtedly continue long past the extinction of the human race,[1] but the rate at which this energy arrives is also fixed and finite. Of course, for this energy to be useful, it must be captured, and at present virtually all of that capture is performed by a finite stock of photosynthesizing organisms. In other words, it appears that we live on a finite planet. Why waste words on such an obvious fact?

Continued economic growth is the explicit goal of most economists and policy makers. Many economists even argue that economic growth is not only compatible with a clean environment, it is a prerequisite for achieving one. A clean environment is a luxury good, the story goes. People who are struggling simply to feed themselves cannot be concerned with pollution. The fact that throughout the Third World, poverty forces people to actually live and work in garbage dumps, finding food to eat, clothes to wear, and goods and materials to recycle speaks for itself—survival takes precedence over environment. And work in a factory, no matter how much it pollutes, must be better than life in a dump. Only in rich nations can we afford the luxury of clean water and clean air. This would explain the fact that water quality and air quality in the United States has improved since the 1970s (we will return to this apparent paradox later), and even forest cover is expanding in many areas. The best way to clean up the planet and preserve its remaining ecosystems, it is often argued, is through economic growth.

THINK ABOUT IT!

Do you think the environment in wealthy countries has improved over the past 20 years? Have the global environmental impacts of wealthy countries diminished over the past 20 years? Where do most of the things you buy come from? Do you think their production has negative impacts on the environment?

In contrast to this scenario, the laws of physics tell us that we cannot create something from nothing. Economic production therefore requires

---

[1] The average life span of a mammalian species is only one million years, while the sun is expected to last for several billion years. See R. Foley, "Pattern and Process in Hominid Evolution." In J. Bintliff, ed. *Structure and Contingency*. Leicester, England: Leicester University Press, 1999.

raw material inputs, and the finite supply of those inputs limits the size of the economy. The economic system cannot grow indefinitely, no matter how much we can substitute a new resource for an exhausted one. For example, human populations cannot continue growing forever. A simple calculation shows that even at a continuous 1% rate of growth, the human population would have a mass greater than the entire planet in just over 3000 years.[2] Similarly, we could not conceivably continue to increase the physical mass of artifacts we own and consume over the next 1000 years at the same rate as we have during the past 50. But population growth rates are already slowing. The most recent U.N. report estimates that the worldwide population will stabilize at about 11 billion people by the year 2200,[3] though many ecologists believe planetary ecosystems could not sustain even half that number.[4] Some also argue that we can produce more using less, so the physical mass of artifacts need not increase. It is true that we can now produce 12 aluminum cans from the same material it once took to produce one, but we still use more aluminum than ever before, and aluminum can only be rolled so thin. Still others assert that economic value is not a measure of a physical quantity, and therefore it is not at all obvious that the production of economic value has physical limits.

It is true that economic value is not a physical quantity. Economic production is really all about creating welfare, quality of life, utility, or whatever else we choose to call this psychic flux of satisfaction. Does it really matter, then, that we live on a finite planet? Certainly it matters in terms of economic production. Economic production, as it is typically understood, is the transformation of raw materials supplied by the ecosystem into something of value to humans. Transformation requires energy, and it inevitably generates waste. Even the service sector requires physical inputs to sustain those who provide the service. We have finite supplies of energy, finite supplies of raw materials, finite absorption capacities for our

---

[2] Some would say that this type of calculation is really just a straw man argument, and that no one argues that human population growth will continue indefinitely. However, University of Maryland Professor Julian Simon once claimed that human populations could continue growing at the same rate for the next 7 million years with existing technologies (J. Simon, *The Ultimate Resource*, 2nd ed. Princeton, NJ: Princeton University Press, 1996). A steady 1% growth rate of the current population for that long would leave us with more people than the estimated number of atoms in the universe. Simon is widely and favorably cited in a recent influential book by Bjorn Lomborg, *The Skeptical Environmentalist*, Cambridge: Cambridge University Press, 2001.

[3] United Nations Population Division, Department of Economic and Social Affairs 1998. World Population Projections to 2150: Executive Summary. Online: http://www.undp.org/popin/wdtrends/execsum.htm.

[4] For example, G. Daily, A. Ehrlich, and P. Ehrlich, Optimum Human Population Size. *Population and Environment* 15(6) (1994) argue that 5.5 billion people clearly exceeds the planet's carrying capacity and suggest optimal populations of 1.5 to 2 billion.

wastes, and poorly understood but finite capacities for ecosystems to provide a host of goods and services essential for our survival. And evidence suggests that we are reaching the limits with respect to these resources, as we will describe in greater detail below. With continued growth in production, the economic subsystem must eventually overwhelm the capacity of the global ecosystem to sustain it.

All of this does not mean economic value cannot continue to grow indefinitely. Indeed, we believe that perhaps it can if we define economic value in terms of the psychic flux of human satisfaction, and we learn to attain this satisfaction through nonmaterial means. Ecological economics does not call for an end to economic development, merely to physical growth, while mainstream economists' definitions of economic progress confusingly conflate the two. The problem is that the existing market economy is ill-suited to providing nonmaterial satisfaction. Even if one accepts some variant of the NCEs' assertion that infinite economic "growth" is possible by redefining growth as the ever-greater provision of psychic satisfaction (what we call economic development), the conventional economic paradigm is probably an inadequate guide for achieving this goal—but we'll come back to that later. Our point for now is that constant growth in physical throughput is impossible. Once we understand this, the question becomes how to decide when economic production becomes uneconomic, particularly if this has already happened. Before we address this last question, however, we need to look more closely at the assertion stated above—that infinite growth is impossible in a closed system. The branch of science most relevant to this issue, and indeed most relevant to the economic problem, is thermodynamics.

THINK ABOUT IT!

Of all the activities and objects that give you satisfaction, which ones consume the fewest resources and produce the least waste? Which consume the most resources and produce the most waste? Which of these are produced by the market economy?

THE LAWS OF THERMODYNAMICS

A Brief History of Thermodynamics

With the advent of the Industrial Revolution and the machine age at the end of the eighteenth century, scientists became intrigued by the idea of a perpetual motion machine—a machine fueled by the very same heat it generated while it worked. In 1824, the French scientist Sadi Carnot, while trying to calculate the greatest amount of work that could be done by a given amount of heat, realized that a heat engine (e.g., a steam engine) could only perform work by taking heat from one reservoir and transferring it to another at a lower temperature. In fact, the performance of work in general required a temperature differential between two reservoirs, and all else being equal, the greater the differential, the more work that could be performed. However, even with a temperature differential, it was impossible to convert heat or any kind of energy directly into work with 100% efficiency. It turned out that this was related to the obvious fact that heat would naturally flow from a hotter item to a colder one, and not vice versa. While heat could be made to flow from a colder object to a hotter one, the amount of work required to make this happen was greater than the amount of energy latent in the increased temperature of the hotter object.[5] To the dismay of industrialists, physical laws did not allow a perpetual motion machine.

Within the course of the next few decades, some other important facts were established. Robert Mayer and Herman Helmholtz showed that energy cannot be created or destroyed, and James Joule performed experiments demonstrating that energy and work are equivalent. Rudolf Clausius recognized that there were two related principles at work here, which came to be called the First and Second Laws of Thermodynamics. The First Law established that energy could not be created or destroyed, and the Second Law established that energy moved inevitably toward greater homogeneity. Because work requires a temperature differential, homogeneity means that energy becomes increasingly unavailable to perform work. In the words of Georgescu-Roegen, "all kinds of energy are gradually transformed into heat, and heat becomes so dissipated in the end that mankind can no longer use it."[6] Clausius coined the term *entropy* for the Second Law, derived from the Greek word for transformation, in recognition of the fact that entropy was a one-way street of irreversible change, a continual increase in disorder in the universe. While the First Law of Thermodynamics relates to quantity, the Second Law relates to quality.

A dictionary definition of **entropy** is a measure of the unavailable energy in a thermodynamic system. "Unavailable" means unavailable to do work. Unavailable energy is also known as bound energy, and available energy as free energy. For example, gasoline carries a form of free energy: It can be burned in an internal combustion engine to generate work. Work can be transformed into free energy in a different form (e.g., it can carry a car to the top of a big hill, where it has the potential energy to coast back down) or into heat, which diffuses into the surrounding environment. The energy in the gasoline transformed into heat has not

---

[5] L. P. Wheeler, *Josiah Willard Gibbs: The History of a Great Mind*, New Haven, CT: Archon Books, 1999.

[6] N. Georgescu-Roegen, *Energy and Economic Myths: Institutional and Analytic Economic Essays*, New York: Pergamon Press, p. 8.

disappeared but has instead become bound energy, unavailable to perform work. In the well-cited example used by Georgescu-Roegen, the ocean contains enormous amounts of energy, but that energy is not available to run a ship.[7] It is bound energy, because there is no reservoir of a lower temperature to which the energy within the ocean can be transferred, and Carnot showed that such a temperature differential was essential to perform work.

THINK ABOUT IT!

Would you invest in a revolutionary new automobile designed to capture its own exhaust and burn it again?

Does matter, as well as energy, obey the laws of thermodynamics? Einstein's famous $E = mc^2$ established the equivalence between matter and energy, and thus the fact that the First Law applies to matter as well as energy. Georgescu-Roegen argued that the entropy law also applies to matter, and proposed that this be recognized as the fourth law of thermodynamics.[8] Although physicists dispute the idea of a formal "fourth law," there is no dispute about matter being subject to entropy in the sense of a natural tendency to disorder. When a cube of sugar is dropped into a cup of water it gradually dissolves, losing its order. Nor will that order spontaneously reappear. This is equally obvious for mixing liquids and gases, or more generally for any substance that is soluble in another. It is less obvious for materials in environments in which they are not soluble. However, friction, erosion, and chemical breakdown inexorably lead to the breakdown and diffusion of even the hardest metals over sufficient time, resulting in increased disorder.

It is important to recognize that the laws of thermodynamics were developed more from experimental evidence than from theory, and the mechanism behind entropy is still not completely understood.[9] When the laws of thermodynamics were first proposed, mechanical physics was the dominant paradigm in science. In a mechanical system, every action has an equal and opposite reaction, and is thus inherently reversible. One theoretical explanation of entropy comes from efforts to harmonize the irreversibility inherent to entropy with the reversibility that characterizes mechanical physics. This has resulted in the field of statistical mechanics, best explained by referring to the example of the sugar cube used above. When in a cube on a shelf, sugar molecules are not free to disperse—there

---

[7] Ibid., p. 6.

[8] The third law of thermodynamics states that the entropy of any pure, perfect crystalline element or compound at absolute zero (0 K) is equal to zero. This is not particularly relevant to economics.

[9] R. Beard and G. Lozada, *Economics, Entropy and the Environment: The Extraordinary Economics of Nicholas Georgescu-Roegen*, Cheltenham, England: Edward Elgar, 2000.

is only one state space available to them. When placed into a container of water, in which sugar is soluble, sugar molecules are free to move. Suddenly, there are almost countless possible arrangements the sugar molecules can take within that container. Each arrangement may have an equal probability, but only one of those arrangements is that of the cube. Thus, the probability of the cube remaining intact is almost immeasurably small. According to this statistical version of thermodynamics, or statistical mechanics, a sugar cube dissolved in water could spontaneously reassemble, and a cold pot of water could spontaneously come to a boil; it is simply not very likely. But unlikely events are quasi-certain to happen if we wait long enough, and indeed might happen tomorrow with the same (low) probability as for the day after a billion years from now. So the fact that we have never observed a cold pot of water spontaneously come to a boil, or even less significant instances of spontaneous increases in low entropy, remains an empirical difficulty for statistical mechanics.

Statistical mechanics is a far from universally accepted explanation of entropy, and while it does seem to allow for reversibility, which is compatible with mechanical physics, it also depends entirely on random motion, which is incompatible. If the defenders of statistical mechanics believe that it reconciles entropy theory with mechanical physics, they must also believe that if every atom in the universe happened to be traveling in the opposite direction to which it now moves, then heat would move from colder objects to warmer ones, and order would spontaneously appear.[10] If the statistical view of entropy is correct, the gradual dispersion of material via physical and chemical erosion may not be entropy per se, because the physical and chemical erosion of matter is fundamentally different from the dissipation of heat. Regardless of the explanation, however, the end result and the practical implications are the same: Both matter and energy move irreversibly toward less-ordered states, and lower-entropy states can only be restored by converting low entropy to high entropy elsewhere in the system—and the increase in entropy elsewhere will be greater than the local decrease in entropy that it made possible.

Entropy and Life

If all matter-energy moves toward greater disorder, how, then, do we explain life? Is life not a form of spontaneous order that emerged from the chaotic maelstrom that was our early planet? Has not the continued evolution of life on Earth led to highly complex and ordered life forms? And don't ecosystems exhibit yet another level of complexity and order that

---

[10] N. Georgescu-Roegen, *The Entropy Law and the Economic Process*, Cambridge, MA: Harvard University Press, 1971.

arises from the mutual interactions of the organisms of which they are composed? These facts in no way contradict entropy, but to understand why this is so, we remember the distinction made in Chapter 2 between isolated, closed, and open systems. Isolated systems are those in which neither matter nor energy can enter or leave. The universe is such a system. The Earth, in contrast, is a materially closed system, in which radiant energy can enter and leave, but for all practical purposes, matter does not. The Earth is continually bathed in the low entropy of solar radiation that has allowed the complexity and order of life to emerge and increase. Any living thing on our planet is an open system, capable of absorbing and emitting both matter and energy.[11] A biological or ecological system is only capable of maintaining its low entropy by drawing on even greater amounts of low entropy from the system in which it exists, and returning high entropy back into the system. Erwin Schrodinger has described life as a system in steady-state thermodynamic disequilibrium that maintains its constant distance from equilibrium (death) by feeding on low entropy from its environment—that is, by exchanging high-entropy outputs for low-entropy inputs.[12] This exchange results in a net increase in entropy. Hence, life on our planet requires a constant flow of low-entropy inputs from the sun simply to maintain itself.

Entropy and Economics

What, then, are the implications of the entropy law for the science of economics? The goal of the early neoclassical economists was to establish economics as a science, and in the words of William Stanley Jevons, "it is clear that economics, if it is to be a science at all, must be a mathematical science."[13] The basic argument was that economics focused on quantities of goods, services, and money and therefore was amenable to quantitative (i.e., mathematical) analysis. Such analysis enabled economists to build logically consistent theories from fundamental axioms. These theories could then be applied to problems in the real world. In the words of Leon Walras, "from real type concepts, [the physico-mathematical] sciences abstract ideal-type concepts which they define, and then on the basis of these definitions they construct *a priori* the whole framework of their the-

---

[11] H.E. Daly and J. Cobb, *For the Common Good: Redirecting the Economy Towards Community, the Environment, and a Sustainable Future*. Boston: Beacon Press, 1989, p. 253. Such open systems are often called "dissipative structures." The nonequilibrium thermodynamics of dissipative structures is a field of thermodynamics under development by Nobel laureate physicist Ilya Prigogine and his collaborators. See his *The End of Certainty*, New York: Free Press, 1996.

[12] E. Schrodinger, *What Is Life?* Cambridge, England: Cambridge University Press, 1944.

[13] W. S. Jevons, quoted in R. Heilbronner, *Teachings from the Worldly Philosophy*, New York: Norton, p. 210.

orems and proofs. After that they go back to experience not to confirm but to apply their conclusions."[14] Mechanical physics was the best-developed and most successful application of this approach in the sciences at the time the original neoclassicals were writing, and thus was explicitly accepted as a model to emulate.[15]

In mechanical physics, all processes were considered reversible. For example, if one struck a billiard ball, an equal and opposite strike would return it exactly to its initial position. In contrast, the Second Law of Thermodynamics established the existence of irreversible processes as a fundamental law of physics. Entropy meant that in any isolated system, energy and matter would move toward a thermodynamic equilibrium in which they were equally diffused throughout the closed space. This implies an absence of temperature differentials and an inability to perform work. Quality, or order, was more important than quantity, and net quality changed in one direction only. The universe as a whole is an isolated system, and thus must be inevitably progressing toward a "heat death" in which all energy is evenly dispersed.

This notion was radical in the early nineteenth century and had profound implications for science as well as philosophy. If the laws of mechanical physics were universal, then the universe was governed by the same principles as a pool table. Not only was there no such thing as irreversible change, but if one could determine the position and velocity of every atom in the universe, one would know the past and could predict the future. Though this implies no free will, no alternatives and no sense in worrying about policy, it was during the nineteenth century the reigning worldview among scientists in the West and still holds considerable sway today. In the world of mechanical physics, the circular flow vision of economics discussed in Chapter 2 makes sense, as one can continually return to the same starting point. In a world where entropy reigns, it cannot.

Indeed, if we accept the laws of thermodynamics,[16] the entire nature of the economic system is entropic. The First Law of Thermodynamics tells us that we cannot make something from nothing, and hence that all human production must ultimately be based on resources provided by nature. These resources are transformed through the production process into something of use to humans, and transformation requires work. Only low entropy or free energy can provide work. The First Law also ensures

---

[14] L. Walras, quoted in Heilbronner, ibid., p. 225.

[15] Alfred Marshall, perhaps the most famous of the founding fathers of NCE, argued that in the future, the complex science of biology would provide a better model for economics, but in the meantime he relied extensively on the methodologies of physics. Heilbronner, ibid.

[16] Though in truth, physical laws, such as gravity, function the same whether we accept them or not!

that any waste generated by the economy cannot simply disappear but must be accounted for as an integral part of the production process. And the entropy law tells us that inevitably whatever resources we transform into something useful must disintegrate, decay, fall apart, or dissipate into something useless, returning in the form of waste to the sustaining system that generated the resource. The economy is thus an ordered system for transforming low-entropy raw materials and energy into high-entropy waste and unavailable energy, providing humans with a "psychic flux" of satisfaction in the process. Most importantly, the order in our economic system, its ability to produce and provide us with satisfaction, can only be maintained by a steady stream of low-entropy matter-energy, and this high-quality, useful matter-energy is only a fraction of the gross mass of matter-energy of which the Earth is composed.

> **THINK ABOUT IT!**
> *Many people have proposed putting our toxic waste output onto rockets and shooting it into space. Based on your knowledge of thermodynamics, do you think this is a feasible solution for the pollution problem? Why or why not?*

While we stress the fundamental importance of entropy to the economic process, we do *not* advocate an "entropy theory of value" similar to the classical economists' "labor theory of value." Value has psychic roots in want satisfaction, as well as physical roots in entropy. To propose an "entropy theory of value" would be to focus on the supply side only and neglect demand. And even on the supply side, entropy does not reflect many qualitative differences in materials that are economically important (e.g., hardness, strength, ductility, conductivity, etc.). On the other hand, any theory of value that ignores entropy is dangerously deficient.

STOCK-FLOW RESOURCES AND FUND-SERVICE RESOURCES

We now turn our attention to an important distinction between different types of scarce resources too often neglected by conventional economists—that of stock-flow and fund-service. Conventional economics uses the phrase "factors of production." Factors of production are the inputs into a production process necessary to create any output. For example, when you make a pizza, you need a cook, a kitchen with an oven, and the raw ingredients. If you think about it carefully, however, you will clearly see that the cook and kitchen are different in some fundamental ways from the raw ingredients. The cook and kitchen are approximately the same before making the pizza as after, though just a bit more worn out. The raw ingredients, however, are used up, transformed first into the pizza itself, then rapidly thereafter into waste. The cook and kitchen are not physically embodied in the pizza, but the raw ingredients are. Thousands of years ago, Aristotle discussed this important distinction and divided causation (factors) into *material cause*, that which is transformed, and *efficient cause*, that which causes the transformation without itself being transformed in the process. Raw ingredients are the material cause, and the cook and kitchen are the efficient cause.

Other differences between these factors of production also exist. If we have enough raw ingredients to make 1000 pizzas, those ingredients could be used to make 1000 pizzas in one night, or one pizza a night for 1000 nights (assuming the ingredients were frozen and wouldn't spoil, and we had enough cooks and kitchens). The economy can use the existing stock of raw materials at virtually any rate, and time is not a factor. The productivity of raw ingredients is simply measured as the physical number of pizzas into which they can be transformed. In addition, as the ingredients for a pizza are produced over time, those ingredients can be used when they are produced, or stockpiled for future use. In contrast, while a cook or a kitchen may be capable of producing many thousands of pizzas over the course of their lifetimes, they can produce no more than a few pizzas in any given evening, even if limitless ingredients are available. The productivity of cooks and kitchens is measured as a number of pizzas per hour. However, this productivity cannot be stockpiled. For example, if we rest a cook for 6 nights, his capacity to produce a week's worth of pizzas cannot be used up all on the seventh night.

Georgescu-Roegen used the terms "stock" and "fund" to distinguish between these fundamentally different types of resources. A **stock-flow resource** is materially transformed into what it produces. A stock can provide a flow of material, and the flow can be of virtually any magnitude; that is, the stock can be used at almost any rate desired. Time does not enter into the equation, so the appropriate unit for measuring the production of a stock-flow resource is the physical amount of goods or services it can produce. Further, a flow can be stockpiled for future use. Finally, stock-flow resources are used up, not worn out. A **fund-service resource**, in contrast, suffers wear and tear from production but does not become a part of (does not become embodied in) the thing produced. Instead, a fund provides a service at a fixed rate, and the appropriate unit for measuring the service is physical output per unit of time. The service from a fund cannot be stockpiled for future use, and fund-service resources are worn out, not used up.[17]

---

[17] Georgescu-Roegen, *The Entropy Law*, op. cit.

Box 4-1 STOCK-FLOW AND FUND-SERVICE RESOURCES

In the academic literature, there are many distinct definitions for stocks, flows, funds, and services. To make it clear, we are discussing the specific definitions given here. Future references will be to stock-flow and fund-service resources.

Stock-flow resources:
- Are materially transformed into what they produce (material cause).
- Can be used at virtually any rate desired (subject to the availability of fund-service resources required for their transformation), and their productivity is measured by the number of physical units of the product into which they are transformed.
- Can be stockpiled.
- Are used up, not worn out.

Fund-service resources:
- Are not materially transformed into what they produce (efficient cause).
- Can only be used at a given rate, and their productivity is measured as output per unit of time.
- Cannot be stockpiled.
- Are worn out, not used up.

The stock-flow and fund-service concepts are important when analyzing human production, and probably more so when focusing on the goods and services provided by nature. Note that "material cause" is always stock-flow in nature, and "efficient cause" is always fund-service.

THINK ABOUT IT!

Think about a specific ecosystem—or better yet, go visit one, and take along a field notebook. Make a list of three stock-flow resources provided by (or found in) that ecosystem, and three fund-service resources. (Note that you will need to be very specific about the use of each resource. For example, drinking water is a stock-flow, while water for swimming is a fund-service). Tick off the attributes of stock-flow and fund-service for each (see Box 4.1).

EXCLUDABILITY AND RIVALNESS

Excludability and rivalness are also crucial concepts for economic analysis, and rivalness is in fact related to the stock-flow, fund-service distinction. Though conventional economists first introduced these concepts, they rarely receive the attention they deserve. We believe they are important enough to be described in some detail both here and in Chapter 10.

Excludability is a legal concept that when enforced allows an owner to prevent others from using his or her asset. An **excludable resource** is one whose ownership allows the owner to use it while simultaneously denying others the privilege. For example, in modern society, when I own a bicycle, I can prohibit you from using it. In the absence of social institutions enforcing ownership, nothing is excludable. However, the characteristics of some goods and services are such that it is impossible or else highly impractical to make them excludable. While someone could conceivably own a streetlight on a public street, when that streetlight is turned on, there is no practical way to deny other people on the street the right to use its light. There is no conceivable way that an individual can own climate stability, or atmospheric gas regulation, or protection from UV radiation, since there is no feasible institution or technology that could allow one person to deny all others access. When no institution or technology exists that makes a good or service excludable, it is known as a **nonexcludable resource**.

Rivalness is an inherent characteristic of certain resources whereby consumption or use by one person reduces the amount available for everyone else. A **rival resource** is one whose use by one person precludes its use by another person. A pizza (a stock-flow resource) is clearly rival, because if I eat it, it is no longer available for you to eat. A bicycle (a fund-service resource that provides the service of transportation) is also rival, because if I am using it, you cannot. While you can use it after I am done, the bicycle has worn out a bit from my use and is not the same as it was. A **nonrival resource** is one whose use by one person does not affect its use by another. If I use the light of a streetlight when riding my bike at night, it does not decrease the amount of light available for you to use. Similarly, if I use the ozone layer to protect me from skin cancer, there is just as much left for you to use for the same purpose. It is possible to deplete the ozone layer (through the emission of chlorofluorocarbons, for example), but depletion does not occur through use. Rivalness is a physical characteristic of a good or service and is not affected by human institutions.

Note that all stock-flow resources are rival, and all nonrival goods are fund-service. However, some fund-service goods are rival. For example, my bicycle is a fund that provides the service of transportation, but it is rival; the ozone layer is a fund that provides the service of screening UV rays, but it is nonrival.

As you will see when we turn to allocative mechanisms in subsequent chapters, the concepts of rivalness and excludability are very important.

THINK ABOUT IT!

For the list of resources you made earlier, answer the following questions:

Is the resource rival or nonrival? In general, can you think of any stock-flow resources that are nonrival? Can you think of any fund-service resources provided by nature that are rival?

Is the resource excludable or nonexcludable? (Note that excludability may differ depending on the specific value in question.) If it is nonexcludable, can you think of an institution or technology that could make it excludable? Do you think it should be made excludable? Why or why not?

Is the resource a market good or a nonmarket good?

In general, can you think of any stock-flow resources that cannot be made excludable? Can you think of fund-service resources provided by nature that can be made excludable?

GOODS AND SERVICES PROVIDED BY THE SUSTAINING SYSTEM

To make this discussion of entropy, fund-services, stock-flows, excludability, and rivalness more concrete, and to really understand the implications for economic theory and policy, we must see how these concepts apply to the specific scarce resources available to our economy—the goods and services provided by nature. We undertake this task in the next two chapters, and conclude this one by simply introducing the scarce resources.

For our purposes, we will present eight types of goods and services provided by nature, divided for convenience into nonliving and living resources. Clearly this is an enormous abstraction from the number and complexity of resources our Earth actually does supply, but these categories illustrate why the specific characteristics of goods and services we have described are of fundamental importance to economic policy.

1. *Fossil fuels*. For practical purposes, fossil fuels are a nonrenewable source of low-entropy energy. They are also very important as material building blocks.
2. *Minerals*. The Earth provides fixed stocks of the basic elements in varying combinations and degrees of purity, which we will refer to hereafter simply as minerals. This is the raw material on which all economic activity and life itself ultimately depends. Rocks in which specific minerals are found in relatively pure form we refer to as ores. Ores in which minerals are highly concentrated are a nonre-

newable source of low-entropy matter. We will refer to mineral resources and fossil fuels together as **nonrenewable resources**, and the first five goods and services in this list as abiotic resources (see Chapter 5).

3. *Water*. The Earth provides a fixed stock of water, of which fresh water is only a miniscule fraction. All life on Earth depends on water, and human life depends on fresh water.
4. *Land*. The Earth provides a physical structure to support us that is capable of capturing the solar radiation and rain that falls upon it. Land as a physical structure, a substrate, or a *site* has economic properties unrelated to the productivity of its soil, and is thus distinct from land as a *source* of nutrients and minerals. To capture this distinction, we will refer to land as a physical structure and location as Ricardian land.[18] The quantity and quality of soil available on a given piece of Ricardian land will be grouped with minerals, discussed below.
5. *Solar energy*. The sustaining system provides solar energy, the ultimate source of low entropy upon which the entire system depends.
6. *Renewable resources*. Life is able to harness solar energy to organize water and basic elements into more useful structures (from the human perspective) that we can use as raw materials in the economic process. Only photosynthesizing organisms are capable of achieving this directly, and virtually all other organisms, including humans, depend on these primary producers. These biological resources are traditionally referred to as **renewable resources**, but they are only renewable if extracted more slowly than the rate at which they reproduce. Clearly, species can be exploited to extinction, so, as we shall see, biological resources are exhaustible in a way that mineral resources are not.
7. *Ecosystem services*. Living species interact to create complex ecosystems, and these ecosystems generate **ecosystem functions**. When functions are of use to humans, we refer to them as **ecosystem services**. Many of these ecosystem services are essential to our survival.
8. *Waste absorption*. Ecosystems process waste, render it harmless to humans, and, in most cases, again make it available to renewable resource stocks as a raw material input. This is really a specific type of ecosystem service, but one whose economic characteristics make it worth classifying on its own. We refer to these last three goods and services as biotic resources (see Chapter 6).

---

[18] Ibid., p. 232.

We refer to all the structures and systems that provide these goods and services as **natural capital**. In the following chapters, we will examine these resources in the light of entropy, fund-services, stock-flows, excludability, and rivalness.

BIG IDEAS to remember

- Laws of Thermodynamics
  - –Conservation of matter-energy
  - –The law of increasing entropy
- Stock-flow resource
- Fund-service resource
- Excludable and nonexcludable resources
- Rival and nonrival resources
- Eightfold classification of resources