Environmental and Natural Resource Economics

A Contemporary Approach

Fourth Edition

Jonathan M. Harris and Brian Roach

Environmental and Natural Resource Economics

Environmental issues are of fundamental importance, and a broad approach to understanding the relationship of the human economy and the natural world is essential. In a rapidly changing policy and scientific context, this new edition of *Environmental and Natural Resource Economics* reflects an updated perspective on modern environmental topics.

Now in its fourth edition, this book includes new material on climate change, the cost-competitiveness of renewable energy, global environmental trends, and sustainable economies. The text provides a balanced treatment of both standard environmental economics and ecological economics, based on the belief that these two approaches are complementary. Several chapters focus on the core concepts of environmental economics, including the theory of externalities, the management of public goods, the allocation of resources across time, environmental valuation, and cost-benefit analysis. Material on ecological economics includes such topics as macroeconomic scale, entropy, and "green" national accounting. Topical chapters focus on: energy; climate change; water resources; international trade; forests; fisheries; and agriculture, with an emphasis on designing effective policies to promote sustainability and a "green" economy.

Harris and Roach's premise is that a pluralistic approach is essential to understand the complex nexus between the economy and the environment. This perspective, combined with its emphasis on real-world policies, is particularly appealing to both instructors and students. This is the ideal text for classes on environmental, natural resource, and ecological economics.

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Preface to the Fourth Edition

The fourth edition of *Environmental and Natural Resource Economics*: *A Contemporary Approach* maintains its essential focus on making environmental issues accessible to a broad range of students. The text is a product of over 20 years of teaching environmental and natural resource economics at the undergraduate and graduate levels. It reflects the conviction that environmental issues are of fundamental importance, and that a broad approach to understanding the relationship between the human economy and the natural world is essential.

Environmental economics, and environmental issues in general, are of great current importance and subject to rapid change. In preparing the fourth edition, we have developed much new material and updated perspectives on key issues. Perhaps the most dramatic changes are in the areas of energy and climate change. Chapters have been reorganized to create a new section on "Energy, Climate Change, and Greening the Economy," in which we present the rapid spread of renewable energy, the increased urgency of climate change and new policies to respond to it, and address the broader questions involved in developing an economy compatible with environmental sustainability.

The text retains its balanced approach to environmental and ecological economics. In our view, these two approaches are complementary. Many elements of standard microeconomic analysis are essential for analyzing resource and environmental issues. At the same time, it is important to recognize the limitations of a strictly market-based or cost-benefit approach, and to introduce ecological and biophysical perspectives on the interactions of human and natural systems. This perspective makes it possible to achieve a broad focus on inherently "macro" environmental issues, such as global climate change, ocean pollution, population growth, and global carbon, nitrogen, and water cycles.

NEW TO THE FOURTH EDITION

The fourth edition of *Environmental and Natural Resource Economics*: *A Contemporary Approach* has been updated in response both to developments in the world of environmental policy and to comments and suggestions based on classroom use. New and revised material in the fourth edition (note new chapter numbering) includes:

- Chapter 1: Reorganization of the material on environmental and ecological economics to provide clearer distinctions between the two approaches.
- Chapter 2: A new section on recent environmental trends has been added.
- Chapters 6 and 7: The third edition chapter on valuation and cost-benefit analysis has been divided into a chapter specifically on valuation and another on cost-benefit analysis, including more practical examples and in-depth discussion both of methodologies and limitations of valuation and cost-benefit techniques.

- Chapter 8: This chapter on pollution analysis and policy has been moved to earlier in the text, in order to bring all the core concepts of environmental economics into the same section.
- Chapter 11: Discussion of changing energy production and consumption patterns, the increasing cost-competitiveness of renewable energy, and the potential for expansion of renewables and increased efficiency.
- Chapters 12 and 13: A review of new scientific evidence on climate change and global climate change policy, including the most recent Intergovernmental Panel on Climate Change reports and the 2015 Paris climate agreement. A new focus is the potential for carbon storage in forests and soils. Other features include discussion of the possibility of catastrophic impacts and the policies needed to avoid them, the European Union Emissions Trading Scheme and other carbon trading systems, and carbon taxes in Canada and elsewhere.
- Chapter 14: The chapter on the Green Economy has been extensively updated to include the most recent empirical analyses of the relationship between the economy and the environment.
- Chapter 15: New material on recent population developments, including changing fertility rates, projections for population growth through 2050 and beyond, and practical examples of population policies.
- Chapter 16: Updated projections for agricultural demand and supply, the impact of the "food crisis," rising meat consumption, biofuels, climate change, and genetically modified crops.
- Chapter 20: An expanded chapter on water economics, including analysis of virtual water and water footprint, water demand management, water pricing, and water privatization.
- Chapter 22: A new section on the UN's global Sustainable Development Goals, policies needed to achieve them, and data on potential job creation through renewable energy development.

Throughout all chapters we have updated data and figures, drawing on the most recent data on population growth, energy use, carbon emissions, mineral prices, food production and prices, and renewable resource supply and demand. Two-color printing makes the figures more user-friendly. Many new boxes have been added and others updated to provide current real-world context for the issues discussed in the text.

ORGANIZATION OF THE TEXT

The text is structured so as to be appropriate for a variety of courses. It assumes a background in basic microeconomics and can be used in an upper-level undergraduate course or a policy-oriented master's-level course. Part I provides a broad overview of different approaches to economic analysis of resources and environment and of the fundamental issues of economy/environment interactions. Part II covers the basics of standard environmental and resource economics, including the theory of externalities, resource allocation over time, common property resources, public goods, valuation, cost-benefit analysis, and pollution control policies. Part III offers an introduction to the ecological economics approach, including fundamental concepts of ecological economics, payment for ecosystem services, and "greening" national accounts.

Part IV covers energy, climate change, and policies for a green economy. These chapters have been placed together for a more cohesive approach to some of the central issues of developing sustainable economic systems. Part V focuses on population, agriculture, and resources, including reviewing different theories of population and its relationship to the economy and the environment, giving an overview of the environmental impacts of world

agricultural systems and discussing issues of renewable and nonrenewable resource supply, demand, and management.

Part VI brings together the themes developed in the preceding chapters in a consideration of environmental impacts of trade and policies for sustainable development.

PEDAGOGICAL AIDS FOR STUDENTS AND INSTRUCTORS

Each chapter has discussion questions, and the more quantitative chapters have numerical exercises. Key terms in each chapter are compiled in an extensive glossary. Useful web sites are also listed. Instructors and students are urged to make full use of the text's supporting web sites at **http://www.gdae.org/environ-econ.**

The instructor web site includes teaching tips and objectives, answers to text problems, and test questions. The student site includes chapter review questions and web-based exercises. The support sites will be updated periodically with bulletins on topical environmental issues.

ACKNOWLEDGMENTS

The preparation of a text covering such an extensive area, in addition to the supporting materials, is a vast enterprise, and our indebtedness to all those who have contributed to the effort is accordingly great. Colleagues at the Global Development and Environment Institute have supplied essential help and inspiration. Research Associate Anne-Marie Codur has made extensive contributions to this edition, especially in the chapters on climate change, population, agriculture, water, and sustainable development. This edition, like previous editions, would not have been possible without the unwavering support of the Institute's co-director, Neva Goodwin, who has long championed the importance of educational materials that bring broader perspectives to the teaching of economics.

Our colleagues Timothy Wise, William Moomaw, Frank Ackerman, Kevin Gallagher, and Julie Nelson have provided insights on specific issues. Research support and technical expertise, especially in presenting data and graphics, was organized by Mitchell Stallman, ably assisted by Max Schmulewitz and Jacob Mittelman. Angela Trowbridge and Erin Coutts provided administrative and outreach support.

This and previous editions have greatly benefited from the comments of reviewers and users including Kris Feder, Richard Horan, Gary Lynne, Helen Mercer, Gerda Kits, Gina Shamshak, Jinhua Zhao, John Sorrentino, Richard England, Maximilian Auffhammer, Guillermo Donoso, Mitchell Dudley, Lawrence McKenna, and Alfonso Sanchez-Penalver. Faculty members, including Fred Curtis, Rafael Reuveny, Ernest Diedrich, Lisi Krall, Richard Culas, and many others in the United States and worldwide, have provided valuable feedback from class use. Others whose work has provided special inspiration for this text include Herman Daly, Richard Norgaard, Richard Howarth, Robert Costanza, Faye Duchin, Glenn-Marie Lange, John Proops, Joan Martinez-Alier, and many other members of the International Society for Ecological Economics. Our editors at Routledge, Andy Humphries, Laura Johnson, and Sarah Douglas, have provided support and guidance throughout. Finally we thank the many students we have had the privilege to teach over the years—you continually inspire us and provide hope for a better future.

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PART

I

Introduction: The Economy and the Environment

CHAPTER

1

Changing Perspectives on the Environment

Chapter 1 Focus Questions

- What major environmental issues do we face in the twenty-first century?
- What are the main frameworks that economists use to understand these issues?
- What principles can promote economic and ecological sustainability?

1.1 OVERVIEW OF ENVIRONMENTAL ISSUES

Over the past five decades, we have become increasingly aware of environmental problems at the local, national, and global levels. During this period, many natural resource and environmental issues have grown in scope and urgency. In 1970, the Environmental Protection Agency was created in the United States to respond to what was at that time a relatively new public concern with air and water pollution. In 1972, the first international conference on the environment, the United Nations Conference on the Human Environment, met in Stockholm. Since then, growing worldwide attention has been devoted to environmental issues. (See Box 1.1 for more important events in modern environmental history.)

In 1992 the United Nations Conference on Environment and Development (UNCED) met in Rio de Janeiro, Brazil, to focus on major global issues, including depletion of the earth's protective ozone layer, destruction of tropical and old-growth forests and wetlands, species extinction, and the steady buildup of carbon dioxide and other "greenhouse" gases causing global warming and climate change. Twenty years later, at the United Nations Rio + 20 Conference on Sustainable Development, countries of the world reaffirmed their commitment to integrating environment and development but acknowledged limited progress toward these goals.[1] In 2012, the United Nations Environment Programme (UNEP) report *Global Environmental Outlook 5* found that "burgeoning populations and growing economies are pushing ecosystems to destabilizing limits." According to the report:

> [The twentieth century] was characterized by exceptional growth both in the human population and in the size of the global economy, with the population quadrupling to 7 billion [in 2011] and global economic output increasing about 20-fold. This expansion has been accompanied by fundamental changes in the scale, intensity, and character of society's relationship with the natural world. . . . Drivers of environmental change are growing, evolving, and combining at such an accelerating pace, at such a large scale and with such widespread reach, that they are exerting unprecedented pressure on the environment.[2]

With the exception of ozone depletion, an area in which major reductions in emissions have been achieved by international agreement, the UNEP report offers evidence that the global environmental problems identified at UNCED in 1992 in the areas of atmosphere, land, water, biodiversity, chemicals, and wastes have continued or worsened. Other UNEP *Global Environmental Outlook* reports have identified nitrogen pollution in freshwater and oceans, exposure to toxic chemicals and hazardous wastes, forest and freshwater ecosystem damage, water contamination and declining groundwater supplies, urban air pollution and wastes, and overexploitation of major ocean fisheries as major global issues.

Climate change has emerged as perhaps the greatest environmental threat of our time. The 2014 report by the United Nations' Intergovernmental Panel on Climate Change concludes that:

> continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems.[3]

In December 2015, a United Nations conference held in Paris resulted in a 195-country agreement to limit and eventually reduce the greenhouse gas emissions that cause climate change.

Box 1.1 IMPORTANT EVENTS IN MODERN ENVIRONMENTAL HISTORY

1962: The publication of Rachel Carson's *Silent Spring*, widely recognized as the catalyst of the modern environmental movement, details the dangers posed by excessive pesticide use.

1964: The passage of the Wilderness Act in the United States, which protects public lands that are "untrammeled by man, where man himself is a visitor who does not remain."

1969: The Cuyahoga River in Ohio is so polluted by oil and other chemicals that it catches on fire, prompting widespread concern about water pollution and eventually the passage of the Clean Water Act in 1972.

1970: The creation of the Environmental Protection Agency by President Richard Nixon. Also, over 20 million participate in the first Earth Day on April 22.

1972: The creation of the United Nation's Environment Programme (UNEP), headquartered in Nairobi, Kenya.

1979: The partial meltdown of the Three Mile Island nuclear reactor in Pennsylvania raises concerns about the safety of nuclear energy. These concerns are exacerbated by the explosion of the Chernobyl reactor in the Soviet Union in 1986.

1987: The United Nations' Brundtland Commission publishes "Our Common Future," which defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

1992: The Rio Declaration on Environment and Development recognizes "the integral and independent nature of the Earth, our home," and lists 27 principles of sustainable development including reducing global inequities, international cooperation, and the promotion of an economic system that addresses environmental problems.

1997: The Kyoto Protocol is negotiated, the first international treaty that commits ratifying nations to reduce their greenhouse gas emissions. Although rejected by the United States, the treaty was ratified by 191 nations and entered into force in 2005.

2002: The Johannesburg Declaration on Sustainable Development recognized that "humanity is at a crossroads" and there exists "a collective responsibility to advance and strengthen the . . . pillars of sustainable development—economic development, social development, and environmental protection."

2009: Nations participating in climate change talks in Copenhagen agree that actions should be implemented to limit eventual global warming to no more than 2°C, though no binding commitments are made to reduce emissions.

2015: The Paris Agreement on climate change, approved by 195 countries, calls for a "global peaking of greenhouse gas emissions as soon as possible" with a goal of "holding the increase in global average temperature to well below 2°C above pre-industrial levels." Over 150 countries submit plans to limit their greenhouse gas emissions.

Also in 2015, the United Nations adopted the Sustainable Development Goals including combating climate change and environmental degradation.

Underlying all these problems is global population growth, which adds more than 70 million people a year. World population, which surpassed 7 billion in 2011, is expected to grow to around 9.7 billion by 2050, with almost all of the growth occurring in developing nations.[4]

Scientists, policy makers, and the general public have begun to grapple with questions such as: What will the future look like? Can we respond to these multiple threats adequately and in time to prevent irreversible damage to the planetary systems that support life? One of the most important components of the problem, which rarely receives sufficient attention, is an economic analysis of environmental issues.

Some may argue that environmental issues transcend economics and should be judged in different terms from the money values used in economic analysis. Indeed, this assertion holds some truth. We find, however, that environmental protection policies are often measured—and sometimes rejected—in terms of their economic costs. For example, it is extremely difficult to preserve open land that has high commercial development value. Either large sums must be raised to purchase the land, or strong political opposition to "locking up" land must be overcome. Environmental protection organizations face a continuing battle with ever-increasing economic development pressures.

Often public policy issues are framed in terms of a conflict between development and the environment. An example is the recent debate over "fracking," or hydraulic fracturing, to obtain natural gas. Producing natural gas can be profitable and increase energy supplies, but there are social and environmental costs to communities. Similarly, opponents of international agreements to reduce carbon dioxide emissions argue that the economic costs of such measures are too high. Supporters of increased oil production clash with advocates of protecting the Arctic National Wildlife Refuge in Alaska. In developing countries, the tension between the urgency of human needs and environmental protection can be even greater.

Does economic development necessarily result in a high environmental price? Although all economic development must affect the environment to some degree, is "environment-friendly" development possible? If we must make a tradeoff between development and the environment, how should the proper balance be reached? Questions such as these highlight the importance of environmental economics.

1.2 ECONOMIC APPROACHES TO THE ENVIRONMENT

While economists have thought about various natural resource issues for hundreds of years, the existence of **environmental economics**[5] as a specific field of economics dates back only to the 1960s, concurrent with the growing awareness of environmental issues discussed above.[6] Environmental economists apply mainstream economic principles to environmental and natural resource issues.

Even more recently (dating back to the 1980s), **ecological economics** has emerged as a field which brings together viewpoints from different academic disciplines to study the interactions between economic and ecological systems. Unlike environmental economics, ecological economics is defined not so much by the application of a particular set of economic principles, but by analyzing economic activity *in the context of* the biological and physical systems that support life, including all human activities.[7]

We will draw upon both approaches in this book. For most of the remainder of this chapter we will discuss the main differences between the two approaches. However, we should first emphasize that the boundary between environmental and ecological economics is a blurred one, with considerable overlap. A 2014 review of journal articles published in both fields finds that they have grown closer over time.[8] Some economists consider

environmental economics a field of economics which applies mainstream economic principles to environmental and natural resource issues

ecological economics a field which brings together viewpoints from different academic disciplines and views the economic system as a subset of the broader ecosystem and subject to biophysical laws.

the two fields to have essentially merged into "environmental and ecological economics."[9] Others call for a new term, such as "sustainability economics" which "lies at the intersection of the two and uses concepts and methods of both."[10]

The economic and ecological analyses that we will review offer a spectrum of viewpoints which can all contribute to solving myriad environmental challenges. But enough differences still exist so that one can differentiate between environmental economics and ecological economics in several respects. We now try to do that in more detail.

Main Principles of Environmental Economics

Environmental economics is based on the application of several mainstream economic theories and principles to environmental issues. We can identify the core of environmental economics as being comprised of four concepts:

1. The theory of environmental externalities
2. The optimal management of common property and public goods
3. The optimal management of natural resources over time
4. The economic valuation of environmental goods and services

Economists since the time of Adam Smith in the eighteenth century have asserted that voluntary market exchanges between buyers and sellers leave both parties better off than when they started. But market exchanges can also impact parties other than the buyers and sellers, either in a positive or negative manner. For example, someone buying gasoline affects other people, such as those exposed to air pollution from producing and burning the gasoline. Economists have long recognized that these "third-party" impacts, known as **externalities**, need to be considered when assessing the overall costs and benefits of market activity. Economic theory provides guidance on devising effective policies in the presence of externalities. We will explore externalities in more detail in Chapter 3.

externalities an effect of a market transaction that impacts the utility, positively or negatively, of those outside the transaction.

market failure situations in which an unregulated market fails to produce an outcome that is the most beneficial to society as a whole.

common property resource a resource that is available to everyone (nonexcludable), but use of the resource may diminish the quantity or quality available to others (rival).

public goods goods that are available to all (nonexcludable) and whose use by one person does not reduce their availability to others (nonrival).

Externalities are an example of **market failure**—situations in which an unregulated market fails to produce an outcome that is the most beneficial to society as a whole. Another important instance of market failure is the allocation of **common property resources** such as the atmosphere and the oceans, and **public goods** such as natural parks and wildlife preserves. Because these resources are not privately owned, we normally can't rely upon markets to maintain them in adequate supply, and in general the principles governing their use are different from those affecting privately owned and marketed goods. Environmental economists have developed a set of economic theories relevant to common property resources and public goods, which we will explore further in Chapter 4.

A third application of mainstream economic theory deals with the management of natural resources over time. According to this perspective, natural resources should be managed to provide society with the highest aggregate benefits summed across generations. A critical question in this analysis is how we value benefits that occur in the future relative to benefits received in the present. We present a basic model of resource management over time in Chapter 5.

The final core concept in environmental economics is that most environmental goods and services can, in principle, be valued in monetary terms. Environmental economists use a set of methods for estimating the monetary value of such things as asthma cases caused as a result of air pollution, the benefits of endangered species, or the value of a scenic view. By measuring these impacts in monetary terms, economists seek to determine the "optimal" degree of environmental protection based on a comparison of costs and benefits. We will discuss methods of valuation, and how they are applied, in Chapters 6 and 7.

Core Concepts of Ecological Economics

The core concepts in ecological economics are somewhat harder to define, as it is a broader field than environmental economics. There is also more variation in viewpoints and disciplinary approaches among ecological economists, including perspectives from biology, ecology, and other sciences, as well as engineering, systems modeling, history, and philosophy.

Nonetheless, we can identify a set of core concepts to which ecological economists generally subscribe. These three core concepts are:

1. The economic system is a subset of the broader ecological system
2. Sustainability should be defined according to ecological, rather than economic, criteria
3. It is essential to rely upon a range of academic disciplines and perspectives, in addition to economics, to provide insight into environmental issues

These core concepts have implications for both how economic analysis is conducted and for policy recommendations. We will explore each of these three core concepts in this chapter, comparing them to mainstream environmental economic approaches, and will return to their implications for analysis and policy in greater detail in Chapter 9.

1.3 PRINCIPLES OF ECOLOGICAL ECONOMICS

The Economic System in an Environmental Context

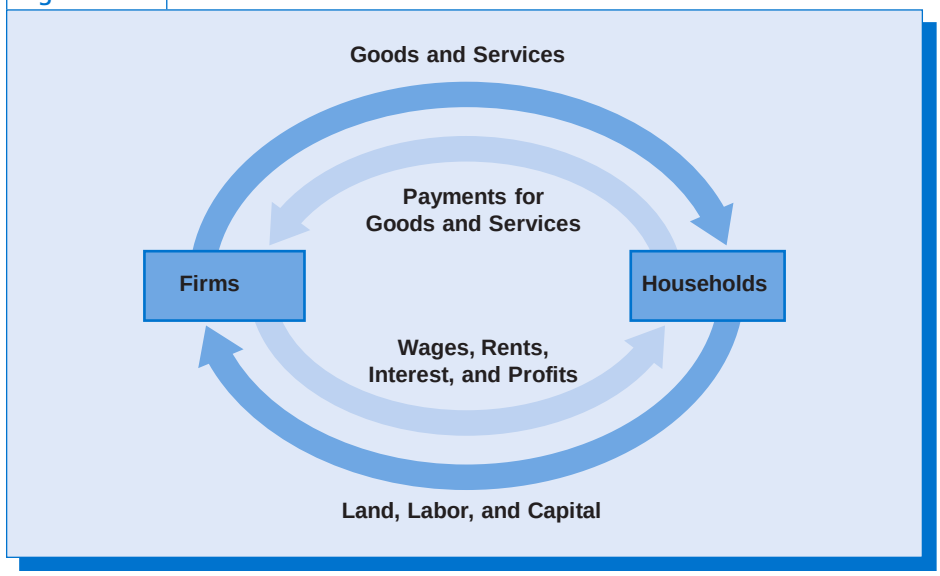
A basic building block of mainstream economic theory is the **standard circular flow model** of an economic system. As illustrated in Figure 1.1, this simple model depicts the relationships between households and business firms in two markets: the market for goods and services and the market for factors of production. Factors of production are generally defined as land, labor, and capital. The services that these factors provide are "inputs" into the production of goods and services, which in turn provide for households' consumption needs. Goods, services, and factors flow clockwise; their economic values are reflected in the flows of money used to pay for them, moving counterclockwise. In both markets, the interaction of supply and demand determines a market-clearing price and establishes an equilibrium level of output.

Where do natural resources and the environment fit in this diagram? **Natural resources**, including minerals, water, fossil fuels, forests, fisheries, and farmland, generally fall under the inclusive category of "land." The two other major factors of production, labor

standard circular flow model a diagram that illustrates the ways goods, services, capital, and money flows between households and businesses.

natural resources the endowment of land and resources including air, water, soil, forests, fisheries, minerals, and ecological life-support systems

Figure 1.1 The Standard Circular Flow Model



and capital, continually regenerate through the economic circular flow process, but by what processes do natural resources regenerate for future economic use? Environmental economists recognize that it is necessary to address the limitations of the standard circular flow model in this respect. But ecological economists place a particular emphasis on a broader circular flow model that takes into account ecosystem processes as well as economic activity (Figure 1.2).

Taking this broader view, we notice that the standard circular flow diagram also omits the effects of wastes and pollution generated in the production process. These wastes, from both firms and households, must flow back into the ecosystem somewhere, either being recycled, through disposal, or as air and water pollution.

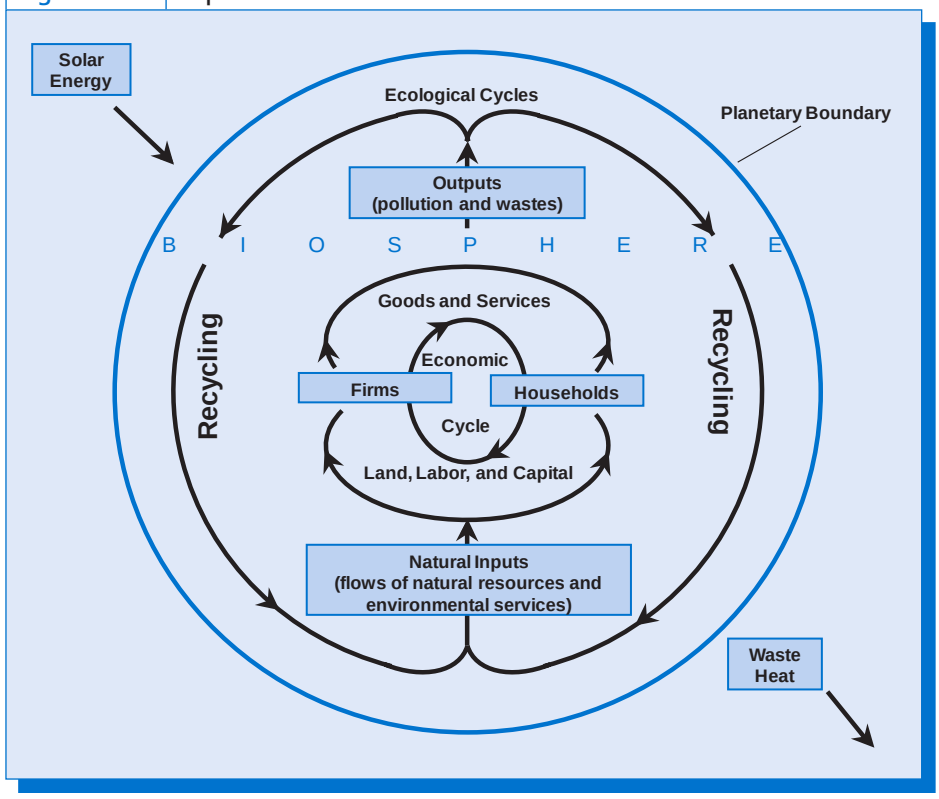
In addition to the simple processes of extracting resources from the ecosystem and returning wastes to it, economic activities also affect broader natural systems in subtler and more pervasive ways not illustrated in Figure 1.2. For example, modern intensive agriculture changes the composition and ecology of soil and water systems, as well as affecting nitrogen and carbon cycles in the environment.

renewable resources resources that are regenerated over time through ecological processes, such as forests and fisheries, but can be depleted through exploitation.

nonrenewable resources resources that do not regenerate through ecological processes, at least on a human time scale, such as oil, coal, and mineral ores.

Figure 1.2 provides a broader framework for placing the economic system in its ecological context. Natural resources include both renewable and nonrenewable resources. **Renewable resources** are those that are regenerated over time through ecological processes, such as forests and fisheries. Renewable resources can be managed sustainably if extraction rates don't exceed natural regeneration rates. However, if renewable resources are overexploited they can be depleted, such as species that go extinct through over-harvesting. **Nonrenewable resources** are those that do not regenerate through ecological processes, at least on a human time scale. Nonrenewable resources such as oil, coal, and mineral ores are ultimately available in a fixed supply, although new resources can be discovered to expand the known available supply. The other input into the economic system is solar energy, which as we will see later in the text provides a limited but incredibly abundant source of continual energy.

Figure 1.2 Expanded Circular Flow Model



What does this expanded circular flow model imply for economic theory? There are at least three major implications:

1. The recognition that natural resources and solar energy provide the essential input into economic processes implies that human well-being is ultimately dependent on these resources. Measuring well-being using standard economic metrics, such as gross domestic product, understates the importance of natural resources. This suggests a need for alternative indicators of well-being, which we will discuss in Chapter 10.
2. As shown in Figure 1.2, the ecological system has its own circular flow, which is determined by physical and biological rather than economic laws. This broader flow has only one net "input"—solar energy—and only one net "output"—waste heat. Everything else must somehow be recycled or contained within the planetary ecosystem.
3. In the standard circular flow model, the economic system is unbounded and can theoretically grow indefinitely. But in the expanded model, economic activity is limited by both the availability of natural resources and the ability of the environment to assimilate wastes and pollution. Thus the overall scale of the economy relative to the available natural resources must be considered.

As with some of the other questions we have discussed, there can be significant overlap between environmental and ecological economics perspectives on these issues. In terms of the double circular flow shown in Figure 1.2, a standard environmental economics perspective