Environmental and Natural Resource Economics

11th Edition

Tom Tietenberg
and Lynne Lewis

Companion Website
Routledge

Environmental and Natural Resource Economics

Environmental and Natural Resource Economics is the best-selling text for natural resource economics and environmental economics courses, offering a policy-oriented approach and introducing economic theory and empirical work from the field. Students will leave the course with a global perspective of both environmental and natural resource economics and how they interact. Complemented by a number of case studies showing how underlying economic principles provided the foundation for specific environmental and resource policies, this key text highlights what can be learned from the actual experience. This new, 11th edition includes updated data, a number of new studies and brings a more international focus to the subject. Key features include:

- Extensive coverage of the major issues including climate change, air and water pollution, sustainable development, and environmental justice.
- Dedicated chapters on a full range of resources including water, land, forests, fisheries, and recyclables.
- Introductions to the theory and method of environmental economics including externalities, benefit-cost analysis, valuation methods, and ecosystem goods and services.
- Boxed 'Examples' and 'Debates' throughout the text which highlight global examples and major talking points.

The text is fully supported with end-of-chapter summaries, discussion questions, and self-test exercises in the book and multiple-choice questions, simulations, references, slides, and an instructor's manual on the Companion Website.

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Contents in Brief

Contents in Full

Preface

A glance at any newspaper will confirm that environmental economics is now a major player in environmental policy. Concepts such as cap-and-trade, renewable portfolio standards, block pricing, renewable energy credits, development impact fees, conservation easements, carbon trading, the commons, congestion pricing, corporate average fuel economy standards, pay-as-you-throw, debt-for-nature swaps, extended producer responsibility, sprawl, leapfrogging, pollution havens, strategic petroleum reserves, payments for ecosystem services, and sustainable development have moved from the textbook to the legislative hearing room. As the large number of current examples in *Environmental and Natural Resource Economics* demonstrates, not only are ideas that were once restricted to academic discussions now part of the policy mix, but they are making a significant difference as well.

New to this Edition

In addition to updating the data in the text, tables, and charts, this edition brings a more international focus. It incorporates many new studies, and as noted below, new topics, new figures, new discussion questions, and new examples. Chapters receiving an especially large amount of new material include valuation, energy, water, and climate change.

New or Expanded Topics

- Social cost of carbon (Chapter 3)
- The 2017 contemporary guidelines on best practice for both contingent valuation and choice experiments (Chapter 4)
- The Environmental Valuation Reference Inventory (Chapter 4)
- Choice Experiments and Benefit Transfer (Chapter 4)
- The EU Renewable Energy Directive (Chapter 7)
- Microgrids (Chapter 7)
- Varieties of pay-as-you-throw trash disposal pricing (Chapter 8)
- Plastic disposal bag bans and fees (Chapter 8)
- The EU Water Framework Directive (Chapter 9)
- Full Cost Recovery Pricing (Chapter 9)
- Narco-deforestation (Chapter 11)
- Catch share programs in the United States (Chapter 12)
- European Common Fisheries Policy (Chapter 12)

- Fisheries enforcement: illegal, unreported, and unmanaged fish stocks (Chapter 12)
- Ecosystem Services Valuation (Chapter 13)
- A review of existing cap-and-trade programs (Chapter 15)
- Fuel economy standards in the European Union and other countries (Chapter 16)
- The economics of bike sharing programs (Chapter 16)
- The dynamics of the Paris Accord and their impacts on climate change (Chapter 17)
- The Montreal Protocol and its effect on climate change impacts (Chapter 17)
- Using the revenue from carbon-pricing programs (Chapter 17)
- Price collars as a check on price volatility (Chapter 17)
- The economics of investment in adaptation to a changing climate (Chapter 17)
- The European Water Framework Directive (Chapter 18)
- Societal costs of exposure to toxic substances (Chapter 19)
- The Flint Michigan lead contamination case (Chapter 19)
- The economics of natural disasters (Chapter 20)
- The California Global Warming Solutions Act (Chapter 21)

New or Expanded Examples and Debates

- Climate Change and Water Accessibility: How Are these Challenges Linked?
- What Is the Proper Geographic Scope for the Social Cost of Carbon?
- Is the Two for One Rule a Good Way to Manage Regulatory Overreach?
- The Value of U.S. National Parks
- Fuel from Shale: The Bakken Experience
- Energy Efficiency: Rebound and Backfire Effects
- Thinking about Energy Cost Reduction Outside of the Box: The Boothbay Pilot Project
- The Economics of Solar Microgrids in Kenya
- The Cost of Water Conservation: Revenue Stability vs. Equitable Pricing
- The Changing Economics of Monitoring and Its Role in Invasive Species Management
- The Swedish Nitrogen Oxide Charge
- Monitoring and Enforcement: The Volkswagen Experience
- Fuel Economy Standards When Fuel Prices Are Falling
- Betting on Climate Science
- Deepwater Horizon BP Oil Spill—Estimating the Damages
- Would the Protection of Elephant Populations Be Enhanced or Diminished by Allowing Limited International Trade in Ivory?
- Enhancing Resilience Against Natural Disasters with Flood Insurance

New Features

- New discussion questions (Chapter 1, Chapter 2, Chapter 13, Chapter 15, Chapter 17, Chapter 18, Chapter 20)
- New self-test exercises (Chapter 6, Chapter 7)
- New further reading references (Chapter 1, Chapter 4, Chapter 5, Chapter 6, Chapter 7, Chapter 8, Chapter 11, Chapter 14, chapter 15, Chapter 17, Chapter 20, Chapter 21)
- New figures (Chapter 2, Chapter 9, Chapter 12, Chapter 18)
- New terms added to the glossary

An Overview of the Book

Environmental and Natural Resource Economics attempts to bring those who are beginning the study of environmental and natural resource economics close to the frontiers of knowledge. Although the book is designed to be accessible to students who have completed a two-semester introductory course in economics or a one-semester introductory microeconomics course, it has been used successfully in several institutions in lower-level and upper-level undergraduate courses as well as lower-level graduate courses.

The structure and topical coverage of this book facilitates its use in a variety of contexts. For a survey course in environmental and natural resource economics, all chapters are appropriate, although many of us find that the book contains somewhat more material than can be adequately covered in a quarter or even a semester. This surplus material provides flexibility for the instructor to choose those topics that best fit his or her course design. A one-term course in natural resource economics could be based on Chapters 1–13 and 20–21. A brief introduction to environmental economics could be added by including Chapter 14. A single-term course in environmental economics could be structured around Chapters 1–4 and 14–21.

In this eleventh edition, we examine many of these newly popular market mechanisms within the context of both theory and practice. Environmental and natural resource economics is a rapidly growing and changing field as many environmental issues become global in nature. In this text, we tackle some of the complex issues that face our globe and explore both the nature of the problems and how economics can provide potential solutions.

This edition retains a strong policy orientation. Although a great deal of theory and empirical evidence is discussed, their inclusion is motivated by the desire to increase understanding of intriguing market situations and policy problems. This explicit integration of research and policy within each chapter avoids a problem frequently encountered in applied economics textbooks—that is, in such texts the theory developed in earlier chapters is often only loosely connected to the rest of the book.

This is an economics book, but it goes beyond economics. Insights from the natural and physical sciences, literature, political science, and other disciplines are scattered liberally throughout the text. In some cases these references raise outstanding issues that economic analysis can help resolve, while in other cases they affect the structure of the economic analysis or provide a contrasting point of view. They play an important role in overcoming the tendency to accept the material uncritically at a superficial level by highlighting those characteristics that make the economics approach unique.

Intertemporal optimization is introduced using graphical two-period models, and all mathematics, other than simple algebra, is relegated to chapter appendices. Graphs and numerical examples provide an intuitive understanding of the principles suggested by the math and the reasons for their validity. In the eleventh edition, we have retained the strengths that are particularly valued by readers, while expanding the number of applications of economic principles, clarifying some of the more difficult arguments, and updating the material to include the very latest global developments.

Reflecting this new role of environmental economics in policy, a number of journals are now devoted either exclusively or mostly to the topics covered in this book. One journal, *Ecological Economics*, is dedicated to bringing economists and ecologists closer together in a common search for appropriate solutions for environmental challenges. Interested readers can also find advanced work in the field in *Land Economics*, *Journal of Environmental Economics and Management*, *Review of Environmental Economics and Policy*, *Environmental and*

Resource Economics, *International Review of Environmental and National Resource Economics*, *Environment and Development Economics*, *Resource and Energy Economics*, and *Natural Resources Journal*, among others.

A discussion list that involves material covered by this book is ResEcon. It is an academically inclined list focusing on problems related to environmental and natural resource management.

A very useful blog that deals with issues in environmental economics and their relationship to policy is located at www.env-econ.net.

Services on the Internet change so rapidly that some of this information may become obsolete. To keep updated on the various web options, visit the Companion Website of this text at www.routledge.com/cw/tietenberg. The site includes an online reference section with all the references cited in the book.

Supplements

For each chapter in the text, the *Online Instructor's Manual*, originally written by Lynne Lewis of Bates College and revised by Pallab Mozumder, provides an overview, teaching objectives, a chapter outline with key terms, common student difficulties, and suggested classroom exercises. PowerPoint® presentations, prepared by Hui Li of Eastern Illinois University, are available for instructors and include all art and figures from the text as well as lecture notes for each chapter. Professors can download the *Online Instructor's Manual* and the PowerPoint® presentations at the Instructor Resource Center (www.routledge.com/cw/tietenberg).

The book's Companion Website, www.routledge.com/cw/tietenberg, features chapter-by-chapter web links to additional reading and economic data. The site also contains Excel-based models that can be used to solve common depletable resource problems numerically. These models, developed by Arthur Caplan and John Gilbert of Utah State University, may be presented in lectures to accentuate the intuition provided in the text, or they may underlie specific questions on a homework assignment.

The Companion Website also provides self-study quizzes for each chapter. Written and updated by Elizabeth Wheaton of Southern Methodist University, each of these chapter quizzes contains multiple-choice questions for students to test what they have learned.

Acknowledgments

The most rewarding part of writing this book is that we have met so many thoughtful people. We very much appreciate the faculty and students who pointed out areas of particular strength or areas where coverage could be expanded. Their support has been gratifying and energizing. One can begin to understand the magnitude of our debt to our colleagues by glancing at the several hundred names in the lists of references. Because their research contributions make this an exciting field, full of insights worthy of being shared, our task was easier and a lot more fun than it might otherwise have been.

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Working with all of the fine young scholars who have assisted with this text over the years has made it all the more obvious why teaching is the world's most satisfying profession.

Finally, Tom would like to express publicly his deep appreciation to his wife, Gretchen, his daughter Heidi, and his son Eric for their love and support. Lynne would like to express her gratitude to Jack for his unwavering support, patience, and generosity. Thank you.

Tom Tietenberg
Lynne Lewis

Chapter 1

Visions of the Future

> From the arch of the bridge to which his guide has carried him, Dante now sees the Diviners . . . coming slowly along the bottom of the fourth Chasm. By help of their incantations and evil agents, they had endeavored to pry into the future which belongs to the almighty alone, and now their faces are painfully twisted the contrary way; and being unable to look before them, they are forced to walk backwards.
>
> —Dante Alighieri, *Divine Comedy: The Inferno*, translated by Carlyle (1867)

Introduction

The Self-Extinction Premise

About the time the American colonies won independence, Edward Gibbon completed his monumental *The History of the Decline and Fall of the Roman Empire*. In a particularly poignant passage that opens the last chapter of his opus, he re-creates a scene in which the learned Poggius, a friend, and two servants ascend the Capitoline Hill after the fall of Rome. They are awed by the contrast between what Rome once was and what Rome has become:

> In the time of the poet it was crowned with the golden roofs of a temple; the temple is overthrown, the gold has been pillaged, the wheel of fortune has accomplished her revolution, and the sacred ground is again disfigured with thorns and brambles. . . . The forum of the Roman people, where they assembled to enact their laws and elect their magistrates is now enclosed for the cultivation of potherbs, or thrown open for the reception of swine and buffaloes. The public and private edifices that were founded for eternity lie prostrate, naked, and broken, like the limbs of a mighty giant; and the ruin is the more visible, from the stupendous relics that have survived the injuries of time and fortune.
>
> (Vol. 6, pp. 650–651)

What could cause the demise of such a grand and powerful society? Gibbon weaves a complex thesis to answer this question, suggesting ultimately that the seeds for Rome's destruction were sown by the Empire itself. Although Rome finally succumbed to such external forces as fires and invasions, its vulnerability was based upon internal weakness.

The premise that societies can germinate the seeds of their own destruction has long fascinated scholars. In 1798, Thomas Malthus published his classic *An Essay on the Principle of Population*, in which he foresaw a time when the urge to reproduce would cause population growth to exceed the land's potential to supply sufficient food, resulting in starvation and death. In his view, the most likely response to this crisis would involve rising death rates caused by environmental constraints, rather than a recognition of impending scarcity followed either by innovation or self-restraint.

Historically, our society has been remarkably robust, having survived wars and shortages, while dramatically increasing living standards and life expectancy. Yet, actual historical examples suggest that Malthus's self-extinction vision may sometimes have merit. Example 1.1 examines two specific cases: the Mayan civilization and Easter Island.

Future Environmental Challenges

Future societies will also face challenges arising from resource scarcity and accumulating pollutants. Many specific examples of these broad categories of problems are discussed in detail in the following chapters. This section provides a flavor of what is to come by illustrating the challenges posed by one pollution problem (climate change) and one resource scarcity problem (water accessibility).

Climate Change

Energy from the sun drives the earth's weather and climate. Incoming rays heat the earth's surface, radiating heat energy back into space. Atmospheric "greenhouse" gases (water vapor, carbon dioxide, and other gases) trap some of the outgoing energy.

Without this natural "greenhouse effect," temperatures on the earth would be much lower than they are now and life as we know it would be impossible. It is possible, however, to have too much of a good thing. Problems arise when the concentration of greenhouse gases increases beyond normal levels, thus retaining excessive heat somewhat like a car with its windows closed in the summer.

Since the Industrial Revolution, greenhouse gas emissions have increased, considerably enhancing the heat-trapping capability of the earth's atmosphere. According to the U.S. Global Change Research Program (USGCRP) (2014):[1]

> Evidence from the top of the atmosphere to the depths of the oceans, collected by scientists and engineers from around the world, tells an unambiguous story: the planet is warming, and over the last half century, this warming has been driven primarily by human activity—predominantly the burning of fossil fuels.

As the earth warms, the consequences are expected to affect both humans and ecosystems. Humans are susceptible to increased heat, as shown by the thousands of deaths in Europe in the summer of 2003 due to the abnormal heat waves. Human health can also be affected by diseases such as Lyme disease, which spread more widely as the earth warms. Rising sea levels (as warmer water expands and previously frozen glaciers melt), coupled with an increase in

EXAMPLE 1.1

A Tale of Two Cultures

The Mayan civilization, a vibrant and highly cultured society that occupied parts of Central America, did not survive. One of the major settlements, Copán, has been studied in sufficient detail to learn reasons for its collapse.

After AD 400 the population growth began to bump into an environmental constraint, specifically the agricultural carrying capacity of the land. The growing population depended heavily on a single, locally grown crop—maize—for food. By early in the sixth century, however, the carrying capacity of the most productive local lands was exceeded, and farmers began to depend upon more fragile parts of the ecosystem. Newly acquired climate data show that a two-century period with a favorable climate was followed by a general drying trend lasting four centuries that led to a series of major droughts. Food production failed to keep pace with the increasing population.

By the eighth and ninth centuries, the evidence reveals not only high levels of infant and adolescent mortality but also widespread malnutrition. The royal dynasty, an important source of leadership, collapsed rather abruptly sometime about AD 820–822.

The second case study, Easter Island, shares some remarkable similarities with both the Mayan case and the Malthusian vision. Easter Island lies some 2000 miles off the coast of Chile. Current visitors note that it is distinguished by two features: (1) its enormous statues carved from volcanic rock and (2) a surprisingly sparse vegetation, given the island's favorable climate and conditions. Both the existence of these imposing statues and the fact that they were erected at a considerable distance from the quarry suggests the presence of an advanced civilization, but current observers see no sign of it. What happened? According to scholars, the short answer is that a rising population, coupled with a heavy reliance on wood for housing, canoe building, and statue transportation, decimated the forest (Brander and Taylor, 1998). The loss of the forest contributed to soil erosion, declining soil productivity, and, ultimately, diminished food production. How did the community react to the impending scarcity? Apparently, the social response was war among the remaining island factions and, ultimately, cannibalism.

We would like to believe not only that in the face of impending scarcity societies would react by changing behavior to adapt to the diminishing resource supplies, but also that this benign response would follow automatically from a recognition of the problem. We even have a cliché to capture this sentiment: "necessity is the mother of invention." These stories do point out, however, that nothing is automatic about a problem-solving response. As we shall see as this book unfolds, sometimes societies not only fail to solve the problem but their reactions can actually intensify it.

Sources: Webster, D., Freter, A., & Golin, N. (2000). *Copan: The Rise and Fall of an Ancient Maya Kingdom*. Fort Worth, TX: Harcourt Brace Publishers; Brander, J. A., & Taylor, M. S. (1998). The simple economics of Easter Island: A Ricardo–Malthus model of renewable resource use. *The American Economic Review*, *88*(1), 119–138; Turner, B. L., & Sabloff, J. A. (2012). Classic period collapse of the central Maya lowlands: Insights about human–environment relationships for sustainability. *Proceedings of the National Academy of Sciences*, *109*(35), 13908–13914; Pringle, Heather. (2012). Climate change had political, human impact on ancient Maya. *Science* (November 9), 730–731.

storm intensity, are expected to flood coastal communities with greater frequency. Ecosystems will be subjected to unaccustomed temperatures; some species will adapt by migrating to new areas, but many others are not expected to be able to react in time. While these processes have already begun, they will intensify throughout the century.

Climate change also has an important moral dimension. Due to their more limited adaptation capabilities, many developing countries, which have produced relatively small amounts of greenhouse gases, are expected to be the hardest hit as the climate changes.

Dealing with climate change will require a coordinated international response. That is a significant challenge to a world system where the nation-state reigns supreme and international organizations are relatively weak.

Water Accessibility

Another class of threats is posed by the interaction of a rising demand for resources in the face of a finite supply. Water provides a particularly interesting example because it is so vital to life.

According to the United Nations, about 40 percent of the world's population lives in areas with moderate-to-high water stress. ("Moderate stress" is defined in the U.N. Assessment of Freshwater Resources as "human consumption of more than 20 percent of all accessible renewable freshwater resources," whereas "severe stress" denotes consumption greater than 40 percent.) By 2025, it is estimated that about two-thirds of the world's population—about 5.5 billion people—will live in areas facing either moderate or severe water stress.

This stress is not uniformly distributed around the globe. For example, in parts of the United States, Mexico, China, and India, groundwater is already being consumed faster than it is being replenished, and aquifer levels are steadily falling. Some rivers, such as the Colorado in the western United States and the Yellow in China, often run dry before they reach the sea. Formerly enormous bodies of water, such as the Aral Sea and Lake Chad, are now a fraction of their once-historic sizes. Glaciers that feed many Asian rivers are shrinking.

According to U.N. data, the continents most burdened by a lack of access to sufficient clean water are Africa and Asia. Up to 50 percent of Africa's urban residents and 75 percent of Asians are estimated to lack adequate access to a safe water supply.

The availability of potable water is further limited by human activities that contaminate the remaining supplies. According to the United Nations, 90 percent of sewage and 70 percent of industrial waste in developing countries are discharged without treatment. And climate change is expected to intensify both the frequency and duration of droughts, simultaneously increasing the demand for water and reducing its supply.

Some arid areas have compensated for their lack of water by importing it via aqueducts from more richly endowed regions or by building large reservoirs. This solution can, however, promote conflict when the water transfer or the relocation of people living in the area to be flooded by the reservoir produces a backlash. Additionally, aqueducts and dams may be geologically vulnerable. For example, in California, many of the aqueducts cross or lie on known earthquake-prone fault lines (Reisner, 2003). The reservoir behind the Three Gorges Dam in China is so vast that the pressure and weight from the stored water have caused tremors and landslides.

Furthermore, climate change and water accessibility are interdependent problems. Example 1.2 explores both their relationship and why it matters.

EXAMPLE 1.2

Climate Change and Water Accessibility: How Are these Challenges Linked?

From a policy analysis point of view, whether these challenges are interdependent matters. If they are linked, their interactions must be considered in the design of any polices created to meet the challenges. Otherwise the response may be neither efficient nor effective.

On May 3, 2016, the World Bank released a report that documents and analyzes the nature and economic implications of the linkages. It notes that climate change will exacerbate water scarcity even as demand for water increases, potentially leading to negative economic impacts and security challenges. According to the report:

> Within the next 3 decades, the global food system will require between 40 to 50 percent more water; municipal and industrial water demand will increase by 50 to 70 percent; the energy sector will see water demand increase by 85 percent; and the environment, already the residual claimant, may receive even less.

The report further anticipates that in the Middle East and Africa conditions will worsen, costing these regions up to six percent of their GDP by 2050.

The report concludes:

> While adopting policy reforms and investments will be demanding, the costs of inaction are far higher. The future will be thirsty and uncertain, but with the right reforms, governments can help ensure that people and ecosystems are not left vulnerable to the consequences of a world subject to more severe water-related shocks and adverse rainfall trends. (p. ix)

Source: World Bank. (2016). *High and Dry: Climate Change, Water, and the Economy*. Washington, D.C.: World Bank. License: Creative Commons Attribution CC BY 3.0 IGO.

Meeting the Challenges

As the scale of economic activity has proceeded steadily upward, the scope of environmental problems triggered by that activity has transcended both geographic and generational boundaries. When the environmental problems were smaller in scale, the nation-state used to be a sufficient form of political organization for resolving them, but is that still the case? Whereas each generation used to have the luxury of being able to satisfy its own needs without worrying about the needs of generations to come, intergenerational effects are now more prominent. Solving problems such as poverty, climate change, ozone depletion, and the loss of biodiversity requires international cooperation. Because future generations cannot speak for themselves, the current generation must speak for them. Current policies must incorporate our obligation to future generations, however difficult or imperfect that incorporation might prove to be.

International cooperation is by no means a foregone conclusion. Global environmental problems can result in very different effects on countries that will sit around the negotiating table. While low-lying countries could be completely submerged by the sea level rise predicted by some climate change models, arid nations could see their marginal agricultural lands succumb to desertification. Other nations may see agricultural productivity rise as warmer climates in traditionally intemperate regions support longer growing seasons.

Countries that unilaterally set out to improve the global environmental situation run the risk of making their businesses vulnerable to competition from less conscientious nations. Industrialized countries that undertake stringent environmental policies may not suffer much at the national level due to offsetting increases in income and employment in industries that supply renewable, cleaner energy and pollution control equipment. Some specific industries facing stringent environmental regulations, however, may well face higher costs than their competitors, and can be expected to lose market share accordingly. Declining market share and employment resulting from especially stringent regulations and the threat of out-sourced production are powerful influences. The search for solutions must accommodate these concerns.

The market system is remarkably resilient in how it responds to challenges. As we shall see, prices provide incentives not only for the wise use of current resources, but also for promoting innovations that can broaden the menu of future options.

Yet, as we shall also see, market incentives are not always consistent with promoting sustainable outcomes. Currently, many individuals and institutions have a large stake in maintaining the status quo, even when it poses an existential threat. Fishermen harvesting their catch from an overexploited fishery are loath to reduce harvests, even when the reduction may be necessary to conserve the stock and to return the population to a healthy level. Farmers who depend on fertilizer and pesticide subsidies will give them up reluctantly. Coal companies resist any attempt to reduce carbon emissions from coal-fired power plants.

How Will Societies Respond?

The fundamental question is how our society will respond to these challenges. One way to think systematically about this question involves feedback loops.

Positive feedback loops are those in which secondary effects tend to reinforce the basic trend. The process of capital accumulation illustrates one positive feedback loop. New investment generates greater output, which when sold, generates profits. These profits can be used to fund additional new investments. Notice that with positive feedback loops, the process is self-reinforcing.

Positive feedback loops are also involved in climate change. Scientists believe, for example, that the relationship between emissions of methane and climate change may be described as a positive feedback loop. Because methane is a greenhouse gas, increases in methane emissions contribute to climate change. The rise of the planetary temperature, however, is triggering the release of extremely large quantities of additional methane that was previously trapped in the permafrost layer of the earth; the resulting larger methane emissions intensify the temperature increases, resulting in the release of more methane—a positive feedback.

Human behavior can also deepen environmental problems through positive feedback loops. When shortages of a commodity are imminent, for example, consumers typically begin to hoard the commodity. Hoarding intensifies the shortage. Similarly, people faced with shortages of food may be forced to eat the seed that is the key to more plentiful food in the future. Situations giving rise to this kind of downward spiral are particularly troublesome.

In contrast, a negative feedback loop is self-limiting rather than self-reinforcing. Perhaps the best-known planetary-scale example of a negative feedback loop is provided in a theory advanced by the English scientist James Lovelock. Called the *Gaia hypothesis*, after the Greek concept for Mother Earth, this view of the world suggests that the earth is a living organism with a complex feedback system that seeks an optimal physical and chemical environment. Deviations from this optimal environment trigger natural, nonhuman response mechanisms that restore the balance. In essence, according to the Gaia hypothesis, the planetary environment is characterized by negative feedback loops and, therefore, is, within limits, a self-limiting process.

As we proceed with our investigation, the degree to which our economic and political institutions serve to intensify or to limit emerging environmental problems will be a key focus of our analysis.

The Role of Economics

How societies respond to challenges will depend largely on the behavior of humans acting individually or collectively. Economic analysis provides an incredibly useful set of tools for anyone interested in understanding and/or modifying human behavior, particularly in the face of scarcity. In many cases, this analysis points out the sources of the market system's resilience as embodied in negative feedback loops. In others, it provides a basis not only for identifying the circumstances where markets fail, but also for clarifying how and why that specific set of circumstances supports degradation. This understanding can then be used as the basis for designing new incentives that restore a sense of harmony in the relationship between the economy and the environment for those cases where the market fails.

Over the years, two different, but related, economic approaches have been devised to address the challenges the future holds. Debate 1.1 explores the similarities and the differences of ecological economics and environmental economics and what they both can bring to the table.

DEBATE 1.1

Ecological Economics versus Environmental Economics

Over several decades or so, the community of scholars dealing with the role of the economy and the environment has settled into two camps: ecological economics (www.ecoeco.org/) and environmental economics (www.aere.org/). Although they share many similarities, ecological economics is consciously more methodologically pluralist, while environmental economics is based solidly on the standard paradigm of neoclassical economics. While neoclassical economics emphasizes maximizing human welfare and using economic incentives to modify destructive human behavior, ecological economics uses a variety of methodologies, including neoclassical economics, depending upon the purpose of the investigation.

While some observers see the two approaches as competitive (presenting an "either–or" choice), others, including the authors of this text, see them as complementary. Complementarity, of course, does not mean full acceptance. Significant differences exist not only between these two fields, but also within them over such topics as the valuation of environmental resources, the impact of trade on the environment, and the appropriate means for evaluating policy strategies for long-duration problems such as climate change. These differences arise not only over methodologies but also over the values that are brought to bear on the analysis.

This book draws from both fields. Although the basic foundation for the analysis is environmental economics, the chapters draw heavily from ecological economics to critique that view when it is controversial and to complement it with useful insights drawn from outside the neoclassical paradigm, when appropriate. Pragmatism is the reigning criterion. If a particular approach or study helps us to understand environmental problems and their resolution, it has been included in the text regardless of which field it came from.

The Use of Models

All of the topics covered in this book will be examined as part of the general focus on satisfying human wants and needs in light of limited environmental and natural resources. Because this subject is complex, it is better understood when broken into manageable portions. Once we master the components in individual chapters, we will be able to coalesce the individual insights into a more complete picture in the concluding chapter.

In economics, as in most other disciplines, we use models to investigate complex subjects such as relationships between the economy and the environment. Models are simplified characterizations of reality. Consider a familiar analog. Maps, by design, leave out much detail. They are, nonetheless, useful guides to reality. By showing how various locations relate to each other, maps give an overall perspective. Although they cannot capture all of the unique details that characterize particular locations, maps highlight those characteristics that are crucial for the purpose at hand.

The models in this text are similar. Through simplification, less detail is considered so that the main concepts and the relationships among them become more obvious.

Fortunately, models allow us to study rigorously issues that are interrelated and global in scale. Unfortunately, due to their selectivity, models may yield conclusions that are dead wrong. Details that are omitted may turn out, in retrospect, to be crucial in understanding a particular dimension. Therefore, models are useful abstractions, but the conclusions they yield depend on the structure of the model. As you shall see as you proceed though this book, change that structure and you are likely to change the conclusions. As a result, models should always be viewed with some caution.

Most people's views of the world are based on models, although frequently the assumptions and relationships involved may be implicit, perhaps even subconscious. In economics, the models are explicit; objectives, relationships, and assumptions are clearly specified so that the reader understands exactly how the conclusions are derived. The models are transparent.

The validity and reliability of economic models are tested by examining the degree to which they can explain actual behavior in markets or other settings. An empirical field known as *econometrics* uses statistical techniques, primarily regression analysis, to derive key economic functions. These data-derived functions, such as cost curves or demand functions, can then be used for such diverse purposes as testing hypotheses about the effects of various water policies or forecasting future prices of solar panels.

Examining human behavior in a non-laboratory setting, however, poses special challenges because it is nearly impossible to control completely for all the various factors that influence an outcome beyond those of primary interest. The search for more control over the circumstances that provide the data we use to understand human behavior has given rise to the use of another complementary analytical approach—*experimental economics* (see Example 1.3). Together, econometrics and experimental economics can provide different lenses to help us understand human behavior and its impact on the world around us.

The Road Ahead

Are current societies on a self-destructive path? In part, the answer depends on whether human behavior is perceived as a positive or a negative feedback loop. If increasing scarcity results in a behavioral response that involves a positive feedback loop (intensifies the pressure on the environment), pessimism is justified. If, on the other hand, human responses serve to reduce those pressures or could be reformed so as to reduce those pressures, optimism may be justified.

Not only does environmental and natural resource economics provide a firm basis for understanding the behavioral sources of environmental problems, but it also provides a firm foundation for crafting specific solutions to them. In subsequent chapters, for example, you will be exposed to how economic analysis can be (and has been) used to forge solutions to such diverse areas as climate change, biodiversity loss, and water scarcity. Many of the solutions are quite novel.

Market forces are extremely powerful. Attempts to solve environmental problems that ignore these forces run a high risk of failure. Where normal market forces are compatible with efficient and sustainable outcomes, those outcomes can be supported and reinforced. Where normal market forces prove inefficient and/or unsustainable, they can be channeled into new directions that restore compatibility between outcomes and objectives. Environmental and natural resource economics provide a specific set of directions for how this compatibility between goals and outcomes can be achieved.

The Underlying Questions

As we look to the future optimists see a continued prosperity based upon a market system that effectively responds to challenges, while pessimists see the challenges as sufficiently different in scope and scale as to raise doubts about our ability to deal with them in time. (Debate 1.2).