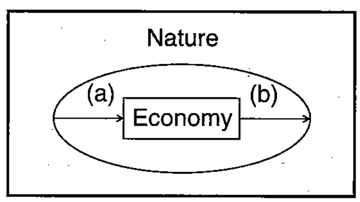
Chapter 2

The Economy and the Environment

The **economy** is a collection of technological, legal, and social arrangements through which individuals in society seek to increase their material and spiritual well-being. The two elementary economic functions pursued by society are **production** and **distribution.** Production refers to all those activities that determine the quantities of goods and services that are produced and the technological and managerial means by which this production is carried out. **Distribution** refers to the way in which goods and services are divided up, or distributed, among the individuals and groups that make up society. Distribution puts goods and services in the hands of individuals, households, and organizations; the final utilization of these goods and services is termed **consumption.**

Any economic system exists within, and is encompassed by, the natural world. Its processes and changes are of course governed by the **laws of nature.** In addition, economies make use directly of natural assets of all types. One role the natural world plays is that of provider of raw materials and energy inputs, without which production and consumption would be impossible. Thus, one type of impact that an economic system has on nature is by drawing upon raw materials to keep the system functioning. Production and consumption activities also produce leftover waste products, called "residuals," and sooner or later these must find their way back into the natural world. Depending on how they are handled, these residuals may lead to pollution or the degradation of the natural environment. We can illustrate these fundamental relationships with a simple schematic:



The link marked (a) represents raw materials flowing into production and consumption. The study of nature in its role as provider of raw materials is called **natural resource economics.** The link labeled (b) shows the impact of economic activity on the quality of the natural environment. The study of this residuals flow and its resultant impacts in the natural world comes under the heading of **environmental economics.** Although pollution control is the major topic within environmental economics, it is not the only one. Human beings have an impact on the environment in many ways that are not related to pollution in the traditional sense. Habitat disruption from housing developments and scenic degradation from any number of human activities are examples of environmental impacts that are not related to the discharge of specific pollutants.

The topic of this book is environmental economics. We will study the management of waste flows and the impacts of human activity on the quality of environmental assets. But in a real sense many of these problems originate in the earlier, raw material phase of the nature–economy interaction. So before proceeding, we consider briefly the major dimensions of natural resource economics.

Natural Resource Economics

In modern industrial/urban societies it is sometimes easy to overlook the fact that a large part of total economic activity still relies on the extraction and utilization of natural resources. **Natural resource economics** is the application of economic principles to the study of these activities. To get a general impression of what this discipline includes, the following is a list of its major subdivisions and examples of questions pursued in each one.[1]

Mineral economics: What is the appropriate rate at which to extract ore from a mine? How do exploration and the addition to reserves respond to mineral prices?

Forest economics: What is the appropriate rate to harvest timber? How do government policies affect the harvest rates pursued by timber companies?

Marine economics: What kinds of rules need to be established for managing fisheries? How do different harvest rates affect the stocks of fish?

Land economics: How do people in the private sector (builders, home purchasers) make decisions about the use of land? How do the laws of property rights and public land use regulations affect the way space is devoted to different uses?

Energy economics: What are the appropriate rates for extracting underground petroleum deposits? How sensitive is energy use to changes in energy prices?

[1] Natural resource economics is the subject of a companion book written by one of the authors. See *Natural Resource Economics, An Introduction,* by Barry C. Field, McGraw-Hill, 2000; reissued by Waveland Press, 2005.

Water economics: How do different water laws affect the way water is utilized by different people? What kinds of regulations should govern the reallocation of water from, for example, agriculture to urban users?

Agricultural economics: How do farmers make decisions about using conservation practices in cultivating their land? How do government programs affect the choices farmers make regarding what crops to produce and how to produce them?

A fundamental distinction in natural resource economics is that of **renewable** and **nonrenewable** resources. The living resources, such as fisheries and timber, are renewable; they grow in time according to biological processes. Some nonliving resources are also renewable—the classic example being the sun's energy that reaches the earth. Nonrenewable resources are those for which there are no processes of replenishment—once used they are gone forever. Classic examples are petroleum reservoirs and nonenergy mineral deposits. Certain resources, such as many groundwater aquifers, have replenishment rates that are so low that they are in effect nonrenewable.

It is easy to see that the use of nonrenewable resources is a problem with a strong **intertemporal** dimension; it involves trade-offs between the present and the future. If more oil is pumped out of an underground deposit this year, less will be available to extract in future years. Establishing today's correct pumping rate, therefore, requires a comparison of the value of oil now with the anticipated value of oil in the future.

But complicated intertemporal trade-offs also exist with renewable resources. What should today's codfish harvesting rate be, considering that the size of the remaining stock will affect its future growth and availability? Should this timber be cut today or does its expected rate of growth warrant holding off harvesting until some time in the future? Biological and ecological processes create connections between the rates of resource use in the present and the quantity and quality of resources available to future generations. It is these connections that are the focus of what has come to be called **sustainability.**

A resource use rate that is sustainable is one that can be maintained over the long run without impairing the fundamental ability of the natural resource base to support future generations. Sustainability does not mean that resources must remain untouched; rather, it means that their rates of use be chosen so as not to jeopardize future generations. In the case of nonrenewable resources, this implies using the extracted resource in such a way that it contributes to the long-run economic and social health of the population. For renewable resources, it means establishing rates of use that are coordinated with the natural productivity rates affecting the way the resources grow and decline.

Many environmental problems also have strong intertemporal dimensions, that is, important trade-offs between today and the future. For example, many pollutants tend to accumulate in the environment rather than dissipate and disappear. Heavy metals, for example, can accumulate in water and soil. Carbon dioxide emissions over many decades have accumulated in the earth's atmosphere. What is in fact being depleted here is the earth's **assimilative**

capacity, the ability of the natural system to accept certain pollutants and render them benign or inoffensive. Some of the theoretical ideas about the depletion of natural resources are also useful in understanding environmental pollution. In this sense assimilative capacity is a natural resource akin to traditional resources such as oil deposits and forests.

A resource that has only recently impressed itself upon us is one that resides not in any one substance but in a collection of elements: **biological diversity.** Biologists estimate that there may be as many as 30 million different species of living organisms in the world today. These represent a vast and important source of genetic information that is useful for the development of medicines, natural pesticides, resistant varieties of plants and animals, and so on. Human activities have substantially increased the rate of species extinctions, so habitat conservation and species preservation have become important contemporary resource problems.

One feature of the modern world is that the dividing line between natural resources and environmental resources is blurring in many cases. Many resource extraction processes, such as timber cutting and strip mining, have direct repercussions on environmental quality. In addition, there are many instances where environmental pollution or disruption has an impact on resource extraction processes. Estuarine water pollution that interferes with the replenishment of fish stocks is an example, as is air pollution that reduces agricultural yields. Furthermore, certain things, such as wildlife, may be considered both natural resources and attributes of the environment. In recent years there has been a substantial shift in public concern away from natural resource use in the traditional sense and toward **natural resource preservation.** This can be regarded both as a natural resource and an environmental decision.

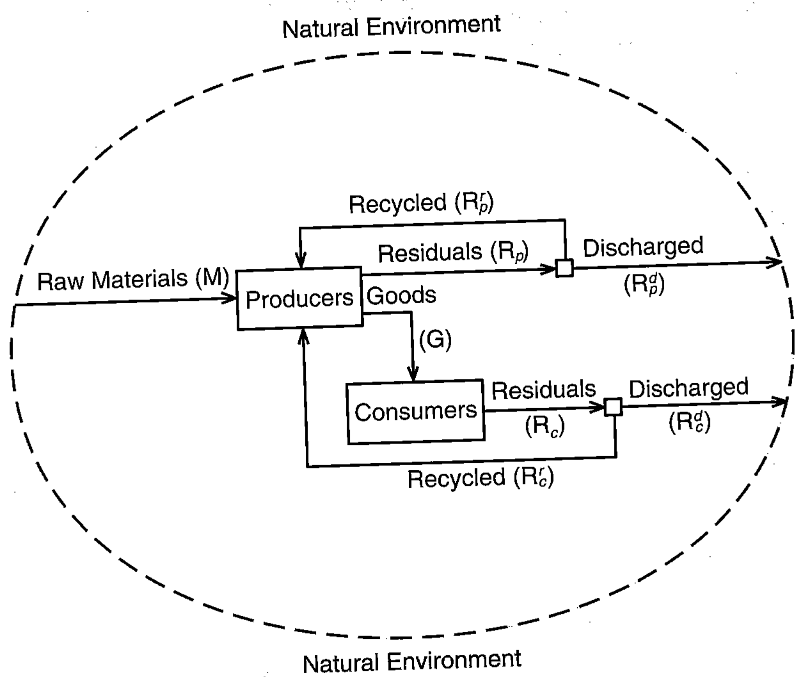
Despite the very close connections, however, the distinction that economists have made between these two services of the natural world—as raw materials and as environment—is sufficiently strong and well developed that it makes sense for us to proceed with a book that focuses primarily on the latter. We begin by considering a somewhat more complicated version of the simple diagram depicted at the beginning of the chapter.

The Fundamental Balance

In this book you will find a lot of simple analytical models of situations that in reality are somewhat complex. A model is a way of trying to show the essential structure and relationships in something, without going into all of its details, much as a caricature of a person accentuates distinguishing features at the cost of all the details.

Figure 2.1 is a more complex rendering of the relationships shown at the beginning of the chapter. The elements within the circle are parts of the economic system, the whole of which is basically encapsulated within the natural environment. The economy has been divided into two broad segments, **producers** and **consumers.**

FIGURE 2.1 The Environment and the Economy



- The producers category includes all private firms that take inputs and convert them to outputs; it also includes units such as public agencies; nonprofit organizations; and firms producing services, such as transportation. The primary inputs from the natural environment to the producing sector are materials, in the form of fuels, nonfuel minerals, and wood; fluids (e.g., water and petroleum); and gases of various types (e.g., natural gas and oxygen). All goods and services are derived from materials with the application of energy inputs.
- The consumers category includes all of the private households to whom the vast collections of final goods and services are distributed. One could argue that consumers sometimes use inputs directly from nature, like producers; many households, for example, get their water supplies directly from groundwater aquifers rather than water distribution companies. In the interest of keeping the model simple, however, we have not drawn this type of relationship.

It needs to be kept in mind that producers and consumers actually consist of the same people in different capacities. The "us vs. them" quality that characterizes many environmental disputes is really an internal disagreement within a single group. Society as a whole is essentially in the same position as a single household that pumps water from its own well and discharges wastes into its own septic system, which happens to be near the well.

Production and consumption create **residuals,** which is another way of saying leftovers. They include all types of material residuals that may be emitted into the air or water or disposed of on land. The list is incredibly long: sulfur dioxide, volatile organic compounds, toxic solvents, animal manure, pesticides, particulate matter of all types, waste building materials, heavy metals, and so on. Waste energy in the form of heat and noise, and radioactivity, which has characteristics of both material and energy, are also important production residuals. Consumers are also responsible for enormous quantities of residuals, chief among which are domestic sewage and automobile emissions. All materials in consumer goods must eventually end up as leftovers, even though they may be recycled along the way. These are the source of large quantities of solid waste as well as hazardous materials such as toxic chemicals and used oil.

Let us first consider the question of production and consumption residuals from a strictly physical standpoint. Figure 2.1 shows raw materials and energy being extracted from the natural environment (M) and residuals being discharged back into the environment.

In the early days of environmental concern, the main focus was on the end flows of discharged residuals by producers (R_p^d) and by consumers (R_c^d). By treating these residuals and otherwise changing the time and place of discharge, their impacts on humans and the environment could be substantially changed. While this is still an important locus of activity, recent years have seen a broadening of perspective to what is called **environmental management.**

To appreciate this broadening of focus, let us consider the flows of Figure 2.1 in greater detail. From physics, the law of the conservation of matter assures us that, in the long run, these two flows must be equal. In terms of the symbols of Figure 2.1:[2]

$$M = R_p^d + R_c^d$$

We must say "in the long run" for several reasons. If the system is growing, it can retain some proportion of the natural inputs, which go toward increasing the size of the system through a growing population, the accumulation of capital equipment, and so on. These would be disposed of if and when the system ceases to grow. Also, recycling can obviously delay the disposal of residuals. But recycling can never be perfect; each cycle must lose some proportion of the recycled material. Thus, the fundamental **materials/energy balance** equation must hold in the long run. This shows us something very fundamental: To reduce the mass of residuals disposed of in the natural environment, it is necessary to reduce the quantity of raw materials taken into the system.[3] To look

[2] To make these direct comparisons all flows must be expressed in terms of mass.

[3] Note that $G = R_c$, that is, everything that flows to the consumption sector eventually ends up as a residual from that sector.

more closely at the various options for doing this, substitute for M. According to the flow diagram,

$$R_p^d + R_c^d = M = G + R_p - R_p^r - R_c^r$$

which says that the quantity of raw materials (M) is equal to output of goods and services (G) plus production residuals (R_p), minus the amounts that are recycled from producers (R_p^r) and consumers (R_c^r). There are essentially three ways of reducing M and, therefore, residuals discharged into the natural environment.

Reduce G Assuming the other flows stay the same, we can reduce residuals discharged by reducing the quantity of goods and services produced in the economy. Some people have fastened on this as the best long-run answer to environmental degradation; reducing output, or at least stopping its rate of growth, would allow a similar change in the quantity of residuals discharged. Some have sought to reach this goal by advocating "zero population growth" (ZPG).[4] A slowly growing or stationary population can make it easier to control environmental impacts, but for two reasons it does not in any way ensure this control. First, a stationary population can grow economically, thus increasing its demand for raw materials. Second, environmental impacts can be long-run and cumulative, so that even a stationary population can gradually degrade the environment in which it finds itself. It is certainly true, however, that population growth will often exacerbate the environmental impacts of a particular economy. In the U.S. economy, for example, although the emissions of pollutants per car have dramatically decreased over the last few decades through better emissions-control technology, the sheer growth in the number of cars on the highways has led to an increase in the total quantity of automobile emissions in many regions.

Reduce R_p Another way of reducing M, and therefore residuals discharged, is to reduce R_p. Assuming the other flows are held constant, this means essentially changing the amounts of production residuals produced for a given quantity of output produced. There are basically only two ways of doing this.

- Reduce the **residuals intensity of production** in all sectors of the economy by inventing and adopting new production technologies and practices that leave smaller amounts of residuals per unit of output produced. For example, in later discussions of CO_2 emissions and atmospheric warming, we will see that there is much that can be done to reduce the CO_2 output per unit of output produced, especially by shifting to different fuels, but also by reducing

[4] For example, see Herman E. Daly, *Steady State Economics, Second Edition with New Essays*, Island Press, Washington, DC, 1991.

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(actually by continuing to reduce) the quantities of energy required to produce a unit of final output. This approach has come to be called **pollution prevention,** or **source reduction.**

- Shift the composition of final output; that is, reduce those sectors that have relatively high residuals per unit of output and expand those sectors that produce relatively few residuals per unit of output. Output G actually consists of a large number of different goods and services, with great differences among them in terms of the residuals left after they are produced. So another way to reduce the total quantity of residuals is to shift the composition of G away from high-residuals items and toward low-residuals items, while leaving the total intact. The shift from primarily a manufacturing economy toward services is a step in this direction. This is called a **sectoral shift,** because it changes the relative shares of the different economic sectors in the aggregate economy. The rise of the so-called information sectors is another example. It is not that these new sectors produce no significant residuals; indeed, some of them may produce harsher leftovers than we have known before. The computer industry, for example, uses a variety of chemical solvents for cleaning purposes. But on the whole these sectors probably have a smaller waste disposal problem than the traditional industries they have replaced.

Increase ($R_p^r + R_c^r$) The third possibility is to increase recycling. Instead of discharging production and consumption residuals into the environment, they can be recycled back into the production process. What this shows is that the central role of recycling is to replace a portion of the original flow of virgin materials (M). By substituting recycled materials for virgin materials, the quantity of residuals discharged can be reduced while maintaining the rate of output of goods and services (G). In modern economies recycling offers great opportunities to reduce waste flows. But we have to remember that recycling can never be perfect, even if enormous resources were devoted to the task. Production processes usually transform the physical structure of materials inputs, making them difficult to use again. The process of energy conversion changes the chemical structure of energy materials so thoroughly that recycling is impossible. In addition, recycling processes themselves can create residuals. But materials research will continue to progress and discover new ways of recycling. For a long time, automobile tires could not be recycled because the original production process changed the physical structure of the rubber. But recently new technological means have been found so that vast quantities of used tires, instead of blighting the landscape, can be incorporated into park benches, roads, and other products.

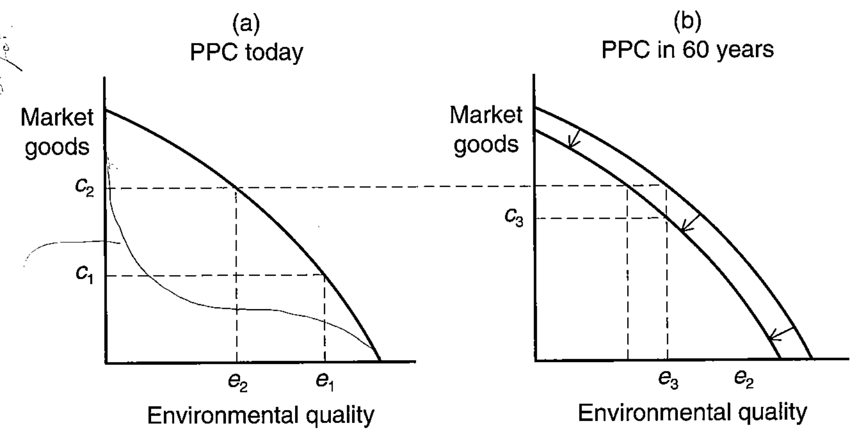
These fundamental relationships are very important. We must remember, however, that our ultimate goal is to reduce the damages caused by the discharge of production and consumption residuals. Reducing the total quantity of these residuals is one major way of doing this, and the relationships discussed indicate the basic ways this may be done. But damages also can be reduced by working directly on the stream of residuals, a fact that must be kept in mind in our later discussions.

The Environment as an Economic and Social Asset

Inputs of natural resources have always been recognized as important in economic production. Environmental quality also may be thought of as a **productive asset** for a society. The productivity of the natural environment lies in its ability to support and enrich human life, as well as, in some cases, its ability to assimilate and render less harmful the waste products of the economic system. The quality of the environmental asset is directly affected by the quantities and types of residuals discharged from the economy.

One way of thinking about this is in terms of a **trade-off** between conventional economic output (conventional goods and services such as cars, loaves of bread, insurance policies, etc.) and environmental quality. A trade-off of this type is depicted in Figure 2.2. Consider first panel (a). This shows a **production possibility curve** (PPC), which is simply a curve showing the different combinations of two things a society may produce at any time, given its resources and technological capabilities. The vertical axis has an index of the aggregate output of an economy, that is, the total market value of conventional economic goods traded in the economy in a year. The horizontal axis has an index of environmental quality, derived from data on different dimensions of the ambient environment, for example, airborne SO_2 concentrations, urban noise levels, and water quality data. The curved relationship shows the different combinations of these two outcomes—marketed output and environmental quality—that are

FIGURE 2.2 **Production Possibility Curves for Current and Future Generations**



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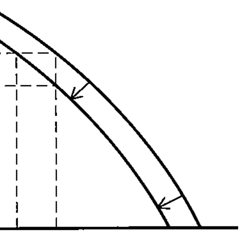

available to a group of people who have a fixed endowment of resources and technology with which to work.[5]

The exact shape and location of the production possibility curve are determined by the **technical capacities** in the economy, together with the ecological facts—meteorology, hydrology, and so on—of the natural system in which the society is situated. It says, for example, that if the current level of economic output is c_1, an increase to c_2 can be obtained only at the cost of a decrease in environmental quality from e_1 to e_2. One major objective of any society, of course, is to change the production possibility curve so that the underlying trade-off is more favorable—in other words, so that a given economic output is consistent with higher levels of environmental quality.

Although the PPC itself is a technical constraint, where a society chooses to locate itself on its PPC is a matter of **social choice.** This depends on the values that people in that society place on conventional economic output as opposed to environmental quality. Where values come from is an open question, but it is clear that values differ from one person to another and even for the same person at different points in time. The study of the values that people place on environmental factors is a major part of environmental economics and will be discussed in more detail in Chapters 7 and 8.

Another matter of concern is that current measures of **aggregate economic output** typically contain only measures of quantities of market goods. This is because the prices of these goods and services are provided by the markets in which they are traded, so their aggregate values can be assessed quite easily. Environmental quality, on the other hand, is generally a **nonmarket** type of outcome, in the sense that elements of environmental quality do not trade directly on markets where prices could be evaluated. If a society puts too much stress on increasing its measured output, it may end up at a point like (c_2, e_2) in Figure 2.2, panel (a), even though true social welfare may be higher at a point like (c_1, e_1).

Production possibility curves can also be used to elucidate other aspects of social choice about the environment. One of the fundamental distinctions that can be made in environmental analysis and the development of environmental policy is that between the **short run** and the **long run.** Short-run decisions are those made on the basis of consequences that happen in the near term or of impacts as they are felt by the present generation. Long-run decisions are those in which attention is paid to consequences that occur well into the future or to future generations. There is a widespread feeling that economic decisions today are being made primarily through short-run considerations, whereas environmental policy needs to be made with long-run considerations in mind. A good way of thinking about this is through the use of production possibility curves, introduced above.

Consider again Figure 2.2. The two panels actually show production possibility curves for two time periods. Panel (a) shows the trade-offs facing the

[5] The extremes of the PPC are drawn with dashed lines. It's not clear what an outcome would be with "zero" environmental quality, or with "zero" economic output. Thus, these extreme points are essentially undefined, and we focus on points in the interior of the diagram.

current generation. Panel (b) shows the production possibility curves for people in, say, 60 to 80 years, the generation consisting of your great grandchildren. According to panel (a), the present generation could choose combinations (c_1, e_1), (c_2, e_2), or any others on the curve. But the future is not independent of the choice made today. It is conceivable, for example, that degrading the environment too much today will affect future possibilities—by depleting certain important resources, by pollution that is so high it causes irreversible damage, or simply by a pollutant that is very long-lived and affects future generations. In effect this could shift the future PPC back from where it otherwise would be. This is depicted in panel (b) of the diagram. Your grandchildren will be confronted with a reduced set of possibilities as compared to the choices we face today. The future generation, finding itself on the inner production possibilities curve, can still have the same level of marketed output we have today (c_2), but only at a lower level of environmental quality (e_3) than we have today. Alternatively, it could enjoy the same level of environmental quality, but only with a reduced level of marketed output (c_3).

It needs to be recognized, of course, that the influence of today's decisions on future production possibilities is much more complicated than this discussion might suggest. It's not only environmental degradation that affects future conditions, but also technical developments and changes in human capacities. Thus, today's decisions could shift the future PPC either in or out, depending on many dynamic factors that are hard to predict. But we need to be particularly alert to avoid decisions today that would have the effect of shifting the future PPC to the left. This is the essence of recent discussions about **sustainability.** Sustainability means that future production possibility curves are not adversely affected by what is done today. It does not mean that we must maximize environmental quality today, because that implies zero output of goods and services. It means simply that environmental impacts need to be reduced enough today to avoid shifting future production possibility curves back in comparison to today's production possibilities. We will meet the idea of sustainability at several points throughout this book.

Terminology

Throughout the chapters that follow we use the following terms:

- **Ambient quality:** *Ambient* refers to the surrounding environment, so ambient quality refers to the quantity of pollutants in the environment, for example, the concentration of SO_2 in the air over a city or the concentration of a particular chemical in the waters of a lake.
- **Environmental quality:** A term used to refer broadly to the state of the natural environment. This includes the notion of ambient quality and such things as the visual and aesthetic quality of the environment.
- **Residuals:** Material that is left over after something has been produced. A plant, for example, takes in a variety of raw materials and converts these into

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some product. Materials and energy left after the product has been produced are *production residuals. Consumption residuals* are whatever is left over after consumers have finished using the products that contained or otherwise used these materials.

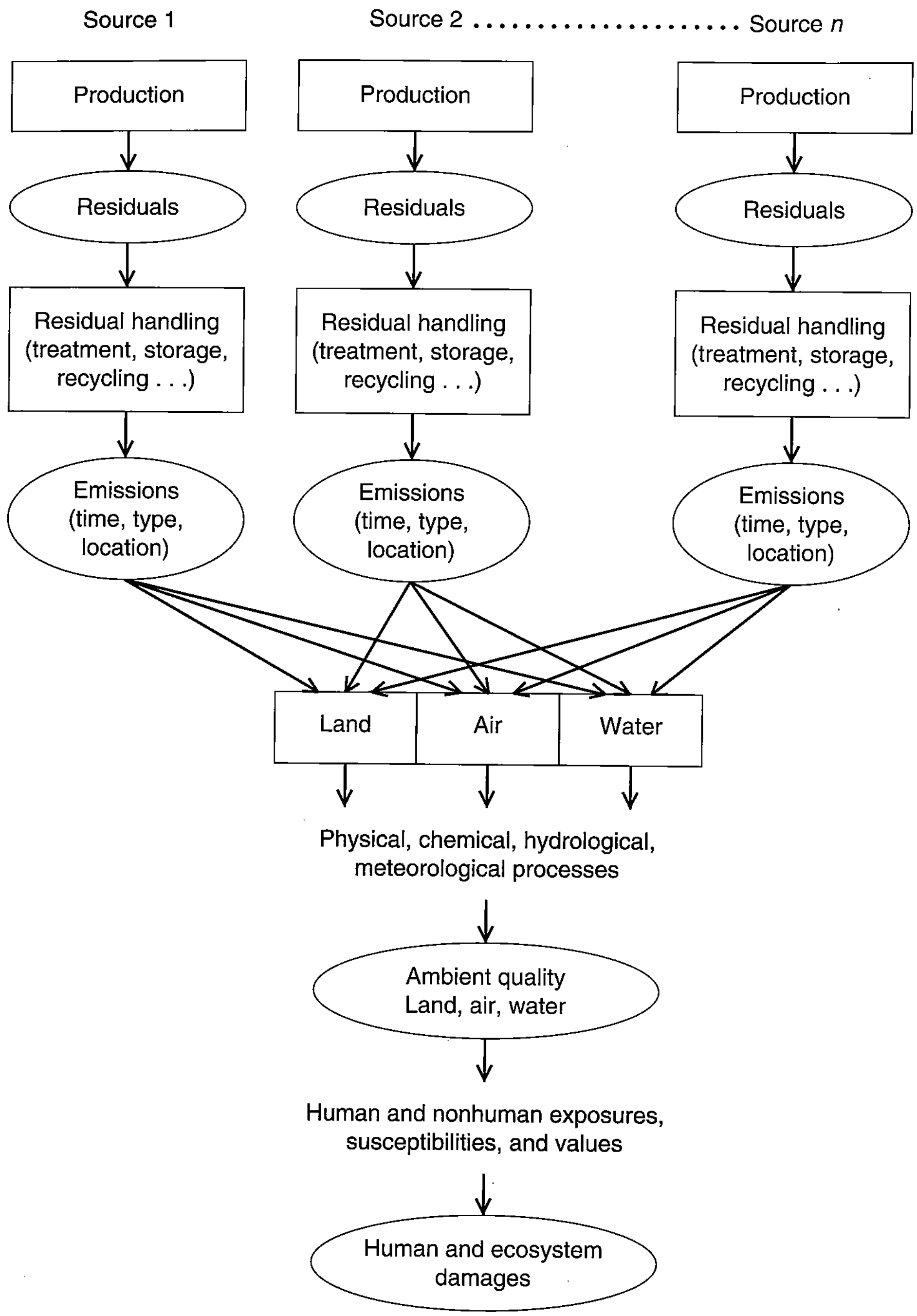
- **Emissions:** The portion of production or consumption residuals that is placed in the environment, sometimes directly, sometimes after treatment.
- **Recycling:** The process of returning some or all of the production or consumption residuals to be used again in production or consumption.
- **Pollutant:** A substance, energy form, or action that, when introduced into the natural environment, results in a lowering of the ambient quality level. We want to think of this as including not only the traditional things, such as oil spilled into oceans or chemicals placed in the air, but also activities, such as certain building developments, that result in "visual pollution."
- **Effluent:** Sometimes *effluent* is used to talk about water pollutants, and *emissions* to refer to air pollutants, but in this book these two words are used interchangeably.
- **Pollution:** *Pollution* is actually a tricky word to define. Some people might say that pollution results when any amount, no matter how small, of a residual has been introduced into the environment. Others hold that pollution is something that happens only when the ambient quality of the environment has been degraded enough to cause some damage.
- **Damages:** The negative impacts produced by environmental pollution on people in the form of health effects, visual degradation, and so on, and on elements of the ecosystem through disruption of ecological linkages, species extinctions, and so forth.
- **Environmental medium:** Broad dimensions of the natural world that collectively constitute the environment, usually classified as land, water, and air.
- **Source:** The location at which emissions occur, such as a factory, an automobile, or a leaking landfill.

Emissions, Ambient Quality, and Damages

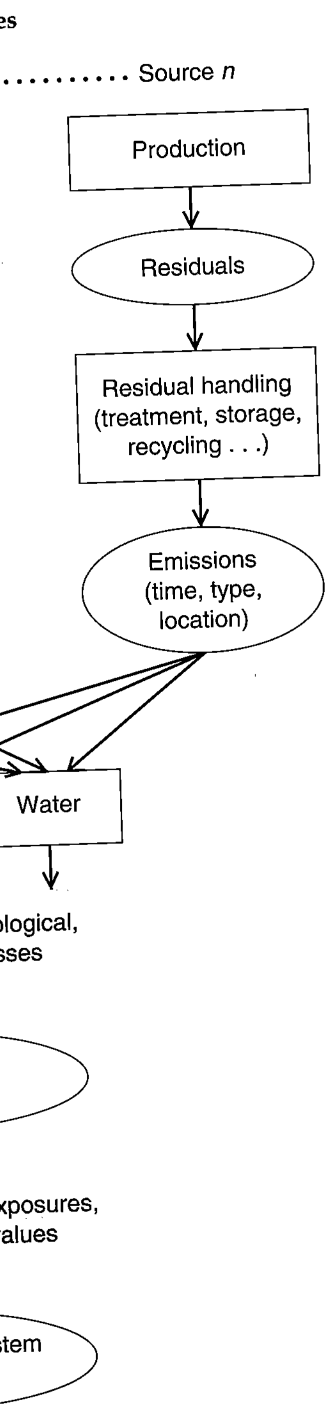
Let us now focus on what happens at the end of those two discharge arrows at the right side of Figure 2.1. Very simply, **emissions** produce changes in ambient levels of environmental quality, which in turn cause damages to humans and nonhumans. Figure 2.3 shows one way of sketching out this relationship. It shows n sources of emissions;[6] they might be private firms, government agencies, or consumers. Sources take in various inputs and use different types of technologies in production and consumption. In the process they produce residuals. How these residuals are handled then has a critical effect on subsequent

[6] In economic writing, the letter n is often used to designate an unspecified number of items, the exact value of which will vary from one situation to another.

FIGURE 2.3 **Emissions, Ambient Quality, and Damages**



Source: *Inspired by John B. Braden and Kathleen Segerson, "Information Problems in the Design of Non-point Source Pollution Policy," in Association of Environmental and Resource Economics (AERE) Workshop Papers,* The Management of Non-point Source Pollution, Lexington. June 6–7, 1991.



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stages. Some may be recovered and recycled back into production or consumption. Many can be put through treatment processes (residuals handling) that can render them more benign when emitted. Some of these processes are strictly physical (mufflers on cars and trucks, settling ponds at wastewater treatment plants, catalytic converters); others involve chemical transformations of various types (advanced treatment of domestic wastewater).

All emissions must necessarily go into one or more of the different **environmental media,** and there is an important relationship among them. There is a natural tendency in policy deliberations to keep these different media in separate compartments, dealing with air pollution separately from water pollution, and so on. But they are obviously interconnected; once residuals are produced, all that are not recycled must end up being discharged into one or more of the different media. Thus, for a given quantity of total residuals, if the amounts going into one medium are reduced, the amounts going into the others must necessarily increase. When sulfur dioxide (SO_2) is removed from the stack gases of power plants, for example, the sulfur compounds have not been destroyed. Instead, we end up with a sulfurous sludge that must be disposed of some other way, perhaps by land burial. If this material is incinerated, airborne emissions result, but there will still be certain quantities of solid residuals that must be disposed of elsewhere.

In a situation involving multiple sources, emissions will often become mixed into a single flow. In the real world this mixing may be complete; for example, the effluent from two pulp mills located at the same point on a river may mix so thoroughly that a few miles downstream it is impossible to differentiate one source's effluent from the other's. When there are a million or so cars moving about an urban area, the emissions from all become uniformly mixed together. In other cases the mixing is less than complete. If one power plant is just outside the city and another is 20 miles upwind, the closer plant will normally bear a greater responsibility for deteriorating air quality in the city than the other.

This mixing of emissions is a more significant problem than might first appear. With just a single source, the line of responsibility is clear, and to get an improvement in ambient quality we know exactly whose emissions have to be controlled. But with multiple sources, responsibilities become less clear. We may know how much we want to cut back total emissions, but the problem of distributing this total reduction among the different sources still exists. Each source then has an incentive to get the others to bear a larger share of the burden of reducing emissions. With every source thinking along the same lines, pollution control programs face a real problem of design and enforcement. We will run into this problem many times in the chapters to come.

Once a given quantity and quality of residuals have been introduced into a particular environmental medium, it is the physical, chemical, biological, meteorological, and so on, processes of the natural system that determine how the residuals translate into particular **ambient quality levels.** For example, wind and temperature conditions will affect whether and how residuals emitted into the air affect nearby neighborhoods, as well as people living farther downwind. In addition, because these meteorological conditions vary from day to day, the same level of emissions can produce different ambient quality levels at different times. Acid rain is produced through chemical processes acting primarily on sulfur dioxide emissions emitted far upwind; smog is also the result of complex chemical reactions involving sunlight and quantities of various pollutants. Underground hydrological processes affect the transportation of materials disposed of in landfills. And so on. Thus, to know how particular emissions will affect ambient quality levels, we must have a good understanding of the physical and chemical workings of the environment itself. This is where the natural and physical sciences come in—to study the full range of environmental phenomena, from small, localized models of groundwater flow in a particular aquifer, to complex models of large lakes and river basins, to studies of interregional wind patterns, to global climate models. The fundamental goal is to determine how particular patterns of emissions are translated into corresponding patterns of ambient quality levels.

Finally, there are **damages.** A given set of ambient conditions translates into particular exposure patterns for living and nonliving systems. Of course, these exposures are a function not only of the physical processes involved, but also of the human choices that are made about where and how to live, and of the susceptibilities of living and nonliving systems to varying environmental conditions. Lastly, damages are related to human values. Human beings do not have amorphous preferences over all possible outcomes of the economic/environmental interaction; they prefer some outcomes over others. A major part of environmental economics is trying to determine the relative values that people place on these different environmental outcomes, a subject to which we will turn in later chapters on benefit–cost analysis.

Types of Pollutants

Physically, the residuals identified in Figure 2.3 consist of a vast assortment of materials and energy flowing into the three environmental media. It is helpful to distinguish among broad types of emissions according to factors that critically affect their economic characteristics.

Cumulative vs. Noncumulative Pollutants

One simple and important dimension of environmental pollutants is whether they accumulate over time or tend to dissipate soon after being emitted. The classic case of a **noncumulative pollutant** is noise; as long as the source operates, noise is emitted into the surrounding air, but as soon as the source is shut down, the noise stops. At the other end of the spectrum there are pollutants that cumulate in the environment in nearly the same amounts as they are emitted. Radioactive waste, for example, decays over time but at such a slow rate in relation to human life spans that for all intents and purposes it will be with us permanently; it is a strictly cumulative type of pollutant. Another **cumulative pollutant** is plastics. The search for a degradable plastic has been going on for decades, but so far plastic is a substance that decays very slowly by human standards; thus, what we dispose of will be in the environment permanently. Many chemicals are cumulative pollutants; once emitted they are basically with us forever.

Between these two ends of the spectrum there are many types of effluent that are to some extent, but not completely, cumulative. The classic case is organic matter emitted into water bodies; for example, the wastes, treated or not, emitted from municipal waste treatment plants. Once emitted the wastes are subject to natural chemical processes that tend to break down the organic materials into their constituent elements, thus rendering them much more benign. The water, in other words, has a natural assimilative capacity that allows it to accept organic substances and render them less harmful. As long as this assimilative capacity has not been exceeded in any particular case, the effluent source can be shut off, and in a few days, weeks, or months the water quality will return to normal. Once emissions exceed this assimilative capacity, however, the process becomes cumulative.

Whether a pollutant is cumulative or noncumulative, the basic problem is essentially the same: trying to figure out the environmental damages and relating these back to the costs of reducing emissions. But this job is much more difficult for cumulative than for noncumulative pollutants. With noncumulative emissions, ambient concentrations are strictly a function of current emissions—reducing these emissions to zero would lead to zero ambient concentrations. But with cumulative pollutants the relationship is more complex. The fact that a pollutant cumulates over time in the environment has the effect of breaking the direct connection between current emissions and current damages. This has a number of implications. For one thing it makes the science more difficult. The cause-and-effect relationships become harder to isolate when there is a lot of time intervening between them. It also may make it more difficult to get people to focus on damages from today's emissions, again because there may only be a weak connection between today's emissions and today's ambient quality levels. Furthermore, cumulative pollutants by definition lead to future damages, and human beings have shown a depressing readiness to discount future events and avoid coming to grips with them in the present.

Local vs. Regional and Global Pollutants

Some emissions have an impact only in restricted, localized regions, whereas others have an impact over wider regions, perhaps on the global environment. Noise pollution and the degradation of the visual environment are local in their impacts; the damages from any particular source are usually limited to relatively small groups of people in a circumscribed region. Note that this is a statement about how widespread the effects are from any particular pollution source, not about how important the overall problem is throughout a country or the world. Many pollutants, on the other hand, have widespread impacts, over a large region or perhaps over the global environment. Acid rain is a regional problem; emissions in one region of the United States (and of Europe) affect people in other parts of the country or region. The ozone-depleting effects of chlorofluorocarbon emissions from various countries work through chemical changes in the earth's stratosphere, which means that the impacts are truly global.

Other things being equal, local environmental problems ought to be easier to deal with than regional or national problems, which in turn ought to be easier to manage than global problems. If I smoke out my neighbor with my wood stove, we may be able to arrange a solution among ourselves, or we can call on local political institutions to do it. But if my behavior causes more distant pollution, solutions may be more difficult. If we are within the same political system, we can call on these institutions to arrange solutions. In recent years, however, we have been encountering a growing number of international and global environmental issues. Here we are far from having effective means of responding, both because the exact nature of the physical impacts is difficult to describe and because the requisite international political institutions are only beginning to appear.

Point-Source vs. Nonpoint-Source Pollutants

Pollution sources differ in terms of the ease with which actual points of discharge may be identified. The points at which sulfur dioxide emissions leave a large power plant are easy to identify; they come out the end of the smokestacks associated with each plant. Municipal waste treatment plants normally have a single outfall from which all of the wastewater is discharged. These are called **point-source pollutants.** There are many pollutants for which there are no well-defined points of discharge. Agricultural chemicals, for example, usually run off the land in a dispersed or diffused pattern, and even though they may pollute specific streams or underground aquifers, there is no single pipe or stack from which these chemicals are emitted. This is a **nonpoint-source** type of pollutant. Urban storm water runoff is also an important nonpoint-source problem.

As one would expect, point-source pollutants are likely to be easier to come to grips with than nonpoint-source pollutants. They will probably be easier to measure and monitor and easier to study in terms of the connections between emissions and impacts. This means that it will ordinarily be easier to develop and administer control policies for point-source pollutants. As we will see, not all pollutants fit neatly into one or another of these categories.

Continuous vs. Episodic Emissions

Emissions from electric power plants or municipal waste treatment plants are more or less continuous. The plants are designed to be in operation continuously, although the operating rate may vary somewhat over the day, week, or season. Thus, the emissions from these operations are more or less continuous, and the policy problem is to manage the rate of these discharges. Immediate comparisons can be made between control programs and rates of emissions. The fact that emissions are continuous does not mean that damages are also continuous, however. Meteorological and hydrological events can turn continuous emissions into uncertain damages. But control programs are often easier to carry out when emissions are not subject to large-scale fluctuations.

Many pollutants are emitted on an episodic basis, however. The classic example is accidental oil or chemical spills. The policy problem here is to design and manage a system so that the probability of accidental discharges is reduced. Yet, with an episodic effluent there may be nothing to measure, at least in the short run. Even though there have been no large-scale radiation releases from U.S. nuclear power plants, for example, there is still a "pollution" problem if they are being managed in such a way as to increase the **probability** of an accidental release in the future. To measure the probabilities of episodic emissions, it is necessary to have data on actual occurrences over a long time period or to

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estimate them from engineering data and similar information. We then have to determine how much insurance we wish to have against these episodic events.

Environmental Damages Not Related to Emissions

So far the discussion has focused on the characteristics of different types of environmental pollutants as they relate to the discharge of residual materials or energy, but there are many important instances of deteriorating environmental quality that are not traceable to residuals discharges. The conversion of land to housing and commercial areas destroys the environmental value of that land, whether it be its ecosystem value, such as habitat or wetland, or its scenic value. Other land uses, such as logging or strip mining, also can have important impacts. In cases such as these, the policy problem is still to understand the incentives of people whose decisions create these impacts and to change these incentives when appropriate. Although there are no physical emissions to monitor and control, there are nevertheless outcomes that can be described, evaluated, and managed with appropriate policies.

Summary

The purpose of this chapter was to explore some basic linkages between the economy and the environment. We differentiated between the role of the natural system as a supplier of raw material inputs for the economy and as a receptor for production and consumption residuals. The first of these is normally called natural resource economics and the second environmental economics. After a very brief review of natural resource economics, we introduced the fundamental balance phenomenon, which says that in the long run all materials taken by human beings out of the natural system must eventually end up back in that system. This means that to reduce residuals flows into the environment we must reduce materials taken from the ecosystem, and we discussed the three fundamental ways that this can be done. This led into a discussion of the inherent trade-off that exists between conventional economic goods and environmental quality and between current and future generations.

We then focused more directly on the flow of residuals back into the environment, making a distinction among emissions, ambient environmental quality, and damages. The environmental damages from a given quantity of emissions can be very substantially altered by handling these emissions in different ways. Our next step was to provide a brief catalogue of the different types of emissions and pollutants, as well as nonpollution types of environmental impacts such as aesthetic effects.

Questions for Further Discussion

1. Economies grow by investing in new sources of productivity, new plants and equipment, infrastructure such as roads, and so on. How does this type of investment affect the flows depicted in Figure 2.1?

2. What is the difference between a residual and a pollutant? Illustrate this in the context of a common airborne emission such as sulfur dioxide (SO_2); with noise; with junked automobiles; with an unsightly building.
3. Why are long-lived, cumulative pollutants so much harder to manage than short-lived, noncumulative pollutants?
4. As depicted in Figure 2.3, most emissions from individual sources get mixed in with those of other sources, to produce the general level of ambient quality. What problems does this present in adopting emission control policies to get a cleaner environment?
5. Considering the various general ways of reducing final emissions in Figure 2.1, illustrate these with a particular industrial product, such as cars.
6. What considerations come into play when considering whether the United States or any other political entity is spending the right amount for environmental quality improvements?

Web Sites

For an introduction to issues in environmental economics, see the Web site of Resources for the Future, **www.rff.org;** for another good source of material of this type see the reports of the Congressional Research Service, **www.cnie.org/nle/crs_main.html.**

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Section 2

Analytical Tools

Scientific analysis consists of giving coherent explanations of relevant events and of showing how other outcomes might have occurred if conditions had been different. It is to show connections among variables and to detail the ways in which they are interrelated. To do this, a science must develop a specialized vocabulary and conceptual structure with which to focus on its chosen subject matter. In this section we cover some of the basic ideas of economics and of their application to environmental problems. Those of you who have already been introduced to microeconomics can treat the next few chapters as a review. For those who are seeing this material for the first time, remember that the purpose is to develop a set of analytical tools that can be used to focus on issues of environmental quality.