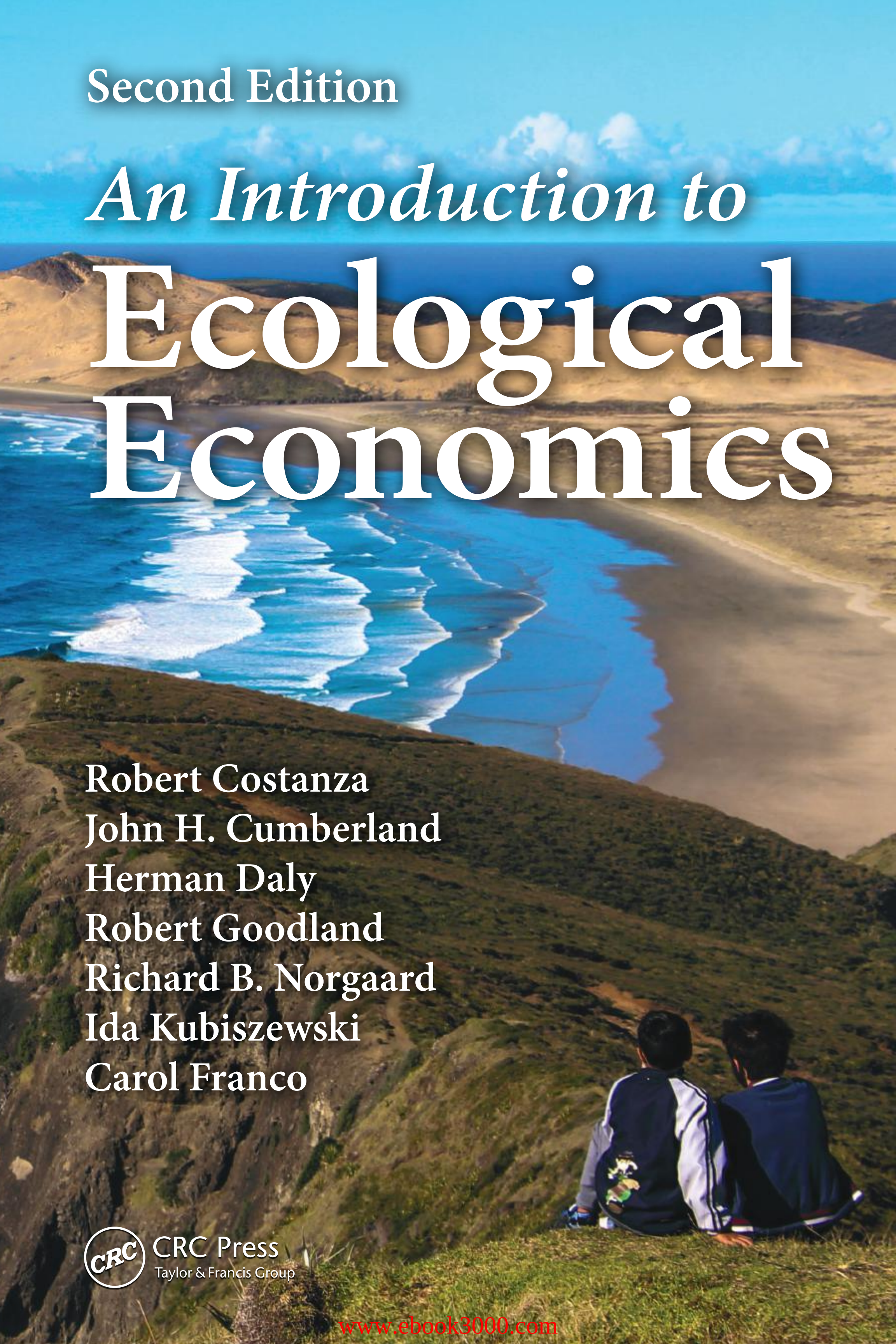

Second Edition

An Introduction to Ecological Economics

Robert Costanza
John H. Cumberland
Herman Daly
Robert Goodland
Richard B. Norgaard
Ida Kubiszewski
Carol Franco

CRC Press
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Preface

This book is not intended to be a stand-alone economics textbook, nor is it a comprehensive treatment of the wide range of activities currently going on in the transdisciplinary field of ecological economics. Rather, it is an introduction to the field from a particular perspective. It is intended to be used in introductory undergraduate or graduate courses, either alone or in combination with other texts. It is also intended for the interested independent reader.

The book is structured in four chapters. We begin with a description of some of the current problems of society and their underlying causes. We trace the causes to problems in the conventional way in which the world and humans' role in it are viewed. Ecological economics is essentially a rethinking of this fundamental relationship and a working out of the implications of a new way of thinking for how we manage our lives and our planet. In Chapter 2, we present a historical narrative of how worldviews have evolved. This emphasizes how much worldviews *do* evolve and change. We outline what we think the next step in this evolution will be (or should be). We present various ideas and models in their proper historical context and as a living narrative, rather than as a list of sterile abstractions. The third chapter is a distillation of what we view as the fundamental principles of ecological economics that are the result of this evolutionary process. The fourth chapter is a set of policies that follow from the principles and a set of instruments that could be used to implement the policies. It lays out the process of shared envisioning as an essential element to achieving sustainability. A brief conclusions section at the end of Chapter 4 summarizes and gives prospects for the future.

The second edition includes several new pieces in each section and a series of independently authored boxes.

Acknowledgments

We are indebted to many individuals and institutions for support and assistance in completing the first edition of this work. The Jesse Smith Noyes Foundation and the Bauman Foundation provided direct financial support to the project. The Pew Charitable Trusts, the University of Maryland Institute for Ecological Economics, and the Beijer International Institute for Ecological Economics also provided support during the preparation of this manuscript. Carl Folke and Richard Howarth gave us detailed and helpful comments on earlier drafts. Sandra Koskoff and Sue Mageau provided editorial assistance and also helped to design and lay out the book. Lisa Speckhardt was responsible for final technical editing, layout, and design.

The second edition benefited greatly from the work of Ida Kubiszewski and Carol Franco, who updated the text, edited the entire document, and added several sections.

Authors

Robert Costanza is a professor and chair in Public Policy at the Crawford School of Public Policy at The Australian National University. Prior to this, he was Distinguished University Professor of Sustainability, in the Institute for Sustainable Solutions at Portland State University (2010–2012), Gund Professor of Ecological Economics and founding director of the Gund Institute for Ecological Economics at the University of Vermont (2002–2010), Professor at the University of Maryland (1988–2002) and at Louisiana State University (1980–1988). His transdisciplinary research integrates the study of humans and the rest of nature to address research, policy and management issues at multiple time and space scales, from small watersheds to the global system. He is co-founder of the International Society for Ecological Economics and founding editor in chief of *Solutions* (http://www.thesolutionsjournal.org). He is author or co-author of over 500 articles and 27 books and has been named one of ISI's Highly Cited Researchers since 2004. More than 200 interviews and reports on his work have appeared in various popular media.

John Cumberland is a professor emeritus at the University of Maryland, where he served as a professor of economics and the director of the Bureau of Business and Economic Research. His teaching, research, and publications have been primarily in the fields of environmental and natural resource economics. He is currently a senior fellow at the University of Maryland Institute for Ecological Economics (IEE).

Herman Daly is the author of many works on ecological economics including *Steady State Economics* (1974) and *For the Common Good* (1989, 1994) with John Cobb. The most recent amplification of his ideas is *Ecological Economics and Sustainable Development* (2007). He is a professor emeritus, at the School of Public Policy, University of Maryland, and a former senior economist with the World Bank. He is cofounder of the ISEE and won the Netherlands Royal Academy Heineken Prize and the Right Livelihood Award in 1996 for pioneering the new discipline of ecological economics.

Robert Goodland was the environmental advisor to the World Bank Group in Washington, DC, between 1978 and 2001. The Library of Congress lists 41 of his publications. He served on the independent Extractive Industry Review of the World Bank Group's oil, gas, and mining portfolio (2001–2004) and then became a senior fellow at the World Resources Institute. He was elected chair of the Ecological Society of America (Metropolitan) and president of the International Association of Impact Assessment. Robert Goodland passed away unexpectedly in 2013.

Richard B. Norgaard is a professor emeritus of energy and resources at the University of California, Berkeley. He acquired his skepticism for market exuberance while earning his PhD in economics at the University of Chicago. He has professional experience in Alaska, the Brazilian Amazon, California, and to a lesser extent in Africa, China, and Vietnam. He helped bring a coevolutionary framing to our understanding of socioecological system dynamics. He is currently writing on "Economism and the Econocene" and "The Challenges of Collectively Understanding Complex Systems." He served on the Fifth Assessment of the Intergovernmental Panel on Climate Change and is a member of California's Delta Independent Science Board.

Ida Kubiszewski is a senior lecturer at the Crawford School of Public Policy at The Australian National University. Prior to this, she was an assistant research professor at Portland State University. She is the co-editor-in-chief of a magazine/journal hybrid called *Solutions* and of the academic journal *Reviews in Ecological Economics*. Dr. Kubiszewski is a cofounder and former managing editor of the "Encyclopedia of Earth," a peer-reviewed wiki about the environment. She is the author or coauthor of more than a dozen scientific papers in the fields of ecological economics, ecosystem services, economics of information, energy, and institutional design.

Carol Franco is a senior research associate at Virginia Tech University. She is an ecological economist experienced in food security, ecosystem services, and policies for economic development and climate change mitigation and adaptation. She has participated in negotiations of the United Nations Framework Convention on Climate Change for 4 years now as a member of the Dominican Republic delegation. She has extensive practical experience working with NGOs, the private sector, Governmental and International Development Institutions (e.g., USAID, EPA, SilvaCarbon, IDB). Her current responsibilities include working with government institutions on REDD+ policy frameworks on the ground in Mexico, Peru, Colombia, and the Dominican Republic.

Remembering Robert Goodland

Robert Goodland
(1939–2013)

Robert Goodland was the first ecologist hired by the World Bank. For 30 years, he worked diligently to improve that institution's environmental and human rights practices. He was the first recipient of the International Union for the Conservation of Nature (IUCN)'s Harold Jefferson Coolidge medal for lifetime achievement in the conservation of nature.

Robert was initially assigned to the task of screening every single proposed World Bank project and selecting for scrutiny those with the largest potential impacts, for which Robert would draft recommendations. But project designers resisted implementing his recommendations. As a remedy, Robert took a lead role in drafting overall environmental and social standards for the World Bank Group, notably covering environmental assessment, indigenous peoples, natural habitats, and physical cultural resources. Robert did much to open the World Bank to dialog with the NGO community.

Robert's work on indigenous peoples led the institution to hire a cadre of anthropologists. A key issue was to prevent forced resettlement and to mitigate its adverse impacts when it did occur. Robert also worked to complete the *Environmental Assessment Sourcebook*, which became a key worldwide reference on various aspects of environmental assessment. As a capstone to Robert's work on the principles of environmental and social assessment, he served a term as president of the International Association of Impact Assessment in 1994–1995.

Earlier, Robert taught tropical ecology and environmental assessment at the University of Brasilia and at the National Amazonian Research Institute in Manaus. His time in Brazil led him to coauthor the book

Amazon Jungle: Green Hell to Red Desert? with Howard Irwin. It became a seminal work on the birth of the international environmental movement.

Robert developed ways to stop the World Bank Group from financing projects involving tobacco and asbestos as well as to avoid the most destructive types of agricultural and forestry projects. Later, after Robert had analyzed the impacts of some of the world's largest hydroelectricity projects, he played a key role in the establishment of the World Commission on Dams in 1997.

Robert cooperated with Salah El Serafy, Herman Daly, and Roefie Hueting to develop a series of conferences throughout the 1980s on greening the United Nations' System of National Accounts. They also collaborated, under Robert's leadership, on a critique of the 1992 World Development Report (the first on the theme of development and the environment), entitled *Environmentally Sustainable Economic Development: Building on Brundtland*, published by UNESCO.

Robert coauthored (with Jeff Anhang) a 2009 article "Livestock and Climate Change," which assessed how replacing some livestock products—and reforesting land thereby freed from livestock and feed production—could be a pragmatic way to stop climate change. Robert was invited by the United Nations' Food and Agriculture Organization to speak about this work in Rome and Berlin, and he was also invited to deliver a keynote speech to the Chinese Academy of Social Sciences in Beijing.

After Robert's official retirement from the World Bank in 2001, Emil Salim recruited him to play a key role in the independent Extractive Industries Review. In retirement, Robert worked all over the world as a consultant, often pro bono, for the protection of the environment and of indigenous peoples. He once remarked that in retirement he was doing much the same things as when at the World Bank, but the difference was that now the people he worked for were more cooperative.

Throughout his career Robert encouraged many people who benefitted greatly from his kindness. Robert's life and career are examples of how with quiet courage, unfailing courtesy, and hard work, one can accomplish much—even in a politically adversarial environment.

—Herman Daly

1

Humanity's Current Dilemma

> … It took Britain half the resources of the planet to achieve its prosperity; how many planets will a country like India require …?
>
> **—Mahatma Gandhi, when asked if, after independence, India would attain British standards of living**

Historically, the recognition by humans of their impact upon the Earth has consistently lagged behind the magnitude of the damage they have imposed, thus seriously weakening efforts to control this damage. Even today, technological optimists and others ignore the mounting evidence of global environmental degradation until it intrudes more inescapably upon their personal welfare. Some draw comfort from the arguments that:

- Gross domestic product (GDP) figures are increasing throughout much of the world.
- Life expectancy is increasing in many nations.
- Certain claims of environmental damage have been exaggerated. Previous predictions of environmental catastrophe have not been borne out.

Each of these statements is correct. However, not one of them is a reason for complacency, and indeed, taken together, they should be viewed as powerful evidence of the need for an innovative approach to environmental analysis and management. GDP and other current measures of national income accounting are notorious for overweighting market transactions, understating resource depletion, omitting pollution damage, and for failing to measure real changes in well-being (see Section 3.5). For example, the Index of Sustainable Economic Welfare (Daly and Cobb 1989; Cobb et al. 1994; Max-Neef 1995), later revised and renamed the Genuine Progress Indicator (Talberth et al. 2007), shows much reduced improvement in real gains, despite great increases in resource depleting throughput (see Section 3.5.6). Increases in life expectancies in many nations by contrast clearly indicate improvements in welfare, but unless accompanied by corresponding decreases in birthrates, they are warnings of acceleration in population growth, which will compound all other environmental problems. In the former USSR, sharply increasing infant mortality rates and declines in life expectancy attest to the dangers of massive accumulations of pollution stocks and neglect of public health (Feshbach and Friendly 1992).

There is a pervasive uncertainty about the basic nature of our ecological life-support systems and a need to build precautionary minimum safe standards into environmental policies. The fact that some environmental problems have been overestimated and that the magnitude of many of these problems has been debated does not reduce the urgency of our responsibility to seek the underlying patterns from many indicators of what is happening to the "balance of the Earth" (Gore 1992).

Due to advances in environmental sciences, global remote sensing, and other monitoring systems, a more comprehensive assessment of local and global environmental deterioration is possible. Evidence is accumulating with respect to accelerating loss of vital rain forests, species extinction, depletion of ocean fisheries, shortages of fresh water in some areas and increased flooding in others, soil erosion, depletion and pollution of underground aquifers, decreases in quantity and quality of irrigation and drinking water, and growing global pollution of the atmosphere and oceans, even in the polar regions (Brown 1997a; Lenton et al. 2008; Rockstrom et al. 2009). Obviously, the exponential growth of human populations is rapidly crowding out other species before we have begun to understand fully our dependence upon species diversity and its impact on whole system resilience. Although post-Cold War conflicts such as those in Haiti, Somalia, Sudan, and Rwanda are characterized in part by ethnic differences, territorial overcrowding and food shortages are contributing factors and consequently provide additional early warning of accumulating global environmental problems.

Clearly, remedial policy responses to date have been local, partial, and inadequate. Early policy discussions and the resulting responses tended to focus on symptoms of environmental damage rather than basic causes. Policy instruments tended to be ad hoc rather than carefully designed for efficiency, fairness, and sustainability. For example, in the 1970s, emphasis centered on end-of-pipe pollution control that although a serious problem was actually a symptom of expanding populations and inefficient technologies that fueled exponential growth of material and energy throughput while threatening the recuperative powers of the planet's life-support systems.

As a result of early perceptions of environmental damage, much was learned about policies and instruments for attacking pollution. These insights will help in dealing with the more fundamental and intractable environmental issues identified here.

The basic problems for which we need innovative policies and management instruments include:

- Unsustainably large and growing human populations that exceed the carrying capacity of the Earth
- Rapidly increasing inequality within and between nations
- Highly entropy-increasing technologies that deplete the Earth of its resources and whose unassimilated wastes poison the air, the water, and the land
- Land conversion that destroys habitat, increases soil erosion, and accelerates loss of species diversity

As emphasized throughout this work, these problems are all evidence that the material scale of human activity exceeds the sustainable carrying capacity of the Earth. We argue that in addressing these problems, we should adopt courses based upon a fair distribution of resources and opportunities between present and future generations as well as among groups within the present generation. These strategies should be based upon an economically efficient allocation of resources that adequately accounts for protecting the stock of natural capital. This section examines the historical record and the emerging transdiscipline of ecological economics for guidance in designing policies and instruments capable of dealing with these problems.

Historically, severe anthropogenic damage began when humans learned to apply highly entropy-increasing technological processes to agriculture. This was sharply escalated by factory production in Europe during the Industrial Revolution. Early public policy responses were feeble to nonexistent, allowing polluters, whose political and economic power began to eclipse that of the feudal magnates, to gain de facto property rights to emit wastes into the common property resources of air and water. In England, it was not until urban agglomeration in London, with its choking smog from coal fires, so discomforted Parliament that it took forceful action. In the mid-twentieth century, incidents of deaths from smog, the result of automobiles and modern industry, began to occur. In 1948, in Donora, Pennsylvania, a "killer smog" produced by a steel mill operating during a week-long temperature inversion killed several people and caused illness in thousands. In London, several thousand people were killed during one winter night in 1952 as a result of the smog from domestic and industrial coal burning. Eventually these incidents led to the passage of clean air legislation and improved technologies.

Even more massive loss of life was accepted from the spread of waterborne diseases until advances in scientific knowledge concerning the role of microorganisms prompted sewage treatment and water purification systems. Vast urban expenditures on such systems eventually reduced the enormous loss of human life from the uncontrolled discharge of human waste into common property waterways. The application of appropriate science, appropriate technology, and community will reduce the costly loss of human life resulting from unprecedented population expansion, concentration of humans into unplanned urban areas, and uncompensated appropriation of common property resources for waste disposal.

Homo sapiens is at another turning point in its relatively long and (so far) inordinately successful history. Our species' activities on the planet have now become of so large a scale that they are beginning to affect the ecological life-support system itself. The entire concept of economic growth (defined as increasing material consumption) must be rethought, especially as a solution to the growing host of interrelated social, economic, and environmental problems. What we need now is real economic and social development (qualitative improvement without growth in resource throughput) and an explicit recognition of the interrelatedness and interdependence of all aspects of life on the planet (see Section 3.3.1 for more on this important distinction between growth and development). We need to move from an economics that ignores this interdependence to one that acknowledges and builds upon it. We need to develop an economics that is fundamentally ecological in its basic view of the problems that now face our species at this crucial point in its history.

As we show in Chapter 2, this new ecological economics is, in a very real sense, a return to the classical roots of economics. It is a return to a point when economics and the other sciences were integrated rather than academically isolated as they are now. Ecological economics is an attempt to transcend the narrow disciplinary boundaries that have grown up in the last 90 years in order to bring the full power of our intellectual capital to bear on the huge problems we now face.

The current dilemma of our species can be summarized in ecological terms as follows: We have moved from an early successional "empty world" (empty of people and their artifacts but full of natural capital) where the emphasis and rewards were on rapid growth and expansion, cutthroat competition, and open waste cycles, to a maturing "full world" (full of people and their artifacts but decreasing in natural capital) (see Figure 1.1) where the needs, whether perceived by decision makers or not, are for qualitative improvement of the linkages among components (development), cooperative alliances, and recycled "closed loop" waste flows.

Can we recognize these fundamental changes and reorganize our society rapidly enough to avoid a catastrophic overshoot? Can we be humble enough to acknowledge the huge uncertainties involved and protect ourselves from their most dire consequences? Can we effectively develop policies to deal with the tricky issues of wealth distribution, population prudence, international trade, and energy supply in a world where the simple palliative of "more growth" is no longer a solution? Can we

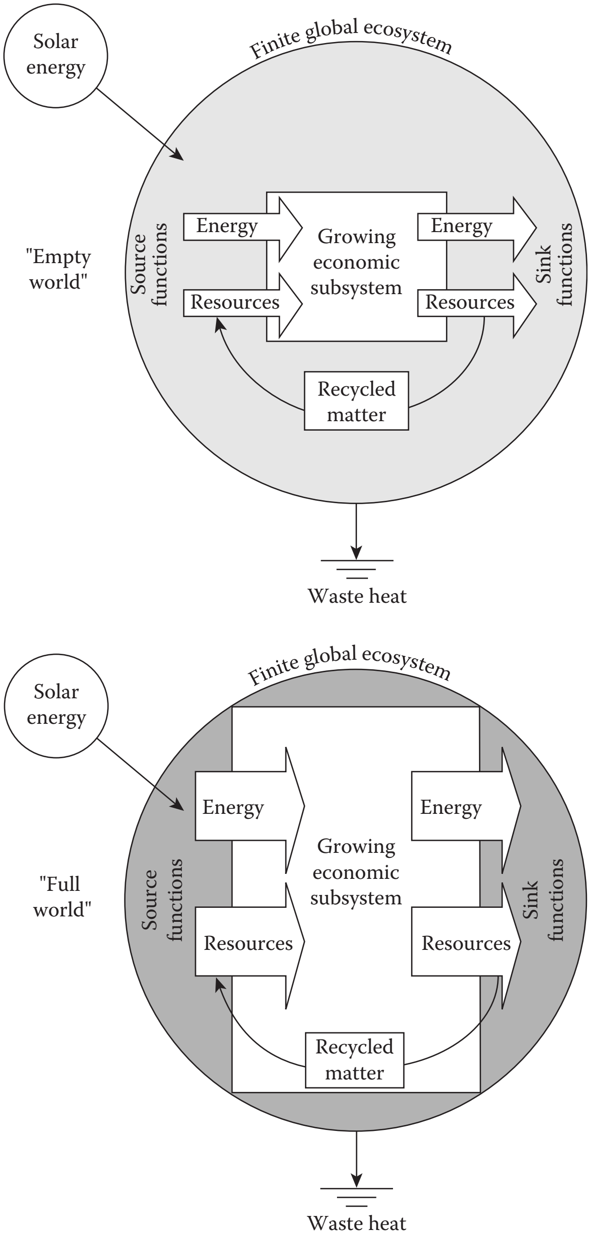

FIGURE 1.1
The finite global ecosystem relative to the economic subsystem. (From Goodland, R. et al., *Population, technology, and lifestyle*, Island Press, Washington, DC, 1992.)

modify our systems of governance at international, national, and local levels to be better adapted to these new and more difficult challenges?

Homo sapiens has successfully adapted to huge challenges in the past. We developed agriculture as a response to the limits of hunting and gathering. We developed an industrial society to adapt to the potential of concentrated forms of energy. Now the challenge is to live sustainably within the material limits of a finite planet. Humans have an ability to conceptualize their world and foresee the future that is more highly developed than that of any other species. We the authors hope that we, the human species, can use this skill of conceptualization and forecasting to meet the new challenge of sustainability. Ecological economics seeks to meet that challenge.

1.1 The Global Ecosystem and the Economic Subsystem

A useful indicator of our environmental predicament is population times per capita resource consumption (Ehrlich and Ehrlich 1990). This is the scale of the human economic subsystem with respect to that of the global ecosystem on which it depends and of which it is a part. The global ecosystem is the source of all material inputs feeding the economic subsystem and is the sink for all its wastes. Population times per capita resource consumption is the total flow—throughput—of resources from the ecosystem to the economic subsystem then back to the ecosystem as waste, as shown in Figure 1.1. The upper diagram illustrates the bygone era when the economic subsystem (depicted by a square) was small relative to the size of the global ecosystem. The lower diagram depicts a situation much nearer to today in which the economic subsystem is very large relative to the global ecosystem.

The global ecosystem's source and sink functions have large but limited capacity to support the economic subsystem. The imperative, therefore, is to maintain the size of the global economy to within the capacity of the ecosystem necessary to sustain it. It took all of human history to grow to the $600 billion per year economy of 1900. Today, the world economy grows by this amount approximately every 1.5 months. Unchecked, 2011's $70 trillion per year global economy (in purchasing power parity [PPP] constant 2005 dollars) may be 2.5 times bigger only one generation or so hence.

It seems unlikely that the world can sustain a doubling of the material economy, let alone the Brundtland Commission's call for "five- to tenfold increase" (WCED 1987). Throughput growth is not the way to reach sustainability; we cannot "grow" our way into sustainability. The global ecosystem, which is the source of all the resources needed for the economic subsystem, is finite and has limited regenerative and assimilative capacities. Although the 21st century may see the human population reach approximately 10 billion, all consuming resources and burdening sinks with their wastes, it seems doubtful that these people can be supported sustainably at anything like current Western levels of material consumption. We have already begun to bump up against various kinds of limits to continued material expansion. The path to sustainable future gains in the human condition will be through qualitative improvement rather than quantitative increases in throughput.

1.2 From Localized Limits to Global Limits

Business-as-usual is a utopian fantasy.

Paul Raskin

The economic subsystem has already reached or exceeded many of the planetary boundaries. There is practically nowhere on Earth where signs of the human activity are absent. From the center of Antarctica to Mount Everest, human wastes are obvious and increasing. It is not possible to find a sample of ocean water with no sign of human wastes. Polychlorinated-biphenyls (PCBs), other persistent toxic chemicals such as DDT, and heavy metal compounds have already accumulated throughout the marine ecosystem. Urban air quality causes approximately 1.3 million deaths annually while indoor air pollution is the cause of about 2 million premature deaths annually, according to the World Health Organization (WHO). And an entire generation of Mexico City children may be intellectually stunted by lead poisoning.

Since the Club of Rome's 1972 "Limits to Growth," the emphasis has shifted from source limits to sink limits. Source limits are more open to substitution, are more amenable to private ownership, and are more localized. Consequently, they are more amenable to control by markets and prices. Sink limits involve common property where markets fail. Since 1972, the case has substantially strengthened so that there are limits to throughput growth on the sink side (Meadows et al. 1992; Randers 2012). Some of these limits are tractable and are being tackled, such as the CFC (chlorofluorocarbon) phaseout under the Montreal Convention. Other limits are less tractable, such as increasing CO_2 emissions and the massive human appropriation of biomass. Another example is landfill sites, which are becoming extremely difficult to find. Garbage is now shipped thousands of miles from industrial to developing countries in search of unfilled sinks. It has so far proved impossible for the U.S. Nuclear Regulatory Commission to rent a nuclear waste site. Although a facility in Yucca Mountain was approved in 2002, the Obama administration cut all funding due to public protests.

No new site has been established. These facts *confirm* that landfill sites and toxic dumps—aspects of sinks—are increasingly hard to find.

One important limit is the sink constraint of fossil energy use. Therefore, the rate of transition to renewable energy sources, including solar and wind energy, parallels the rate of the transition to sustainability. In the face of such high stakes, we should be agnostic on technology. We should encourage sustainable technological development but not bank on it to solve all environmental problems.

The first edition of this book, with this section on global limits, began to refocus the discussion from sources to include input reduction and sink management. In the years since then, Johan Rockström and colleagues have significantly amplified this discussion through the publication of a paper in *Nature* on Earth's planetary boundaries and humanity's safe operating space (Rockström et al. 2009). The limits originally identified in this book include four out of the ten boundaries identified by Rockström.

1.2.1 First Evidence of Limits: Human Biomass Appropriation

The best evidence that there are imminent limits is that the human economy uses—directly or indirectly—from 30% to 55% of the net primary product (NPP) of terrestrial photosynthesis globally (Vitousek et al. 1986; Rojstaczer et al. 2001). (This figure drops to 25% if the oceans and other aquatic ecosystems are included.) This has a significant spatial variance, reaching up to 72% of the NPP in east and south central Asia where about half of the world's population lives. Human appropriation of NPP is about double in developed versus in developing countries, where 83% of the world's population lives. If the populations in developing countries began to appropriate NPP at the same rate as the developed countries do today, human appropriation global NPP would be around 75% (Imhoff et al. 2004).

Desertification, deforestation, urban encroachment onto agricultural land, blacktopping, soil erosion, and pollution are increasing, as is food demand by an expanding population. This means that in only a single doubling of the world's population (say 40–45 years) we will use 80%, and 100% shortly thereafter, of NPP. As Daly (1991c, 1991d) points out, 100% appropriation is ecologically impossible, but even if it were possible, it would be socially undesirable. The world will go from half empty to full in one doubling period, irrespective of the sink being filled or the source being consumed.

1.2.2 Second Evidence of Limits: Climate Change

The second evidence that limits have been exceeded is climate change. The year 2010 was the warmest year on record. Nine out of ten of the hottest years on record all occurred since 2000, the only exception was 1998. The 1990s were 0.5°C (1°F) warmer than the 1890s, while the

2000s were 0.77°C (1.4°F) warmer. This contrasts alarmingly with the preindustrial constancy in which the Earth's temperature did not vary more than 2°–4°F in the last 10,000 years (Costanza et al. 2007). Humanity's entire social and cultural infrastructure over the last 7,000 years has evolved entirely within a global climate that never deviated as much as 2°F from today's climate (Arrhenius and Waltz 1990).

Global change has begun. However, there is still some uncertainty as expected about the precise rates of change and extent of potential impacts. The scale of today's fossil fuel-based human economy, deforestation, and forest fires is the dominant cause of greenhouse gas accumulation (Stern et al. 2007). The biggest contribution to greenhouse warming, carbon dioxide released from burning coal, oil, and natural gas, is accumulating in the atmosphere.

Next in importance contributing to climate change are all other pollutants released by the economy that exceed the biosphere's absorptive capacity: methane, CFCs, and nitrous oxide. Relative to carbon dioxide, these three pollutants are orders of magnitude more damaging per unit, although their amount is much less. The market price to polluters for using atmospheric sink capacity for carbon dioxide disposal is either zero or minimal, depending on location, although the real opportunity cost may turn out to be astronomical. Economists are almost unanimous in persisting in externalizing the costs of CO_2 emissions, even though many nations had signed a treaty to internalize such costs.

The Kyoto Protocol was adopted in 1997 and entered into force in 2005 after it was ratified by all UN nations, except the United States. In 2012, it was decided to extend the Kyoto Protocol until 2020, however Canada, Russia and Japan indicated that they were not going beyond the first commitment period. The United States has still not ratified it. Currently, there is no long-term financing commitment from developed countries to reduce emissions, discouraging developing countries from changing their development path to one with lower CO_2 emissions.

There may be a few exceptions to the negative impacts of global warming, such as plants growing faster in CO_2-enriched laboratories where water and nutrients are not limiting. However, in the real world, it seems more likely that crop belts will not shift quickly enough with changing climate, nor will they grow faster because some other factor (e.g., suitable soils, nutrients, or water) will become limiting. The prodigious North American breadbasket's climate may indeed shift north, but this does not mean the breadbasket will follow because the deep, rich prairie soils will stay put, and Canadian boreal soils and muskeg are very infertile.

In certain parts of the world, a one-degree temperature rise during the growing season reduces grain yields by approximately 10%. Hence, the costs of not taking preventative action, in other words not following the precautionary principle, vastly exceed the costs of adaptation after the impacts have occurred. And yet, emissions have continued to rise. Some of the impacts of climate change can already be seen and are expected to worsen, such as an influx of millions of refugees from low-lying coastal areas, damage to ports and coastal cities, increases in storm intensity, and damage to agriculture.

The relevant component here is the tight relationship between carbon released and the scale of the material economy. Global CO_2 emissions have increased annually since the Industrial Revolution, increasing from 3.74 tonnes/capita in 1971 to 4.44 tonnes/capita in 2010, according to the International Energy Agency. This has lead to quickly rising concentrations of CO_2, reaching 400 parts per million (ppm) for the first time in May 2013. This is a significant event because many scientists are predicting that 350 ppm is the safe upper limit for CO_2 in our atmosphere (Hansen et al. 2008).

To the extent energy use parallels economic activity, carbon emissions are an index of the scale of the material economy. Reducing fossil energy intensity is possible in all industrial economies and in the larger developing economies such as China, Brazil, and India. Increasing energy use without increasing CO_2 means primarily making the transition to renewables: biomass, solar, wind, and hydroelectric power. The other major source of carbon emissions—deforestation—also parallels the scale of the economy. More people needing more land push back the frontier. But such geopolitical frontiers are rapidly vanishing today.

As the carbon released each year by human activity (from fossil fuels and deforestation) accumulates in the atmosphere, it appears, for all practical purposes, to be irreversible. Also, as of 2011, humans were using 135% of the resources that can be sustainably generated in one year, significantly exceeding the Earth's biocapacity (Ecological Footprint 2011). Hence, it is of major concern for the sustainability of future generations.

1.2.3 Third Evidence of Limits: Ozone Shield Rupture

The third evidence that global limits have been reached is the rupture of the ozone shield. It is difficult to imagine more compelling evidence that human activity has already damaged our life-support systems than the cosmic holes in the ozone shield. The fact that CFCs would damage the ozone layer was predicted as far back as 1974 by Sherwood Rowland and Mario Molina. But when the damage was first detected—in 1985 in Antarctica—disbelief was so great that the data were rejected as coming from faulty sensors. Retesting and a search of hitherto undigested computer printouts confirmed that not only did the hole exist in 1985, but that it had appeared each spring since 1979. The world had failed to detect a vast hole that threatened human life and food production and that was more extensive than the United States and taller than Mount Everest.

The single Antarctic ozone hole has now gone global. All subsequent tests have proved that the global ozone layer is thinning far faster than models predicted. A second hole was subsequently discovered over the Arctic; in the early 1990s, ozone shield thinning was detected over both north and south temperate latitudes, including over northern Europe and North America, which has since been halted. Furthermore, the temperate holes have edged from the less dangerous winter into the spring, thus posing more of a threat to sprouting crops and to humans.

The relationship between the increased ultraviolet B radiation let through the impaired ozone shield and skin cancers and cataracts is relatively well-known; every 1% decrease in the ozone layer results in 5% more of certain skin cancers. This is already alarming in certain regions (e.g., Queensland, Australia). The world seems destined for one billion additional skin cancers, many of them fatal, among people alive today. The potentially more serious human health effect is the depression of our immune systems, increasing our vulnerability to an array of tumors, parasites, and infectious diseases. In addition, as the shield weakens, crop yields and marine fisheries decline. But the gravest effect may be the uncertainty, such as upsetting normal balances in natural vegetation. Keystone species—those on which many others depend for survival—may decrease, leading to widespread disruption in environmental services and accelerating extinctions.

The CFCs annually dumped into the biosphere take about 10 years to waft up to the ozone layer, where they destroy it with a half-life of about one century. In 2005, the concentrations of CFCs had decreased by 8%–9% from their peak values in 1992–1994 (Clerbaux et al. 2006). However, the world will be gripped in an unavoidable situation for decades to come.

This shows that the global ecosystem's sink capacity to absorb CFC pollution has been exceeded. Because the limits have been reached and exceeded, mankind is in for damage to environmental services, human health, and food production. The majority of CFCs were released in the industrial north, but the main hole appeared in Antarctica in the ozone layer 20 kilometers up in the atmosphere, showing the damage to be widespread and truly global in nature.

1.2.4 Fourth Evidence of Limits: Land Degradation (Land-System Change)

Land degradation is not new. Land has been degraded by civilization for thousands of years, and in many cases, previously degraded land remains unproductive today. But the scale has mushroomed to about 0.8% per year over the past 40 to 50 years because the majority of our food comes from land rather than aquatic systems (MEA 2005). About 12% of our current land surface is under crop cultivation (Foley et al. 2005; Ramankutty et al. 2008). Such degradation is largely irreversible in any time scale of interest to society, showing that we have exceeded the regenerative capacity of the Earth's soil resources (Box 1.1).

BOX 1.1 ECOSYSTEMS, POVERTY, AND THE CONSUMPTION ELEPHANT

BRENDAN FISHER

The Millennium Ecosystem Assessment (MEA 2005) is an enlightening blueprint for building the knowledge necessary for moving toward sustainability. The importance of ecosystem services for the poor and vulnerable and the macroscale economic drivers of ecosystem change are two important issues raised by the MEA. It is vital that these two points continue to be stressed by ecologists, economists, and decision makers if we are to strive for sustainability in a materially closed system … planet Earth. For some time, the overconsumption of the Earth's finite resources by the developed countries has been the proverbial "elephant in the room."

This elephant is big and getting bigger. Examples abound. The destruction of mangroves, beach forests, and coral reefs, all of which have been shown to reduce the impacts of coastal disasters such as the 2004 Asian tsunami (1, 2) are such a tragedy of the North's consumption. Coral destruction to produce tourist souvenirs (2), mangrove conversion for shrimp farming (3, 4), Amazonian deforestation for soy production for cattle feed (5), and tourism-driven coastal land conversion (6) are only a few such instances of overconsumption by the rich affecting the welfare, livelihoods, and sustainability of those who more directly rely upon ecosystem services.

Also, the developed world's overconsumption of the atmosphere as a carbon sink is likely to have devastating consequences such as sea level rise and possible increased storm potential. These will disproportionally affect the development of the poorer countries. The acknowledgment that often the underlying driver of ecosystem conversion and degradation is overconsumption which is not a strictly local phenomena (3, 7) will be critical for developing policies for equity and sustainability. A research agenda that inherently recognizes this connection between northern "wealth" and southern "illth" (what John Ruskin referred to as the opposite of wealth) will go a long way toward equitable and sustainable development.

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Approximately 40% of cultivated land is experiencing soil erosion, reduction in fertility, or overgrazing (Wood et al. 2000). Soil erosion is worsening as more marginal land is brought into production. Soil loss rates, generally ranging from 10 to 100 t/ha/yr, exceed soil formation rates by at least tenfold (Pimentel et al. 1987; Kendall and Pimentel 1994). Agriculture is leading to erosion, salination, or waterlogging. But it also has larger and longer-term consequences. Besides affecting other planetary boundaries such as biodiversity, water, and climate, changes in land use can also trigger rapid continental changes. One such example is the conversion of the Amazon rain forest into cattle ranching and land cultivated mainly for feed, where an additional small amount of conversion could tip the basin into an irreversible transformation to a semiarid savanna (Oyama and Nobre 2003; Foley et al. 2007). This is a crisis that may seriously affect not only the sustainability of the world's food supply but also the functioning of the global system.

1.2.5 Fifth Evidence of Limits: Biodiversity Loss

The scale of the human economy has grown so large that there is no longer room for all species in the ark (Box 1.2). The rates of habitat destruction and of species extinction have led to the sixth major extinction event in history, and the first one caused by human activity (Chapin et al. 2000). Since the beginning of the Anthropocene, the majority of the world's most species rich habitats, such as tropical forests and coral reefs, have been destroyed or significantly impacted. The extinction rate has increased between 100 and 1,000 times that of background levels and is projected to increase another tenfold before the end of this century (Mace et al. 2005; Rockstrom et al. 2009). About 25% of the existing

BOX 1.2 INEQUITY AND GROWTH

BRENDAN FISHER

The current economic textbook conviction is that income or wealth inequity is good for economic growth (Aghion et al. 1999, 1615). The idea of incentive-driven growth permeates the development and growth agenda so much that equity is rarely discussed in relation to economic growth. The works of Kaldor and Kuznets in the 1950s and 1960s seemed to help establish the idea that equity and growth could not be achieved simultaneously (Forbes 2000). Robert Solow's landmark work on growth theory added to the equity-blind growth agenda so ubiquitous today. The net result was the belief that (1) inequity induced growth, (2) growth would eventually reduce national inequity, and (3) by pursuing growth all nations would converge to the same growth path, hence reducing international inequity.

For his part, Kuznets (1955) found (to his surprise) that as Germany, the United Kingdom and the United States moved from agrarian to industrial societies, the income gap increased at first, peaked several decades after industrialization began, and then decreased as full industrialization approached. His *inverted U* relationship between income growth and equality eventually became known as the Kuznets Curve. Despite the fact that he cautioned that his results were "speculative," this relationship has come to represent the traditional growth path of nations.

Following similar assumptions, Kaldor (1958) formalized saving rates as an increasing function of real income and the idea that profits largely outweighed workers' savings. Building on this assumption, Kaldor (1967) used empirical data to show that productivity growth in the 1950s and 1960s in Organisation for Economic Co-operation and Development (OECD) countries was largely a function of investment behavior. The logic that capitalists and high-income earners had a greater *marginal propensity to save,* combined with the importance of investment for growth, led to the conclusion that inequality fostered growth.

Robert Solow's growth theory suggested that with low initial labor and capital productivity it was assumed that less developed countries (LDCs) would "grow" at a faster rate and would attract the bulk of international investment. This assumption remains today and is often invoked, along with the theory of comparative advantage, as the rational for liberalization policies (Stiglitz 2002, 59). The long-term result is a world without artificial barriers to trade, where both the developed countries and the LDCs would converge on the same growth path.

Taken together, these three streams of thought have helped to establish the equity blind growth prescription so ubiquitous today; but the theories that Kuznets, Kaldor, and Solow advanced do not stand up to recent empirical findings.

Recent data has shown the Kuznets Curve hypothesis is on shaky ground, particularly within many OECD nations that over the past 20 years have experienced a sharp increase in inequity despite strong economic growth (see Figure 1.2). Earnings inequality has accelerated most notably in the United States, the United Kingdom, Canada, Australia, and New Zealand (Aghion et al. 1999; Wade 2004a).

The bulk of more recent empirical work investigating Solow's idea of growth *convergence* has *generally* shown that (1) cross-country convergence has been nonexistent to minimal; (2) poor countries have not seen higher investment rates due to greater marginal return; and (3) inequality can hinder or promote economic growth in the near term but seems to come down on the side of hindering in the longer term.

The development policies of capital accumulation of the 1950s and 1960s, the end to import substitution projects by the International Monetary Fund (IMF) and World Bank in the 1980s (Wade 2004b), and the current neoliberal policies have all greatly affected the development landscape over the past 50 years, often ignoring (implicitly and/or explicitly) equity issues in pursuit of growth.

The vital role played by institutions in Japan and Korea's development (Skott and Auerbach 1995), the recent acknowledgment by the IMF that their liberalization policies may have exacerbated

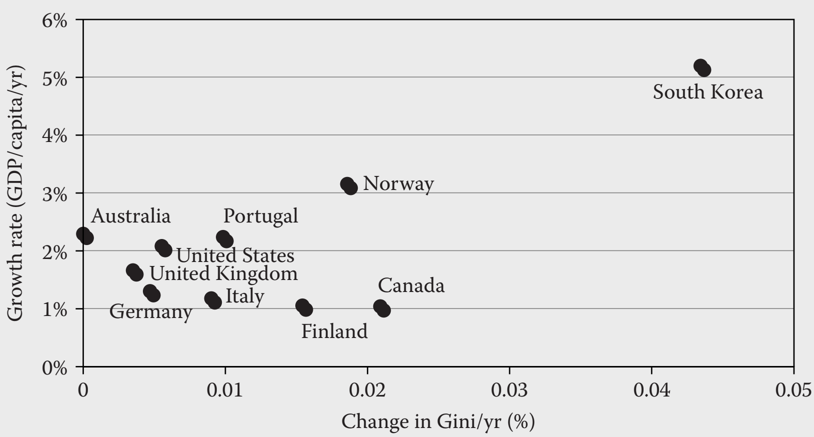

FIGURE 1.2
Changes in equity and growth rate for selected OECD countries since 1990 (positive changes in the gini coefficient represent worsening equity).

the 1997–1998 global financial crisis (Prasad et al. 2003), and the astounding fact that global poverty and inequity are likely to have worsened over the past 20 years of liberalization (see Wade 2004a for review) are all reasons why the current development policy prescriptions should be called into question. The positive growth-equity results in the past 20 years have been mainly the result of institutions, not markets (Wade 2004a), and the lessons of recent empirical work into growth and equity must find their way into economic policy.

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species are threatened with extinction. Much of the recent extinctions have occurred on the main continents due to land use changes, species introduction, and climate change.

Such dramatic changes in biodiversity have far-reaching implications for ecosystem functionality and services. The loss of certain species can increase the vulnerability of terrestrial and aquatic ecosystems to changes in climate and ocean acidity. In the long term, it can cause permanent changes in the biotic composition and functioning of Earth's ecosystems. It also increases the risks of overshoot. Built-in redundancy is a part of many biological systems, but we do not know how near we are to the thresholds. Nor do we know how the nonlinear Earth System will be affected once we reach tipping points.

1.2.6 Latest Evidence of Planetary Boundaries

1.2.6.1 Ocean Acidification

The oceans currently remove approximately 25% of human-emitted CO_2 through dissolution into the seawater and through uptake of carbon by marine organisms. However, this process increases the acidity of surface seawater, endangering critical ecosystem functionality. The rate of acidification is at least 100 times faster than at any other time in the last 20 million years. Currently, surface ocean pH has decreased by about 0.1 units relative to pre-industrial times (Guinotte et al. 2003; Feely et al. 2004; Orr et al. 2005; Guinotte and Fabry 2008; Doney et al. 2009).

Such an increase in acidity is affecting marine organisms sensitive to changes in the ocean's chemistry. For example, one of the first species that will be affected is coral. Reefs would undergo a shift in dynamics and species composition. Such changes are already occurring and are expected to reach quite critical levels by 2050 (Kleypas et al. 1999; Guinotte et al. 2003; Langdon and Atkinson 2005; Hoegh-Guldberg et al. 2007). Marine plankton are also very vulnerable, affecting the food chain all the way up.

However, it is the combination of acidification and warming ocean temperatures that is threatening to reduce the productivity of the reefs (Anthony et al. 2008) and other parts of the ocean. Placing multiple stressors on a system may have negative effects that are unpredictable and greater than just the sum of the individual stressors (Bellwood et al. 2004).

1.2.6.2 Freshwater Use

Today, humans have altered almost every river globally (Shiklomanov and Rodda 2003). Approximately 25% of global river flows never reach the ocean due to alternative uses (Molden et al. 2007). Groundwater aquifers are quickly being drained.

The loss of global freshwater affects not only the biodiversity of the river but also the food sources, health and security of the local community, climate regulation, and carbon sequestration. Estimates show that about 90% of the water that is absorbed by plants and evapotranspired, and 20%–50% of the water that flows through rivers, is necessary for the continued functioning of critical ecosystem services globally. The risks of crossing these thresholds may include the collapse of regional hydrology cycles. For example, consequences may include the shifting or shutting down of the monsoon system or the conversion of the Amazon rain forest to Savannah (Oyama and Nobre 2003).

1.2.6.3 Nitrogen and Phosphorus Cycles

Eutrophication due to human inputs of nitrogen and phosphorus has caused abrupt shifts in lakes (Carpenter 2005) and marine ecosystems (Zillén et al. 2008).

Human activities now convert more N_2 from the atmosphere into reactive forms than all of the Earth's terrestrial processes combined. Most of this new nitrogen is produced to enhance food production via fertilizers; however, the majority of it ends up in waterways and coastal zones. Nitrous oxide, on the other hand, is an important greenhouse gas.

Models suggest that the inflow of phosphorus into oceans exceeds natural background levels by eight to nine times. The additional inflow of phosphorous into the oceans has been suggested as the key driver behind global-scale ocean anoxic events, causing "dead zones" of marine life (Handoh and Lenton 2003).

Although nitrogen and phosphorus influence global subsystems independently, the interaction between the two can cause abrupt shifts in the subsystems of the Earth.

1.2.6.4 Atmospheric Aerosol Loading

Atmospheric aerosol loading has a critical effect on both the climate system and on human health at regional and global scales. Since the pre-industrial era, humans have doubled global concentrations of most aerosols (Tsigaridis et al. 2006).

The effects on the climate system can occur through various methods. Aerosols scatter incoming radiation back into space (Charlson et al. 1991, 1992) or indirectly influence cloud reflectivity and persistence (Twomey 1977; Albrecht 1989). They can also influence and change the mechanisms that form precipitation in clouds, altering the hydrologic cycle (Ferek et al. 2000; Rosenfeld 2000).

Human health is also significantly affected. Atmospheric aerosols are responsible for about 800,000 premature deaths and an annual loss of 6.4 million life years, mostly in Asian countries (Rockström et al. 2009). Besides human health and the global climate system, aerosols can also lead to crop damage, forest degradation, and loss of freshwater fish.

Reducing aerosol emissions will be difficult due to the variety of sources, impacts, and special and temporal dynamics. Also, many of the processes and mechanisms behind the impacts of aerosols are not fully understood (Box 1.3).

BOX 1.3 THE NEW CONSUMERS: THE INFLUENCE OF AFFLUENCE ON THE ENVIRONMENT

NORMAN MYERS

We hear much about China's booming economy. Not surprisingly, this has generated a sizeable middle class. At least 400 million Chinese have lifted themselves out of poverty to enjoy a measure of affluence—so too with India, though on a smaller scale with 240 million "new consumers." There are large-ish numbers of such people in Indonesia, Brazil, Mexico, Turkey, and Russia—in fact, 17 developing and three transition countries are populated by 1.4 billion people with a collective purchasing power far greater than that of the United States. Supposing there are no more financial meltdowns of late 1990s' type? They are likely to have increased their numbers by half and doubled their purchasing power during this decade. We are witnessing the biggest consumption boom in history.

The new consumers command sufficient income to buy household appliances of many sorts, notably refrigerators and freezers, washing machines and air conditioners, plus television sets and iPads—all the usual items that mark the "newly arrived." They are also shifting to a diet strongly based on meat, which they enjoy at least once a day instead of once a week at most. Still more importantly, they are buying cars in large numbers.

These three consumption activities have sizeable environmental impacts. First, household appliances are almost always run off electricity generated by fossil fuels—with all that implies for the build-up of carbon dioxide and other greenhouse gases in the global atmosphere, thus bringing on climate change. Secondly, meat is increasingly raised in major measure on grain, thus putting pressure on limited irrigation water and international grain supplies. Several countries import large amounts of grain for the primary purpose of feeding livestock rather than people, even though most of those countries are populated by many millions of malnourished people. Second, the new consumers possess one-fifth of the global car fleet, a proportion that is rising rapidly. At least one-seventh of CO_2 emissions worldwide comes from passenger cars—to the extent that the entire world community has an interest in all those new cars in new consumer countries (just as the new consumer countries have an interest in the far larger numbers of cars in developed countries). Fortunately, many new consumers can, if they feel inclined, purchase those cars that are more sparing in their CO_2 emissions, notably the Toyota Prius and the Honda Insight.

There are other negative repercussions from the burgeoning "car culture." In India, there are an estimated five million premature deaths each year because of air pollution, as much as 70% is caused by motor vehicles. Some 40 million people suffer the effects of asthma. Fortunately, there have been major efforts to improve air quality in New Delhi as well as in Beijing and Mexico City.

The bottom line: Can we persuade the new consumers to enjoy their high-flying lifestyles in a sustainable fashion? A first step in that direction is to recognize that consumption patterns will inevitably change in the future, if only by force of environmental circumstance (which is becoming ever more forceful). Second, we must try to modify consumption patterns around the world (the new consumers are unlikely to alter their consumption until the rich world consumers take solid steps to adapt their own consumption). Many observers believe that such patterns are set in concrete, but these may prove to be rather more malleable. For example, during a recent 20-year period, some 55 million Americans gave up smoking—a social earthquake, virtually overnight.

Most important of all is the need to establish sustainable consumption as a norm. Sustainable consumption will not only foster far more efficient use of materials and energy but will bring with it an acceptable quality of life for all in perpetuity. We should exemplify sustainable consumption throughout our lifestyles. How, for instance, can we attain a better balance between work and leisure, as between income and consumption? How can we prevent yesterday's luxuries from becoming today's necessities and tomorrow's relicts? How can we make fashion sustainable and sustainability fashionable? However hard it will be to live with the profound changes required, it will not be nearly so hard as to live in a world profoundly impoverished by the environmental injuries of current consumption.

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1.2.6.5 Chemical Pollution

The major forms of chemical pollution include radioactive compounds, heavy metals, and a wide range of organic compounds of human origin. Out of the 80,000 chemicals in commerce, 1,000 are known to be neurotoxic in experiments, 200 are known to be neurotoxic in humans, and five are known to be toxic to human neurodevelopment.

Different chemicals act differently within the Earth system. For example, some, such as mercury or DDT, can undergo long-range transport via ocean or atmospheric dynamics. Chronic, low-dose exposure may lead to subtle sublethal effects that hinder development, disrupt endocrine systems, impede reproduction, or cause mutagenesis. These are usually most visible in top predators and human populations.

1.3 Population and Poverty

Poverty stimulates population growth. Direct poverty alleviation is essential. Business-as-usual on poverty alleviation is irresponsible. MacNeill (1989) states it plainly: "…reducing rates of population growth…" is an essential condition to achieve sustainability. This is as important, if not more so, in industrial countries as it is in developing countries. Industrial countries overconsume per capita, consequently overpollute, and so are responsible for the largest share of our approach to the limits. The world's richest 20% have a personal consumption rate of more than 76% while the world's poorest 20% consume only about 1.5%, according to the World Bank in 2005. Many developed nations already have essentially stable population size, so it is not utopian to expect others to follow. Developing countries contribute to exceeding limits due to their increasing population size and because their populations are increasing far faster than their economies can provide for them. China's and India's economies, for example, have grown drastically since 1950, increasing 15 and 4.8 timesper capita, respectively, between 1950 and 2008. Such a dramatic increase in consumption rate in the two countries that have almost 40% of the world's population, combined, creates a situation that is unsustainable and potentially disastrous to the health of the global environment.

The poor will justifiably demand and must be assisted in reaching at least minimally acceptable material living standards through access to the remaining natural resource base. If industrial nations ever switch from input growth to qualitative development, more resources and environmental functions will be made available for the south's needed growth. It is in the interests of developing countries and the world commons not to follow the fossil fuel model of the industrial countries. It is in the interest of industrial countries to subsidize alternatives. This view is repeated by Dr. Qu Wenhu of the Chinese Academy of Sciences, who says: "... if 'needs' include one automobile for each of a billion Chinese, then it is impossible ..." (OTA 1991).

Merely stopping unintended pregnancies would go a long way to solving the problem. Approximately 40% of pregnancies in developing countries and 47% in developed ones are unintended. More than one-in-five births internationally are from pregnancies women did not wish to have. This means that if all unintended pregnancies were stopped, fertility would immediately fall slightly below the replacement level, and the world population would peak within a few decades and subsequently decline (Engelman 2011).

Providing women with the resources and control they need is not expensive. Meeting unmet demand for family planning would help enormously. Educating young females and providing them with employment opportunities are probably the next most effective measures. Certainly, international development agencies should assist high population growth countries to reduce to world averages as an urgent first step, instead of trying only to increase infrastructure without population measures.

1.4 Beyond Brundtland

The economic subsystem has grown excessively within the global ecosystem on which it depends. The regenerative and assimilative capacities of the global ecosystem's sources and sinks are being exceeded. If we continue with the growth called for by *The Brundtland Report*, we will dangerously exacerbate surpassing the limits outlined earlier. However, opinions differ. MacNeill (1989) claimed that "A minimum of 3% annual per capita income growth is needed to reach sustainability during the first part of the next century," and this would require higher growth in national income, given population trends. Hueting (1990) disagrees, concluding that for sustainability "... what we need least is an increase in national income." Sustainability will be achieved only to the extent quantitative throughput growth stabilizes and is replaced by qualitative development, holding inputs constant or even reducing them. Remembering that the scale of the economy is population times per capita resource use, both per capita resource use and population must stabilize or decline.

The Brundtland Report was excellent on three of the four necessary conditions for sustainability: first, producing more with less (e.g., conservation, efficiency, technological improvements, and recycling); second, reducing the population explosion; and third, redistribution from overconsumers to the poor. Brundtland was probably being politically astute in leaving fuzzy the fourth necessary condition. This is the transition from focusing on the scale of the economy and input growth to qualitative development, holding the scale consistent with the regenerative and assimilative capacities of global life-support systems. In several places *The Brundtland Report* hints at this. Qualitatively improved assets replace depreciated assets, and births replace deaths, so that stocks of wealth and people are continually renewed and even improved (Daly 1990b). A developing economy is one that is getting better, not necessarily bigger, so that the well-being of the (stable) population improves. An economy growing in throughput is mainly getting bigger, exceeding limits, and damaging the self-repairing capacity of the planet.

The poor need an irreducible minimum of basics: food, clothing, shelter, and security. These basics require throughput growth for poor countries, with compensating reductions in such growth in rich countries. Apart from colonial resource drawdowns, industrial country growth has historically increased markets for developing countries' raw materials, hence benefiting poor countries. But it is industrial country growth that has to contract to free up ecological room for the minimum growth needed in poor country economies. Tinbergen and Hueting (1991) put it plainest: "… no further production growth in rich countries …." All approaches to sustainability must internalize this constraint if the crucial goals of poverty alleviation and if halting damage to global life-support systems are to be approached.

1.5 Toward Sustainability

We must shift rapidly to a form of production that is less throughput-intensive. We must accelerate technical improvements in resource productivity, Brundtland's "producing more with less." Presumably this is what the Brundtland Commission and subsequent follow-up authors (e.g., MacNeill 1989) label "growth, but of a different kind." It is also largely true that conservation and efficiency improvements and recycling can be made profitable the instant environmental externalities (e.g., carbon dioxide emissions) are internalized.

But this approach, although necessary, will be insufficient (Goodland 1995) because of the inescapable laws of thermodynamics, which state that all material growth consumes resources and produces wastes—even Brundtland's unspecified new type of growth. First, to the extent we have reached the ecosystem's regenerative and assimilative capacity limits, throughput growth exceeding such limits will not herald sustainability.

Second, the size of the service sector relative to the production of goods has limits. Third, many services are fairly throughput-intensive, such as tourism, higher education, and health care. And fourth, less throughput-intensive growth is "hi-tech." This means that developing countries, where growth is needed most, are least likely to be able to afford Brundtland's "new" growth.

1.6 The Fragmentation of Economics and the Natural Sciences

Before tackling the difficult questions raised in the previous sections, let us first analyze why they are such difficult questions in the first place. A large part of the problem lies in the way we have organized our intellectual activities. The problems outlined earlier are global, long-term, and they involve many academic disciplines—especially the connections between disciplines. The academic disciplines are today still very isolated from each other and this contributes to the difficulty of addressing the questions posed here. But it was not always so.

Until roughly the beginning of the twentieth century, economics and the other sciences were relatively well integrated. There were relatively few scientists then, and one could argue that they had to talk across disciplines just to have someone to talk to. But then there was a shift in worldview. Newtonian physics became the dominant academic paradigm. Its view of the world as linear, separable, mechanical subsystems that could be easily aggregated to yield the behavior of the whole system encouraged the fragmentation of science into separate disciplines. There was also the size problem. As academia and the total body of knowledge grew, it became increasingly difficult to deal with it as a whole. For convenience, it had to be ever more finely subdivided.

The next chapter of the book traces the early, prefragmentation history of economics and the "natural" sciences as they continually interacted with each other. Ecology emerged only in the mid-twentieth century as a science centered around the ideas of holism and system integration. It departed from the Newtonian physics model to develop a worldview that is adapted to deal with complex living systems. It is evolutionary and nonlinear and acknowledges the inability to scale by simple aggregation (Costanza et al. 1993). "Ecology" in this sense is becoming the dominant scientific paradigm, and it is an inherently interdisciplinary, "systems" perspective. Ecological economics represents an attempt to recast economics in this different scientific paradigm, to reintegrate the many academic threads that are needed to weave the whole cloth of sustainability.

2

The Historical Development of Economics and Ecology

As recently as three hundred years ago, philosophers built systemic, logical arguments with respect to the nature of the cosmos, social order, and moral duty. Empiricism was largely associated with the description of broad geographical differences among regions and cultures. The sciences as we now know them arose with the joining of systemic thinking and empirical analyses of different aspects of the natural world. Francis Bacon (1561–1626) argued for joining logic and empiricism. With telescopic observations, Galileo Galilei (1564–1642) provided evidence in support of the sun-centered systemic theory of Nicolaus Copernicus (1473–1543). Discrepancies between Copernicus' theory and astronomical observations were resolved by Isaac Newton (1642–1727) through his theoretical advances with respect to gravity and the mechanics of motion. Thereafter, scientific disciplines began to arise, defined by the subject matter to which logical thinking was applied rather than by the patterns of logic used. Nevertheless, for several centuries, scholars continued to work across broad areas of knowledge. Newton wrote about religion and morals as well as physics. John Locke (1632–1704) contributed to medical knowledge and the revival of the idea of atoms even though his most important contributions were to social philosophy. This scholarly tradition of contributing across disciplines lasted through the nineteenth century. Well into the twentieth century, many scholars maintained an awareness of developments beyond their specialty. Frank Knight (1895–1973), for example, expounded at some length on recent developments in physics and their implications for economic theory and methodology (Knight 1956). By the latter half of the twentieth century, however, transdisciplinary scholarship was extremely rare.

Economics arose in the midst of the transdisciplinary tradition. During the second half of the eighteenth century, at a time of great social change and scientific promise, the formal field of economics emerged from moral philosophy (Canterbury 1987; Nelson 1991). Long-standing moral questions with respect to the obligation of individuals to larger social goals were being challenged by the development of markets and scientific advances, both of which brought new opportunities for personal material improvement and fueled great hopes for a plentiful future.

Then, in the second half of the eighteenth century, as today in the twenty-first century, people were concerned that following one's own self-interest might hurt society as a whole. Economists began to argue, as they continue to do, that markets guided individual behavior as if by an "invisible hand" to the common good.

In the nineteenth century, the formal field of ecology arose from biology and natural history. Like economics, it too was concerned with how systems as a whole could work for the common good of the species that composed them. The two disciplines share some theoretical features and at various times each has drawn on advances in the other. How two conceptually complementary fields, such as ecology and economics, have become associated with such opposing prescriptions for how people should interact with their environment is a fascinating story (cf. Page 1995).

And it is a story that must be understood for ecological economics to emerge from the separate disciplines. The sections in this chapter briefly document some of the historical development of the two disciplines of economics and ecology, showing how they have learned from each other and explaining how they have evolved such different environmental prescriptions from shared conceptual bases. The two disciplines differ markedly in that economics, especially in the United States and as practiced through the international agencies, is conceptually monolithic, while ecology consists of many competing and complementary conceptual frameworks. Similarly, *environmental* economics (a subdiscipline of economics concerned with environmental problems) today presents itself as a single, grandly conceived, coherent theory. The following sections explain how today's environmental economics was constructed from earlier economic theories although the assumptions that drive the theories to policy conclusions are rooted in popular beliefs about nature and technical progress. The earlier theories, which were once very influential within economics, are central to environmental understanding today. Ecology, in addition to maintaining its diverse theoretical roots, also contrasts with economics in that it has combined with quite a different, yet still popular, set of beliefs about nature and technology.

A few of these popular beliefs have long histories. Until 300 years ago, material security was thought to be one of the rewards of moral conduct. Increasingly after the Renaissance, however, it was argued that material security was needed to establish the conditions for moral progress. Scarcity caused greed and even war; scarcity forced people to work so hard that they did not have time to contemplate the Scriptures and live morally. Material progress, in short, was necessary to establish the conditions for moral progress. Thus, as modern economic thought emerged in the eighteenth century, the individual pursuit of materialism was justified on the presumption that once the basic material needs of food, shelter, and clothing were met, people would have the time and conditions to pursue their individual moral and collective social improvement. Today, these earlier concerns with moral and social progress have largely been forgotten while individual materialism for many people has become an end in itself.

In the eighteenth century, as now, technological optimists were convinced that the essentials of life would eventually be assured through the advance of human knowledge leading to a mastery of underlying natural laws and, consequently, dominion over nature. The presumption has been that such laws are relatively few in number and that their mastery would make superfluous our dependence on the particular ways that nature, and people's place therein, evolved. To those only concerned with material well-being, the expectation of such mastery meant that people did not have to be concerned with long-term scarcities or with how their activities otherwise might affect the future (Simon 1981b). Over the past three centuries, scientists have touted the eventual mastering of nature and have justified research on this basis. The book *Scarcity or Abundance? A Debate on the Environment* by Myers and Simon (1994) exposed these two distinct arguments: Myers represents the broad scientific consensus that unchecked human population growth and biodiversity loss are potentially serious problems that we must address because their impacts, although uncertain, are potentially huge and irreversible. Simon represents an extreme technological optimist position (a small minority among scientists) that we do not need to worry because the future will take care of itself just as it always has. The fundamental differences between Simon and Myers are not technical; they are differences of vision. Myers envisions a physically finite planet that we must manage for sustainability. Simon envisions a world of no constraints (except the number of people) where humanity is ultimately freed from its earthly bonds to explore and colonize the universe at will forever (Costanza 1995). The idea that scientific progress will inevitably lead to the control of nature and material plenty is still popularly held and frequently invoked, even by scientists, to support further population increases, technological change, and economic development along their historic, environmentally destructive, unsustainable paths.

Economic thought evolved in the context of these dominant moral, material, and scientific beliefs. Reality, however, does not always unfold as expected; the social and environmental problems associated with economic growth have dampened earlier dominant beliefs and empowered other interpretations. Natural historians and then ecologists have long harbored concerns about the wisdom of human transformation of natural environments. Most scientists no longer think of the world as a system that will soon be understood and brought under control. Rather, the world is an evolving, complex, and uncertain system. With less confidence in their ability to predict and prescribe, scientists tend to be more humble and take a precautionary approach. Most notable among them are environmental scientists, ecologists, and conservation biologists who argue that we need to direct the best of our scientific expertise and far more of our educational effort at learning how to work *with* nature (Ehrenfeld 1978; Meffe 1992). Similarly, environmental ethicists are challenging the vacuity of individual material progress for its own sake. Also, a growing number of economists and positive psychologists have stressed the importance of subjective well-being (SWB) or happiness measures to the assessments of overall well-being (Clark and Oswald 1994; Easterlin 1995; Diener and Suh 1997; Oswald 1997; van Praag and Frijters 1999; Diener 2000; Frey and Stutzer 2002; Gowdy 2005; Layard 2005). Although economic thought is also beginning to evolve in the context of these newer understandings, the historical beliefs remain dominant within the profession as a whole and still influence environmental economics.

As the following chapters highlight, throughout most of their historical development economics and the natural sciences interacted extensively. Of course, there were fewer scientists then and the specialization and fragmentation that characterize modern academia had not yet occurred to the degree it has today. Ecological economics represents an attempt to recapture the spirit of integrated, interactive analysis of problems that defined the early history of science. It is only through this reintegrated analysis that we can hope to comprehend and solve our most pressing and complex social problems.

The sections that follow give a brief overview of the historical development of economics and the natural sciences, especially ecology. Each section is structured around a prominent individual who began a line of inquiry that has been continued and elaborated by subsequent scholars to this day. These lines have tangled over the years and ecological economics attempts to reorganize them into a coherent whole. Figure 2.1 shows the life spans of the various individuals we mention on a time line.

2.1 Early Codevelopment of Economics and Natural Science

> There has been no revolution in economic science, and [there] is not likely to be any. The question we have really to determine is how we can make the best use of the accumulated knowledge of past generations, and to do that we must look more closely into the economic science of the 19th century.
>
> **William A. S. Hewins 1911**

Among the natural sciences, ecology was a "late bloomer." People interested in biology described natural environments and contemplated how

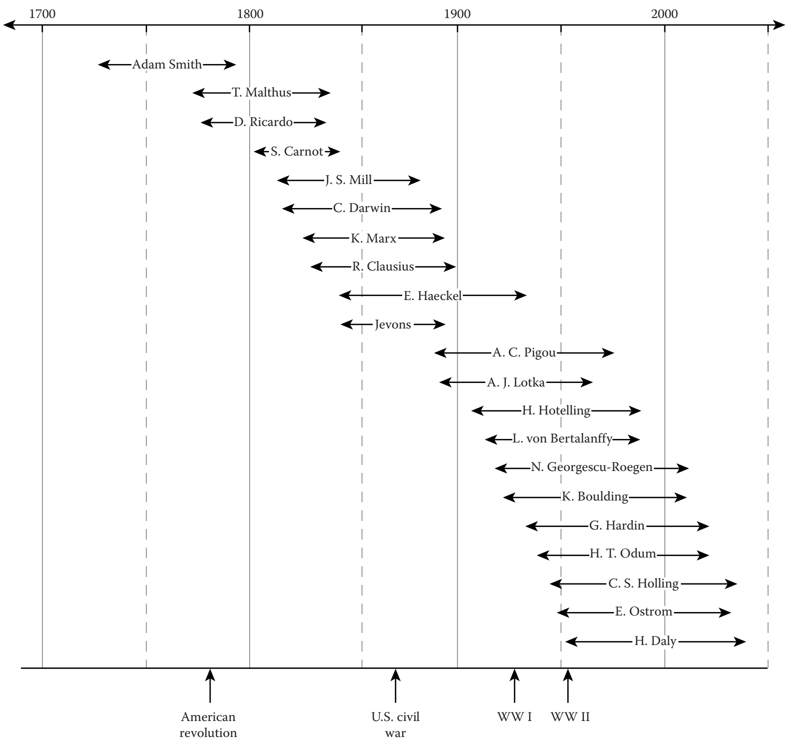

FIGURE 2.1
Life spans of the individuals mentioned in the text.

biological systems developed historically, but such empirical descriptions were not combined with systemic thinking until the second half of the nineteenth century. Thus our story starts with economics.

The "physiocrats," a group of French social philosophers writing in the mid-eighteenth century, were the first school of economics. They believed that the universal laws of physics (hence the school's name) extended their grand rule in some yet to be identified way to create a natural social order. This social order was made up of people with sovereign rights entitled to the produce of their labor. According to the physiocrats, real economic activity consisted of working the land. Food wholesalers, processors, and retailers were simply living off the fruits of farmers and their take should be minimized. The belief that natural law determines social order has taken many forms since the physiocrats, and it inevitably generates controversy. The physiocrats never identified how the laws of physics applied to economic systems, but their insistence on treating individuals as sovereign entities, like atoms, in the tradition of key liberal social philosophers such as Hobbes and Locke who assumed that society is merely the sum of its individuals, has stayed with mainstream economics ever since. Although subsequent economists never discovered how the laws of physics ruled economies, they did duplicate the pattern of thinking of mechanics in their conception of market interactions. Adam Smith initiated this pattern of reasoning.

2.1.1 Adam Smith and the Invisible Hand

Adam Smith (1723–1790), widely recognized as the founder of modern economics, was a moral philosopher. Although the field of economics has assumed a heavy scientific gloss since Smith, critical ethical issues have always been embedded in its theory. And the key ethical issue has always been whether the pursuit of individual greed can be in the interest of society as a whole. Smith reasoned that if two people who are fully informed of the consequences of their decision choose to enter into an exchange, it is because the exchange makes each of them better off. Appealing to Judeo-Christian images of God, Smith invented the metaphor of the "invisible hand," arguing that markets induce people to behave for the common good *as if* they were guided by a higher authority.

Modern economics typically continues to assume that society is simply the sum of its individuals, the social good is the sum of individual wants, and markets automatically guide individual behavior to the common good. By the end of the nineteenth century, the market model had been formalized mathematically, and it turned out to be the same mathematics as used by Newton for mechanical systems. This atomistic view of individuals and mechanistic view of a social system contrasts sharply with the more organic, or ecological, view that community relations define who people are, affect what they want, facilitate collective action, and have a historical continuity of their own. Although Adam Smith was a moral philosopher, his economics made morality less important. For most of human history, people's sense of identity has come through living within a community and its moral precepts. Today, this is increasingly less important among either the materially wealthy or aspirants to material wealth (and may indeed account for their frequent visits to the psychiatrist). Among the multiplicative factors affecting environmental degradation, the role of materialism and its relation to moral behavior is rarely discussed and is in need of broader, more serious scientific and public discourse. We discuss these points in later sections.

The growth of individualism and materialism associated with modernity and the consequent decline in community and concern with moral conduct are not Adam Smith's fault, but he played a decisive role in setting up the reasoning that justified individual greed (Lux 1990). In an age when Europeans and North Americans were rebelling against the tyranny of church and state and social philosophers were building theories from the individual up to the society rather than from society down to the individual, Adam Smith argued that markets link individual greed to the common good without coercive social institutions. And ever since Smith, the critical question, if too rarely discussed, has been whether markets really do this as well as he believed. One glaring contradiction is that the economic model of society argues that individual behavior supports the common good while simultaneously arguing that communities are not needed because markets will provide for the common good. The issues of market and community were addressed at the end of the twentieth century by a variety of scholars who argued that communities are necessary at different geographic scales to define the social good, adapt the social order, and to manage environmental systems (Daly and Cobb 1989; Bellah et al. 1991; Etzioni 1993; Norgaard 1994).

2.1.2 Thomas Malthus and Population Growth

The cleric-turned-economist Thomas R. Malthus (1766–1834) explained the prevalence of war and disease as secular, material phenomena rather than acts of God. He argued that human populations were capable of increasing exponentially and would do so as long as sufficient food and other essentials of life were available (Malthus 1963 [1798]). He further hypothesized that people could expand their food supply arithmetically through new technologies and expansion into new habitats. Given the potential for geometric increases in population and only arithmetic increases in food supply, population periodically surpasses food supply (Figure 2.2). At these times, Malthus argued, people would ravage the land, go to war over food, and succumb to

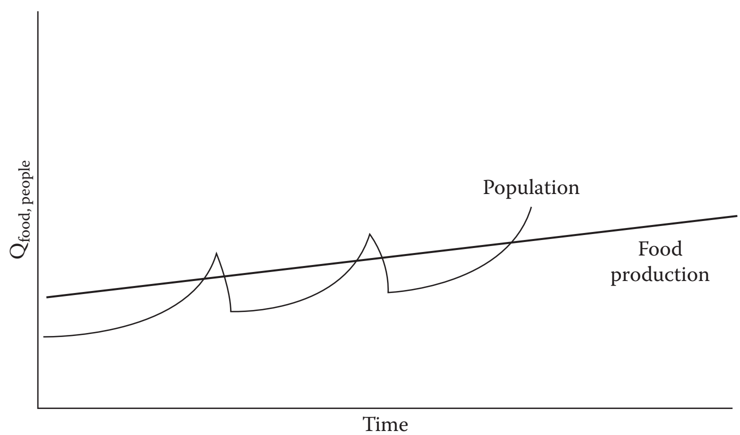

FIGURE 2.2
Thomas Malthus's model of population growth and collapse.

disease and starvation. Human numbers would consequently drop to sustainable levels whence the process would repeat. This basic model from economics is still widely used today by biological scientists.

Malthus's model is beguilingly simple and, consequently, demographic history never quite supports it precisely. Yet periodically in specific places, Malthus's model has been confirmed, and history may yet confirm it globally. Few question whether population must ultimately stabilize in order to sustain human well-being at a reasonable level. The expansion of human populations into previously unpopulated or lightly populated regions, the intensity with which firewood is collected, and the push to increase food production through modern genetically engineered, agrochemical, monocultural techniques, so harmful to biodiversity, are driven over the long run by population increase. The continued rapid rate of population growth in the poorest nations threatens to keep them poor while diminishing the possibilities that the people of these nations will ever be able to consume at levels comparable to people in the rich nations using current modern technologies without vastly accelerating environmental degradation.

Malthus's model has become a part of human consciousness, making it difficult to contemplate—let alone discuss—the issues of population and its effects on the environment without his framing becoming central to the discussion. The success of Malthus's model stems from its simplicity, but the dynamics of population growth and how people depend on the environment are much more complex than the model suggests. Thus, although Malthus provided us with a powerful model, its simplicity restricts its usefulness for policy making beyond the obvious prescription that fewer people would probably be better for sustainability than more people.

In addition to his influence on economic and demographic thought, Malthus had an enormous influence on other key intellectual figures. Charles Darwin and Alfred Russell Wallace credited Malthus with providing them the key insight that led them to the theory of natural selection. Marx developed many of his views in opposition to Malthus. Even John Maynard Keynes (1883–1946) was influenced by Malthus's theory and incorporated it in a theory of underconsumption, inventory buildups, and the business cycle.

2.1.3 David Ricardo and the Geographic Pattern of Economic Activity

David Ricardo (1772–1823) introduced a second model of how economic activity relates to the environment. He was not concerned with environmental degradation or human survival but rather wished to justify why landlords received a rent from land ownership (Ricardo 1926). Ricardo argued that people would initially farm the land that produced the most

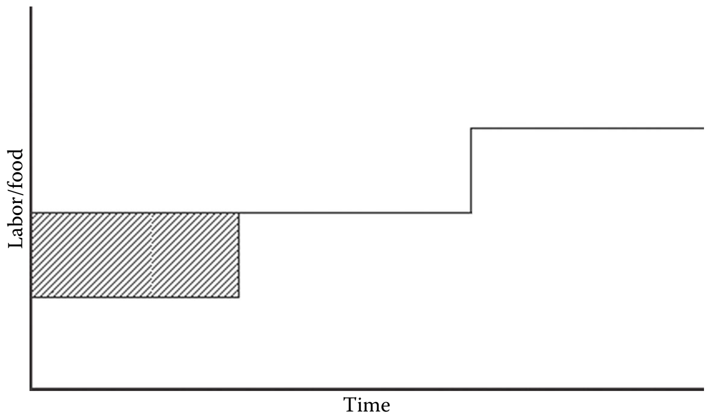

FIGURE 2.3
Ricardo's explanation of rent, represented by the shaded area.

food for the least work (labor per unit of food, the y-axis of Figure 2.3). As population increased, farming would *extend* to less fertile soils requiring more labor (the extensive margin). Food prices would have to rise to cover the cost of the extra labor on the less fertile land. This means that the initial land would earn a rent, a return above production cost, indicated by the shaded area in Figure 2.3. Higher food prices, in turn, would also induce a more *intensive* use of labor on the better land (the intensive margin). This model indicates how increasing population drives people to farm in previously undisturbed areas and how higher food prices lead to the intensification and, in modern agriculture, to the greater use of fertilizers and pesticides on prime agricultural lands. This model also gives us insights into how fluctuations in food prices can result in the periodic entry and exit of farmers on the extensive margin and in shifts in farming practices on the intensive margin. Ricardo's model of how agricultural activities are patterned on the land in response to population growth and changes in food prices is critical to our understanding of the complex interrelations between human survival and ecological life-support systems.

Ricardo's model of resource use patterns is similar to how those in the earth sciences think about the use of mineral resources. Petroleum geologists and mineralogists often presume, just as Ricardo did, that the best quality resources are used first even though history shows that a significant portion of the best quality resources are frequently not discovered until poorer quality resources have already been used.

The models of Malthus and Ricardo led to classical economics being called the "dismal science." The carrying capacity limits of Malthus's model and the lower quality of the next available resources in the model of Ricardo conflicted with the beliefs in progress that were so prevalent during the nineteenth century. The Ricardian theory of differential rent also had dismal distributive consequences because an increasing share of the total product of the land went to landlords.

These models have been touted by environmental scientists concerned about population growth, excessive consumption, and environmental degradation, and have been argued against by mainstream economists. During most of the twentieth century, economists built new models with different assumptions in combinations that support beliefs in unlimited material progress.

2.1.4 Sadi Carnot, Rudolf Clausius, and Thermodynamics

Sadi Carnot (1796–1832) founded thermodynamics with his classic 1824 study of the efficiency of steam engines, *Reflections on the Motive Power of Fire*. Carnot was the first to recognize that the amount of work that could be extracted depended on the temperature gradient between the source and sink. He effectively identified what were to become formalized as the laws of thermodynamics by Rudolf Clausius (1822–1888) a quarter century after Carnot's death. The first law of thermodynamics states that energy can neither be created nor destroyed. The second law, also known as the entropy law, states that the amount of energy available for work in a closed system only decreases with use. The laws of thermodynamics are frequently invoked in the construction of models of ecosystems and have been extended to models of human–environment interactions as well (Georgescu-Roegen 1971; Odum 1971; Hannon 1973; Costanza 1980).

The second law effectively makes physics the dismal science for it states that the total useful energy in the universe—the amount of work remaining that can be done—is constantly declining. Because any action requires energy, any activity today is at the expense of potential activity in the future. What hope is there for progress in a constantly degrading universe? This question has been pursued again and again for well over two centuries. Whether and how it is resolved depends on how fast the entropy of the universe is increasing and just how far into the future we are concerned (see Norgaard 1994, 213–216 for a history of concern motivated by the broader implications of the second law).

An important point to remember, however, is that the Earth is an "open" system, and even if the entropy of the universe is increasing, the entropy of Earth may be declining (by a smaller amount, of course). (The study of the thermodynamics of open, nonequilibrium systems came much later, and we discuss it further on in Section 2.3.) The critical relevance of entropy to economics was first emphasized by Nobel Laureate chemist and underground economist Soddy (1921, 1933) and later developed much more fully by Georgescu-Roegen (1971).

DUALIST ECONOMICS

HERMAN DALY

Frederick Soddy (1877–1956) discovered the existence of isotopes and was a major contributor to atomic theory, for which he received the Nobel Prize in Chemistry in 1921. He foresaw the development of an atomic bomb and was disturbed by the fact that society often used the contributions of science (for which he was partly responsible) for such destructive purposes. The reason for this was, in his view, faulty economics; therefore in the second half of his 80 years he set out to reform economics. He was the first person to coherently lay out the policy of 100% reserve banking, later taken up by the Chicago School economists and by Irving Fischer of Yale—and still an excellent, although ignored, idea. Soddy was considered an outsider and a "monetary crank" by mainstream economists. Nevertheless, his views on money are sound and highly relevant to today's financial debacle ("Nationalize Money, Not Banks", http://www.positivemoney.org/2012/08/nationalize-money-not-banks-by-herman-daly/). As argued here, his philosophical vision of the place of economics in the larger intellectual map of the world is another neglected but increasingly relevant contribution.

For Soddy, economics occupies the middle ground between matter and spirit, between the electron and the soul, as he put it:

> In each direction possibilities of further knowledge extend ad infinitum, but in each direction diametrically away from and not towards the problems of life. It is in this middle field that economics lies, unaffected whether by the ultimate philosophy of the electron or the soul, and concerned rather with the interaction, with the middle world of life of these two end worlds of physics and mind in their commonest everyday aspects, matter and energy on the one hand, obeying the laws of mathematical probability or chance as exhibited in the inanimate universe, and, on the other, with the guidance, direction and willing of these blind forces and processes to predetermined ends. (*Cartesian Economics*, 6)

Soddy did not mean that economists should neglect the two end worlds of electron and soul—much to the contrary—he insisted that wealth must reflect the independent reality of both end worlds. What must be resisted is the "obsessive monism" of either idealism or materialism. We must recognize the fundamental dualism of the material and the spiritual and resist attempts to reduce everything to one or the other.

Wealth has a physical dimension—matter–energy subject to the laws of inanimate mechanism, especially to the laws of thermodynamics—and a teleological dimension of usefulness, subject to the purposes imposed by mind and will. Soddy's concept of wealth reflects his fundamental dualism and is why his first lectures on economics were entitled *Cartesian Economics*, meaning in effect, "Dualist Economics" (not, as might be imagined today, economics diagrammed in terms of Cartesian coordinates). The subtitle of his lectures, *The Bearing of Physical Science on State Stewardship*, better reflects his dualism in the contrast between "physical science" and "stewardship."

Philosophically, Rene Descartes accepted dualism as a brute fact even though the interaction of the two worlds of mind and matter, of soul and body, of *res cogitans* and *res extensa*, remained mysterious. Subsequent philosophers have in Soddy's view succumbed to monistic reductionism, either materialism or idealism, both of which encounter philosophical problems no less grave than dualism as well as provoke greater offenses against common sense and direct experience. It is fashionable to reject dualism nowadays by saying that humans are a "psychosomatic unity" even while recognizing a "polarity" within that unity. Nevertheless, the two poles of electron and soul are very far apart, and the line connecting them is, as Soddy argued, twice discontinuous. Although we are surely in some important sense a "unity," it would be good to recognize the legitimate claims of dualism by writing the word "psycho—somatic" with a long double hyphen (Figure 2.4).

Soddy's view can be represented by a vertical line connecting the electron (physical world, useful matter–energy, ultimate means) at the bottom to the soul (will, purpose, ultimate end) at the top. In the middle is economics (efforts in ordinary life to use ultimate means to serve the ultimate end). Soddy did not draw such a diagram, but it is implicit in his writing. The vertical connecting line has two mysterious discontinuities that thwart monistic attempts to derive soul from electron or electron from soul. The first discontinuity is between inanimate mechanism and life. The second discontinuity is between life and self-conscious mind (will, soul). Monists keep trying, and failing, to leap over both chasms. Dualists accept them as irreducible brute facts about the way the world is.

Dualists use the axiom of duality to interpret other phenomena instead of vainly pursuing the illusion of reductive monism. Nowadays, the dominant monistic obsession is materialism,

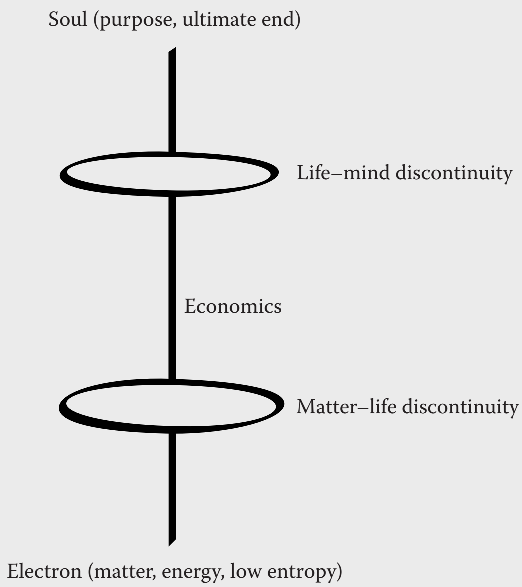

FIGURE 2.4
Soddy's dualist economics.

supported by the impressive successes of the physical sciences and the lesser but still impressive extrapolations of Darwinist biologism. Idealism does not have so much support at present, although modern theoretical physics and cosmology seem to be converting electrons and elementary matter into mathematical equations and strange Platonic ideas that reside more in the minds of theoretical physicists than in the external world, thus perhaps bending the vertical line connecting mind and matter into something more like a circle. Also, a Whiteheadian interpretation of the world as consisting most fundamentally of "occasions of experience" rather than substances is a way to bridge dualism, but once again only with the help of widely separated "polarities." Although these are challenging and important philosophical developments, it remains true that materialism currently retains the upper hand and is claiming an ever-expanding monistic empire, including the middle ground of economics. In addition, physics' modern revival of idealism so far seems morally vacuous—among the equations and Platonic ideas of modern physics one does not find ideas of justice or goodness, or even purpose, so the fact-value dimension of dualism remains.

As Soddy insisted, economics occupies the middle ground between these dualistic extremes. Economics in its everyday aspects remains largely "unaffected whether by the ultimate philosophy of the electron or the soul," but this may be the big weakness of economics, the myopia that leads to its growth forever vision. Each end world reflects unrecognized limits back toward the middle world—limits of possibility from below and limits of desirability from above. Economics seems to assume that if it is possible it must be desirable, indeed practically mandatory. Similarly, if it is desirable it must be possible. So everything possible is considered desirable, and everything desirable is considered possible. Ignoring the mutually limiting interaction of the two end worlds of possibility and desirability has led economists to assume permissiveness to growth of the middle world of the economy that is proving to be false. For Soddy, this is reflected concretely in the economy by our monetary conventions—fractional reserve banking, which allows alchemical creation of money as interest-bearing private debt.

> You cannot permanently pit an absurd human convention, such as the spontaneous increment of debt [compound interest], against the natural law of the spontaneous decrement of wealth [entropy]. (*Cartesian Economics*, 30)

Debt is confused with wealth. But unlike debt, wealth has a physical dimension that limits its growth. This reflects mainly a misunderstanding of the physical world and its limits on wealth. But Soddy also saw limits coming from the world of the soul.

> Just as I am constrained to put a barrier between life and mechanism in the sense that there is no continuous chain of evolution from the atom to life, so I put a barrier between the assimilation and creation of knowledge. (*Cartesian Economics*, 28)

For Soddy, the assimilation of knowledge was mere mimicry and was discontinuous with the creation or discovery of new knowledge, which he saw as involving a spiritual top down influence from the soul, from the mysteriously self-conscious mind that could not be derived from mere animate life by a continuous chain of evolution. Soddy said little about the life–mind discontinuity relative to the matter–life discontinuity, but it was clearly part of his philosophy and has come to the fore in modern philosophical debates about the "hard problem of consciousness."

For the mechanistic biologists, who were already around in his day, Soddy had the following barbed comment:

> I cannot conceive of inanimate mechanism, obeying the laws of probability, by any continued series of successive steps developing the powers of choice and reproduction any more than I can envisage any increase in the complexity of an engine resulting in the production of the "engine-driver" and the power of its reproducing itself. I shall be told that this is a pontifical expression of personal opinion. Unfortunately, however, for this argument, inanimate mechanism happens to be my special study rather than that of the biologist. It is the invariable characteristic of all shallow and pretentious philosophy to seek the explanation of insoluble problems in some other field than that of which the philosopher has first hand acquaintance (*Cartesian Economics*, 6).

To generalize a bit, monists, who deny the two discontinuities, seek to solve the insoluble problems that they thereby embrace, by shallowly and pretentiously appealing to some other field than that of which they have first-hand experience. This is a serious indictment—is it true? I will leave that question open but will note on Soddy's behalf that, regarding the matter–life discontinuity, Francis Crick evidently thought it more likely that first life arrived from outer space (directed panspermia) than that it formed spontaneously from inanimate matter on Earth, given the demonstration by Pasteur and Tyndall that "spontaneous generation is not occurring on the earth nowadays." And, as already mentioned, a number of philosophers and neuroscientists (including John Eccles and Karl Popper) have declared the life–mind discontinuity unbridgeable.

The relevance of Soddy's dualistic economics to steady-state economics is that there are two independent sets of limits to growth, the biophysical and the ethical–economic. The biophysical limit says real GDP cannot grow indefinitely; the ethical–economic limit says that beyond some point GDP growth ceases to increase welfare (and even decreases it) although it may still be biophysically possible. Soddy was truly a pioneer in ecological economics, the middle ground between the electron and the soul. Unlike mainstream economists, ecological economists can proudly claim a *real* Nobel laureate among our ancestors!

2.1.5 Charles Darwin and the Evolutionary Paradigm

Charles Darwin (1809–1882) was influenced by the economic arguments of Malthus as he began thinking about the question: Why are there so many different types of plants and animals? After years of observing the natural and human-dominated ecosystems of his time (most notably as a naturalist aboard the H.M.S. *Beagle* on its voyage around the world in 1831–1836) and thinking about this question, he arrived at what to him seemed the only possible explanation. His answer, which has come to be a cornerstone of modern biology and ecology, was that species evolve by the processes of adaptation and natural selection. Population pressure, associated with the ability of species to expand their numbers to the carrying capacity of their environment, favored the survival of those individuals with the particular characteristics that made them more effective at reproducing themselves.

Darwin waited until late in his professional career to publish his findings. His *On the Origin of Species by Natural Selection* was first published in 1859 when the author was 50 (the same year, by the way, as Karl Marx's *Critique of Political Economy*). Darwin was immediately attacked by those holding what was then the mainstream view of "divine creation." The evolutionary paradigm continues to be attacked to this day by those espousing "creationism," but, in spite of its gaps, no other theory possesses anything approaching the explanatory power of evolution.

Since Darwin's day, the paradigm of evolution has been tested and broadly applied to ecological and economic systems (Boulding 1981; Arthur 1988; Lindgren 1991; Maxwell and Costanza 1993) as a way of formalizing our understanding of adaptation and learning behaviors in non-equilibrium dynamic systems. The general evolutionary paradigm posits a mechanism for adaptation and learning in complex systems at any scale using three basic interacting processes: (1) information storage and transmission; (2) generation of new alternatives; and (3) selection of superior alternatives according to some performance criteria.

The evolutionary paradigm is different from the conventional mechanical paradigm of economics in at least four important respects (Arthur 1988): (1) evolution is path dependent, meaning that the detailed history and dynamics of the system are important; (2) evolution can achieve multiple equilibria; (3) there is no guarantee that optimal efficiency or any other optimal performance will be achieved due in part to path dependence and sensitivity to perturbations; and (4) "lock-in" (survival of the first rather than survival of the fittest) is possible under conditions of increasing returns. Although, as Arthur (1988) notes, "conventional economic theory is built largely on the assumption of diminishing returns on the margin (local negative feedbacks)," life itself can be characterized as a positive feedback, self-reinforcing, autocatalytic process (Kay 1991; Günther and Folke 1993), and we should expect increasing returns, lock-in, path dependence, multiple equilibria, and suboptimal efficiency to be the rule rather than the exception in economic and ecological systems.

In biological evolution, the information storage medium is the genes, the generation of new alternatives is by sexual recombination or genetic mutation, and selection is performed by nature according to a criterion of "fitness" based on reproductive success. The same process of change occurs in other ecological, economic, and cultural systems, but the elements on which the process works are different. For example, in cultural evolution, the storage medium is the culture (the oral tradition, books, film, or other storage medium for passing on behavioral norms), the generation of new alternatives is through innovation by individual members or groups in the culture, and selection is again based on the reproductive success of the alternatives generated, but reproduction is carried out by the spread and copying of the behavior through the culture rather than biological reproduction. One may also talk of "economic" evolution, a subset of cultural evolution dealing with the generation, storage, and selection of alternative ways of producing things and allocating what is produced. Evolutionary theories in economics have already been successfully applied to problems of technical change, to the development of new institutions, and to the evolution of means of payment (Nelson and Winter 1974; Day and Groves 1975; Day 1989; England 1994).

For large, slow-growing animals such as humans, genetic evolution has a built-in bias toward the long run. Changing the genetic structure of a species requires that characteristics (phenotypes) be selected and accumulated by differential reproductive success. Behaviors learned or acquired during the lifetime of an individual cannot be passed on genetically. Genetic evolution is therefore usually a relatively slow process requiring many generations to significantly alter a species' physical and biological characteristics.

Cultural evolution is potentially much faster. Technical change is perhaps the most important and fastest evolving cultural process. Learned behaviors that are successful, at least in the short term, can be almost immediately spread to other members of the culture and passed on in the oral, written, or video record and today by social media through Twitter, Facebook, YouTube, and other avenues. The increased speed of adaptation that this process allows has been largely responsible for *Homo sapiens'* amazing success at appropriating the resources of the planet. In 1986, Vitousek et al. estimated that humans directly controlled from 25% to 40% of the total primary production of the planet's biosphere and are having significant effects on the biosphere, including changes in global climate and in the planet's protective ozone shield (Vitousek et al. 1986). Current estimates, based on satellite data, show that now humans are co-opting approximately one-third of the net primary product (NPP) of terrestrial photosynthesis globally (Rojstaczer et al. 2001; Running 2012).

Thus the costs of this rapid cultural evolution are potentially significant. Like a car that has increased speed, humans are in more danger of running off the road or over a cliff. Cultural evolution lacks the built-in long-run bias of genetic evolution and is susceptible to being sent over a cliff into the abyss by its hyperefficient short-run adaptability.

Another major difference between cultural and genetic evolution may serve as a countervailing bias, however. As Arrow (1962b) has pointed out, cultural and economic evolution, unlike genetic evolution, can at least to some extent employ foresight. If society can see the cliff, perhaps it can be avoided.

Although market forces drive adaptive processes (Kaitala and Pohjola 1988), the systems that evolve are not necessarily optimal, so the question remains: What external influences are needed and when should they be applied in order to improve an economic system via evolutionary adaptation? The challenge faced by ecological economic systems modelers is to first apply the models to gain foresight and to respond to and manage the system feedbacks in a way that helps avoid any foreseen cliffs (Berkes and Folke 1994). Devising policy instruments and identifying incentives that can translate this foresight into effective modifications of the short-run evolutionary dynamics is the challenge (Costanza 1987).

2.1.6 John Stuart Mill and the Steady State

John Stuart Mill (1806–1873) was the son of social philosopher James Mill (1773–1836), who also wrote on economics. Mill is important for having expanded on the linkages between individual behavior and the common good suggested by Adam Smith, arguing that competitive economies had to be based on rules of property use and on a sense of social responsibility that favored the common good. At the same time, he argued that competitive markets were essential to freedom. As a social philosopher seriously concerned with liberty, Mill also wrote on the immorality and waste of human productive talent that resulted from the subjugation of women by men. Although his concern with subjugation of women was perhaps too instrumentally based, he neither saw material prosperity as an end in itself nor foresaw that continuous growth in material well-being was possible. Mill was one of the first economists to plead for conservation of biodiversity or against the conversion of all natural capital into man-made capital. Mill envisioned economies becoming mature and reaching a steady state in which people would be able to enjoy the fruits of their earlier savings, or material abstinence, which had been necessary for the accumulation of industrial capital. The idea that economies would reach a steady state was consistent with the Newtonian view of systems so dominant at the time as well as with natural phenomena. Unceasing growth is not observed in nature, and relatively steady states rather than random change are perceived as "natural." Herman Daly builds on Mill and argues for a steady-state economy where flows of resources into production and of pollutants back to the environment are kept at a steady level. The steady-state metaphor has become critical to finding common ground for achieving sustainable development (Daly 1977).

2.1.7 Karl Marx and the Ownership of Resources

Karl Marx (1818–1883) addressed, among his multiple critiques of capitalism, how the concentration of land and capital among a small portion of society affected how economies worked. There is an extensive collection of literature written by scholars influenced by Marx. Some of this literature addresses the sustainability of development and how the ownership of resources affects the path of development (Redclift 1984; Blaikie and Brookfield 1987). Neoclassical models also readily show how resource ownership affects resource use (Bator 1957). However, for a variety of political reasons, this facet of the neoclassical model was ignored in the West during the Cold War. Indeed, in the United States, economists who were concerned with the *distribution* of ownership of resources were politically disempowered through their association with a central concern of Marx's. Western neoclassical economists, including resource and environmental economists, addressed questions of *efficient allocation* of resources, leaving the initial distribution of resources among people as given, not to be questioned. In the late twentieth century, we recognized that the initial distribution of rights to resources and to the services of the environment is critically important to resource and environmental conservation and to the prospects for sustainability (Howarth and Norgaard 1992).

It has long been known that how economies allocate resources to different ends depends on how resources are distributed among people, that is, whether they are owned by or otherwise under the control of different people. Peasants or others who work land and interact with biological resources owned by someone else have little incentive to protect them. Landlords can only counteract this lack of incentive by diverting their own labor or that of managers under them from other productive activities and employing it to monitor and enforce their interests in protection. This diversion of human potential would not be necessary with a more equal distribution of control. Furthermore, especially wealthy landlords may have little interest in protecting any particular land or biological resource for their descendants when they hold land in such abundance that their foreseeable descendants are certain to have an adequate share.

To illustrate why distribution is important, imagine two countries with identical populations and identical resources allocated by perfect markets. In the first country, rights to resources are distributed among people approximately equally, people have similar incomes, and they consume similar products—perhaps corn, chicken, and cotton clothing. In the second country, rights are concentrated among a few people who can afford luxury goods such as beef, wine, caviar, fine clothes, and tourism, while those who have few rights to resources, living nearly on their labor alone, consume only the most basic of goods such as rice and beans. In each country, markets efficiently allocate resources to the production of products, but how land is used, the types of products produced, and who consumes the products depend on how rights to resources are distributed. For different distributions of rights, the efficient use of resources is different.

Within the twentieth-century global discourse on development policy, many argued that economic injustices within nations, as well as between nations, limited the development options of poor nations and thereby, in the long run, those of the rich as well. Similarly in the late-twentieth-century global environmental discourse, many argued that environmental injustices and the international ecological order limit the possibilities for conservation. The vast majority of the people on the globe still consume very little. The poor are poor for two reasons. First, they do not have sufficient long-term access to resources to meet their ongoing material needs. Second, they are well aware that others consume far more than they do, that their poverty is relative, and they rightfully strive to improve their own relative condition. Striving to meet their material needs and aspirations without long-term secure access to adequate resources, the poor have little choice but to use the few resources at their disposal in an unsustainable manner. The poor, excluded from the productivity of the fertile valleys or fossil hydrocarbon resources controlled by the rich, are forced to work land previously left idle because of its fragility and low agricultural productivity: the tropical forests, the steep hillsides, and the arid regions.

An environmental justice movement addresses why the poor and people of color bear a heavy share of the environmental costs of development. The poor and people of color are more likely to live near waste disposal sites and are more likely to work in polluted environments. This movement also speaks to the excessive material and energy consumption of the wealthy 20% to 30% of the world's population made up of the middle classes and the rich in the northern, industrialized nations as well as the elite in middle income nations and in some poorer ones. The rich consume the bulk of the resources and account for many of our environmental problems. The global access to resources by the rich means that many of the environmental impacts of their consumption decisions occur at a great distance, beyond their view, beyond their perceived responsibility, and beyond their effective control. The relationships among unequal access to resources, the unsustainability of development generally, and the loss of biodiversity in particular were major themes of the United Nations Conference on Environment and Development held in Rio de

Janeiro in June 1992. Rich peoples and political leaders of northern industrialized countries have generally had some difficulty participating in this discourse and even greater difficulty participating in the design of new global institutions to address the role of inequity in environmental degradation. These themes were revisited in the United Nations Conference on Environment and Development held in Rio de Janeiro in June 2012 (Rio+20). However, major heads of state from developed countries were missing, which translated into a lack of political will and, for many, a failure of the conference.

Our understanding of the environmental consequences of concentrated ownership and control are rooted in economic thinking, especially that of Karl Marx. Questions of equity are extremely important to the process of environmental degradation and to the possibilities for sustainable development. The occupation and ecological transformation of the Amazon have been partly driven by the concentration of the ownership of land in the more productive regions of Amazonian nations and partly driven by the economic power and hence political influence of the rich that has enabled them to obtain subsidies to engage in large-scale land speculation or cattle ranching. The ongoing efforts to establish international agreements on the management of biodiversity and climate change have been repeatedly forestalled by debates over the ownership and control of resources. But it is not simply a debate over fairness. The structure of the global economy and how specific economies interact with nature in the future will depend on which nations—the nations of origin or of the northern commercial interests, the likely discoverers of new uses for heretofore unused species—receive the "rent" from resources.

Marx and his followers in communist countries have made a negative contribution to the allocative efficiency problem, even while highlighting issues of just distribution. Their ideological rejection of rent and interest as necessary prices and their insistence on a labor theory of value that neglected nature's contribution were responsible for much of the environmental destruction in communist countries. Marx did however predict the rise of finance capitalism that we seem to be witnessing today.

2.1.8 W. Stanley Jevons and the Scarcity of Stock Resources

W. Stanley Jevons (1835–1882) contributed initially to meteorology, logic, induction, and statistics while also making contributions to economics. He was one of the pioneers of the marginal utility theory of value. However, of more interest to ecological economics is his recognition of the critical importance of energy, which in his day meant coal. It was his argument that the British economy and the success of the empire were dependent on coal, a rapidly dwindling resource (Jevons 1865), that brought him notoriety as an economist and a chair in political economy. He subsequently contributed to the mathematical formalization of economics (Jevons 1871), continued to write on the philosophy of science (Jevons 1874), and speculated on the relationship of sunspots and financial crises (published in *Investigations in Currency and Finance* 1884). Today, he is better known for "the Jevons Paradox," that more efficient use of a resource can result in its increased total use, rather than its decrease (as happened with coal).

2.1.9 Ernst Haeckel and the Beginnings of Ecology

Although ecology has been said to have its roots in the Greek science of Hippocrates, Aristotle, and Theophrastus, or in the eighteenth-century natural history of Linnaeus and Buffon, or in Darwin and Wallace's evolutionary biology, ecology as a named science did not emerge as a "self-conscious" discipline with its own name until Ernst Heinrich Haeckel (1834–1919) first used the word *oecologie* in 1866. Practitioners began to use this term in the last decade of the nineteenth century (Allee et al. 1949), Eugenius Warming (1841–1924) published the first ecology text in 1895 (Goodland 1975), and the first formal ecological societies formed during the second decade of the twentieth century. Thus, as a practical and practiced science, ecology is a twentieth-century phenomenon.

However, it was Haeckel who, in 1870, produced the first full-fledged definition of ecology:

> By ecology we mean the body of knowledge concerning the economy of nature—the investigation of the total relations of the animal both to its inorganic and to its organic environment including above all, its friendly and inimical relations with those animals and plants with which it comes directly or indirectly into contact—in a word, ecology is the study of all those complex interrelations referred to by Darwin as the conditions of the struggle for existence. (translated in Allee et al. 1949, frontispiece)

Thus, even in this initial definition of the field, a deep conceptual relationship with economics is evident. Ecology was, in Haeckel's words, the study of the economy of nature. Economics, conversely, can be thought of as the ecology of humans. But historically the science of ecology evolved out of biology and ethology (the science of animal behavior) and thus had very different intellectual roots than economics. In practical terms, ecology became the study of the economy of that part of nature that does not include humans.

Since Haeckel's early definition, many other interpretations of the definition of ecology proliferated based on changing areas of interest and emphasis. When there was a focus on animal populations, ecology was "the study of the distribution and abundance of animals" (Andrewartha and Birch 1954). Later, when ecosystems became a major focus, ecology was "the study of the structure and function of ecosystems" (Odum 1953). But what has remained at the core is the relationship of organisms to their environment. As the dominant species of animal on the planet, *Homo sapiens* and its relationship to its environment is obviously central to the scope of ecology by any of its various definitions.

Thus, from the very beginning of ecology as a science, there have been continuing attempts to incorporate humans and the social sciences. Most of these attempts, unfortunately, did not get very far. The tendency in the social sciences was to consider humans somehow outside the laws and constraints that applied to other animals, and ecologists were not persistent or effective enough in their attempts to extend ecological thinking to *Homo sapiens*.

As McIntosh (1985) points out:

> If human factors are beyond ecological consideration, what then is human ecology? It is not clear whether ecology will expand to encompass the social sciences and develop as a metascience of ecology. The alternative is a more effective interdisciplinary relationship between ecology and the several social sciences. (319)

Ecological economics can be seen as an attempt to build this more effective interdisciplinary relationship as a bridge to a truly comprehensive science of humans as a component of nature that will fulfill the early goals of ecology. This reintegration of ecology and economics (and the other social sciences) is explored in the last section in this chapter.

2.1.10 Alfred J. Lotka and Systems Thinking

Alfred J. Lotka (1880–1949) was trained as a physical chemist, but his broad interests in chemistry, physics, biology, and economics led to a far-reaching synthesis of these fields together with thermodynamics in his 1925 book, *Elements of Physical Biology* (Lotka 1956 [1925]). Lotka was the first to attempt an integration of ecological and economic systems in quantitative and mathematical terms. He viewed the whole world of interacting biotic and abiotic components as a system, where everything was linked to everything else and nothing could be understood without an understanding of the whole system. He also stressed the importance of looking at systems from an energetic point of view.

Lotka's work was grand in scope and, although recognition was slow in coming, it eventually influenced noted ecologists (such as E. P. Odum and H. T. Odum) and economists (such as Paul Samuelson, Henry Schultz, and Herbert Simon) (Kingsland 1985). Lotka's work was clearly in the synthetic, transdisciplinary spirit of the nineteenth century but was coming at a time when the disciplines had already started to fragment. Lotka was not a professional scholar until late in his career, and his isolation from the pressures of the academic disciplines probably allowed him to more easily achieve and maintain his broad perspective.

Although Lotka is probably best known for his equations describing two-species population dynamics (which were simultaneously discovered by Vito Volterra and have come to be known as the Lotka–Volterra equations); these equations occupied only two pages of his 1925 book. His more important contributions from the perspective of ecological economics were his attempts to treat ecology and economics as an integrated whole, exhibiting nonlinear dynamics constrained and structured by flows of energy. He attempted to model quite explicitly the economy of nature, and he developed a general evolutionary approach to this problem. But because he was interested in systems, not just species and populations, he developed systems criteria to drive evolution. What has come to be known as "Lotka's energy principle" or "Lotka's power principle" posited that systems survive by maximizing their energy flow, defined as the rate of effectively using energy, or power. In single-species populations, this reduced to the usual criterion of reproductive success, but his formulation allowed the generalization to all systems, from simple chemical systems to biological, ecological, and economic systems. These ideas presaged the development of general systems theory (discussed later) and were very influential on later attempts to reintegrate ecology and economics.

2.1.11 Alfred C. Pigou and Market Failure

Alfred C. Pigou (1877–1959) formally elaborated how costs and benefits that are not included in market prices affect how people interrelate with their environment. An *externality* is a phenomenon that is external to markets and hence does not affect how markets operate when in fact it should. Consider, for example, pesticide use in agriculture and the associated loss of biodiversity. In Figure 2.5, S_0 illustrates the willingness of farmers to *supply* food at different prices. As the price of food increases (the y-axis), the quantity of food (the x-axis) that farmers are willing to supply increases. D is the *demand* curve illustrating the willingness of people to purchase greater quantities of food at lower prices. The market clears, in the sense that the quantity supplied equals the quantity demanded, at the price P_0 and quantity Q_0.

Now imagine that we could measure, for example, the value of biodiversity lost through pesticide use and add this to the cost of pesticides. The higher cost of pesticides would reduce the quantity of food that farmers could produce at any given price, shifting the supply curve to S_1, the price of food to P_1, and the quantity of food supplied and demanded to Q_1. By internalizing the cost of lost biodiversity through farmers' decision to use pesticides, we internalize a cost that was previously external to the

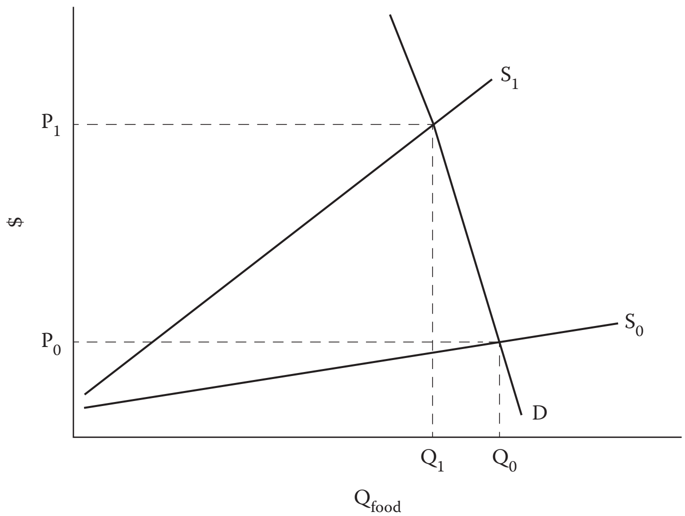

FIGURE 2.5
Market distortion due to an external cost.

market and that affects how the market operates. Following the logic of Pigou and numerous environmental economists since, biodiversity is not adequately protected because its value is not included in the market signals that guide the economic decisions of producers and consumers and thereby the overall operation of the economic system. The logic of market failure has led economists, and increasingly biologists as well, to argue that the critical environmental resources need to be incorporated into the market system (Hanemann 1988; McNeely 1988; Randall 1988).

One way of doing this is to grant private individuals sole rights to use particular environmental resources. These individuals then reap the economic benefits from using the resource now but also may benefit through conserving the resource for use at a later date. This means consumers pay a higher price, reflecting the costs of managing the species in a more sustainable manner. It is important to keep in mind, however, that incorporating species into the market system may not result in their conservation and indeed could even accelerate their extinction. Species within the market system, for example, will not be conserved if their value is expected to grow at less than the rate of interest unless other controls are also put on their harvest (see Section 2.3.5).

The processes of biodiversity loss also interact with each other in a larger, reinforcing process of positive *feedbacks*. The degradation of any particular area increases the economic pressure on other areas. The loss of woody species through climate change reduces the possibilities for carbon fixation and reduces the opportunities to ameliorate further climate change. To bring a system into equilibrium, negative feedbacks are needed. Economics helps us see how biodiversity is decreasing because so few genetic traits, species, or ecosystems have market prices, the negative feedback signals that equilibrate market economies. In market systems, prices increase to reduce the quantity demanded when supplies are low and prices drop to increase the quantity demanded when supplies are high, keeping demand and supply in equilibrium. The problem, economists argue, is that most genetic traits, species, and ecosystems are being lost because they do not have prices acting as a negative feedback system to keep use in equilibrium with availability. When individuals of the species become fewer, increasing price to decrease quantity is not an option. By putting economic values on species and including them in market signals through various ways would reduce biodiversity loss. Furthermore, the economic explanation and solution is systemic. Bioreserves reduce human pressures on species within the protected area while simultaneously increasing those pressures outside the areas. However, by including the value of biodiversity in the price system would beneficially affect decisions in every sector of the economy.

Biologists also find the idea that we need to know the economic values of species compatible with their own understanding that if the true value of species to society were understood, more species would be conserved. Clearly, if we knew the value of biological resources, we would be in a better position to manage them more effectively. And, to the extent these values could be included in the market system, markets themselves could assist in the conservation of biodiversity. The situation can frequently be improved through amending market signals. At the same time, it is important to remember that market values only exist within a larger system of values, which for many people include the preservation of nature for ethical or religious reasons (Sagoff 1988).

When the market alone is unable to conserve species and ecosystems, knowing their economic value can help convince people (and their political representatives) that the ecosystems deserve protection. Environmental valuation can also improve how we analyze the benefits and costs of development projects that affect biodiversity. Two primary techniques for valuation include revealed and stated preferences (Mitchell and Carson 1989; Haab and McConnell 2002). Revealed preference methods involve analyzing individuals' choices in real-world settings and inferring value from those observed choices. Stated preference methods rely on individuals' responses to hypothetical scenarios involving ecosystem services and include contingent valuation and structured choice experiments. In addition, methods are needed that do *not* depend on an individual's knowledge of (and preferences for) the often complex connections between their well-being and ecosystem functioning (Costanza et al. 2011).

Although several techniques for estimating the value of the environment are proving interesting, valuation is by no means an easy task and estimates should be used cautiously. A major difficulty is related to the systemic nature of economics, ecosystems, and the process of environmental degradation. Market systems relate everything to everything else. For example, when the price of oil changes, it causes the price of gasoline to change, which causes the demand and hence the price of products that use gasoline, such as automobiles, to change, which causes the demand for and hence the price of coal to change, and so on. Prices bring markets to equilibrium and their flexibility is essential to this task. Similarly, the "right" price for a given species or ecosystem will depend on the availability of a host of other species or ecosystems with which they are interdependent as well as with other species and ecosystems that may be substitutes or complements in use. To think that a species or ecosystem has a single value is to deny ecosystem and economic system interconnections. Nevertheless, environmental valuation can assist us in understanding at least the minimal importance of ecological services and in conveying this understanding to the public to improve the political process of finding common ground.

2.1.12 Harold Hotelling and the Efficient Use of Resources over Time

Harold Hotelling (1895–1973) developed a model of efficient resource use over time that helps us understand how resources are exploited over time and the conditions under which conservation or depletion occurs (Hotelling 1931). Hotelling reasoned that the owner of mineral resources had two options: that of extracting the resource and putting the profits in the bank where they would earn interest and that of leaving the resource in the ground to appreciate in value. The owner would choose the first option unless the potential profits that could be earned from mining the resource in the future were increasing in value at a rate faster than the rate of interest. If this were the case, then it made sense to leave the resource in the ground. He then reasoned that, under particular conditions, a mining industry consisting of competitive resource owners would behave such that resources in the ground would increase in value at the rate of interest, for this would be the condition under which resource owners would be indifferent between mining and not mining a little more. If this condition were not met, they would all mine more if they could earn more by putting their revenues in the bank, or they would mine less if they could earn more by leaving the resource in the ground. Expectations about the future are critical in Hotelling's model and are embodied in the expected interest rate and expected future price of the resource (Box 2.1).

Clearly the level of the interest rate affects how biological resources are managed and hence the rate and direction of ecosystem transformation and species extinction. Any species or ecosystem that cannot be managed

BOX 2.1 THE RATE OF INTEREST

Hotelling's argument highlights the importance of interest rates in the management of biological resources. If a person can earn an 8% return per year by investing in industrial expansion through stock or bond markets, he or she has little incentive to invest in trees that only increase in value at 3% per year or in the preservation of tropical forests, which have little measurable economic return. By economic logic, biological resources that are not increasing in value as fast as the rate of interest should be exploited and the revenues put into industrial capital markets. The rate of interest affects how, by economic reasoning, people discount the future. If the rate of interest is 10%, one dollar one year from now is worth only $0.91 today because one can put $0.91 in the bank today and, earning 10% interest, it will be worth $1.00 next year. The problem is that $1.00 one decade from now is only worth $0.34 today, two decades from now a mere $0.11 today. Clearly, discounting at 10%, a species has to have a very high value in the distant future to be worth saving today. With a lower rate of interest, it would be discounted less and hence worth more. Thus, lower interest rates appear to favor conservation.

It has long been argued, for example, that trees that grow slower than the rate of interest will never be commercial. Imagine that it costs $10 to plant a tree seedling. Imagine that the rate of interest is 10%. An entrepreneur has the choice of putting $10 in the bank earning 10% or planting the tree seedling and harvesting it at a later date. Each year, the money in the bank (MIB in Figure 2.6) increases in value: to $\$10 \times (1.1)$ or $11.00 at the end of the first year, to $\$10 \times (1.1)^2$ or $12.10 at the end of the second year, to $\$10 \times (1.1)^3$ or $13.31 at the end of the third year, and so on. As long as the value of the tree grows faster than the money in the bank, it is a commercial tree species (CTS), and it pays to invest in the tree. Eventually, of course, the tree would begin to grow more slowly and when it is only growing in value as fast as money in the bank (t_h in Figure 2.6), it pays to cut down the tree. But if the tree never grows in value faster than money in the bank, it is a noncommercial tree species (NCTS), and it never pays to plant the tree in the first place. Slow growing trees such as teak and many other hardwoods will be cut down and not replanted when interest rates are even moderately high. The World Bank considers returns of 15% to be acceptable and hence has rarely financed timber projects except those with very fast growing species such as eucalyptus. Historically, development aid has financed the replacement of natural forests of mixed species by monocultural forests of fast growing species based on this understanding of economic efficiency. High interest rates encourage transformation of ecosystems toward faster growing species.

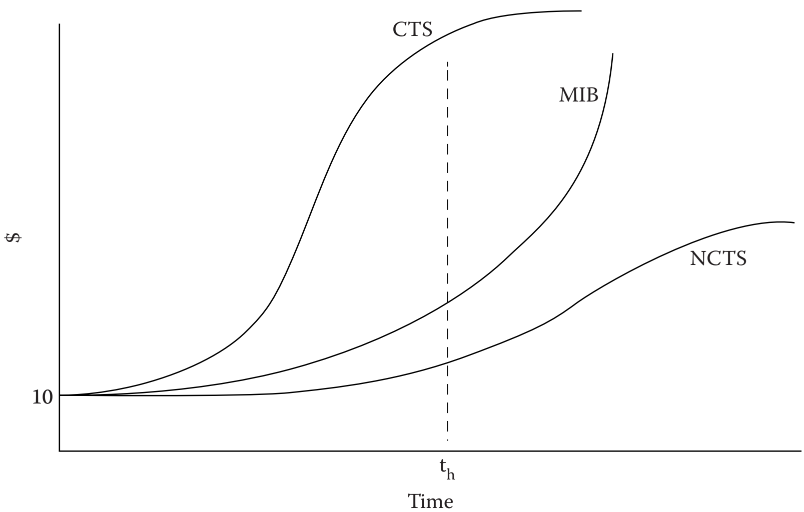

FIGURE 2.6
Commercial and noncommercial tree growth and harvest time.

at a level such that it is generating a flow of services at a rate greater than the rate of interest "should" be depleted (see Figure 2.6). Because even many economists find exploitation to extinction rather crass, there has been considerable interest in whether the interest rate produced by private capital markets reflects the social interest and whether, when these interests are factored in, a social rate of interest would not be significantly lower than the private interest rate. Might private capital markets work imperfectly, generating rates of interest that are too high and hence leading to excessive biodiversity loss (Marglin 1963)? There are good reasons to expect that lower interest rates would favor the conservation of biodiversity, though there are situations when this would not be the case. Low interest rates allocate investments from the fastest growing projects but increase the total number of projects that are worth investing in. Thus, low interest rates favor conservation in terms of their effects on allocation but, in terms of their scale-increasing effect, they work against conservation. This has not been simply an academic argument. The World Bank has realized that its own evaluation policies have hastened biodiversity loss (Box 2.2) and, in part for this reason, has a policy of not financing the transformation of natural forest habitat. Current U.S. Federal Reserve policies of monetary easing are aimed at low interest rates to stimulate growth in scale, which will stimulate investment in extraction rather than putting money in the bank. The efficiency of each investment will also be lower with low (near zero) interest rates, and the volume of these low quality investments will tend to increase.

BOX 2.2 PRESERVING NATURAL CAPITAL AND BIODIVERSITY

Behind the logic of Hotelling's argument with respect to the efficient use of resources over time, there are many assumptions about the characteristics of natural capital and human-produced capital, future technological developments, the limits of people's ability to comprehend social and ecological complexities with respect to how the future will unfold, and the appropriateness of current peoples exposing future peoples to the risks of not having biological diversity they might later find of value. These complications have led economists to argue, given the irreversibility of biodiversity loss (Fisher and Hanemann 1985), that it is appropriate to some extent to maintain biological diversity as an option even though narrow economic reasoning suggests otherwise. Better-safe-than-sorry reasoning has led to the introduction of the concepts of option value, an upward adjustment of price to help assure the conservation of the resource (Bishop 1978). The quantity analogue to option value is a *safe minimum standard,* the setting of a lower limit on the quantity of a resource that must be maintained (Wantrup 1952).

2.2 Economics and Ecology Specialize and Separate

> Every profession lives in a world of its own. The language spoken by its inhabitants, the landmarks familiar to them, their customs and conventions can only be learnt by those who reside there.
>
> **Carr-Saunders and Wilson 1933, iii**

By the end of the nineteenth century, the trend to increasing specialization and professionalization in science was well under way, and economics as a profession became more and more popular (Coats 1993). What has come to be called the "reductionist" paradigm was beginning to hold sway. This paradigm assumes that the world is separable into relatively isolated units that can be studied and understood on their own, and then these are reassembled to give a picture of the whole. As the complexity of science increased, this was a very useful idea because it allowed dividing up the problem into smaller, more manageable pieces that could be attacked intensively. Chemists could study chemistry without being distracted by other aspects of the systems they were studying. Also, the rapid increase in the sheer number of scientists that were actively working made it necessary to organize the work in some way, and the disciplinary structure seemed a logical and useful way to do this. But once university departments were set up in the various disciplines, internal reinforcement systems came to reward only work *within the discipline*. This rapidly led to a reduction in communication across disciplines and a tendency for the disciplines to develop their own unique languages, cultures, and ways of looking at the world.

In economics, this led to a growing isolation from the natural resource (or land) component of the classical triad of land, labor, and capital, and with it a growing isolation from the natural sciences. Economics departments began to reward theory more highly than applications, and the discipline as a whole attempted to pattern itself on physics, which was probably the most successful example of the advantages of the disciplinary model of organization.

This trend continued in the early through the mid-twentieth century and, by the time of the renewed environmental awareness of the 1970s, economics had become highly specialized and abstracted away from its earlier connections with the natural environment. Textbooks at the time barely mentioned the environment and concentrated instead on the microeconomics of supply, demand, and price formation and the macroeconomics of growth in manufactured capital and gross national product (GNP).

At the same time, economics was becoming absorbed with professionalization. As Coats (1993) noted:

> At least since the marginal revolution of the 1870s, mainstream economists have sought to enhance their intellectual authority and autonomy by excluding certain questions which were either sensitive (such as the distribution of income and wealth, and the role of economic power in society) or incapable of being handled by their preferred methods and techniques, or both. These are precisely the questions which are emphasized by their professional and lay critics and, more recently, by many economists who cannot be dismissed by their professional colleagues as either ignorant or incompetent (p. 27).

The story in ecology is somewhat different. As we have previously noted, ecology is a much younger science, and it has always been more explicitly pluralistic and interdisciplinary. But its roots were in biology, and the trend in biology was much the same as in other areas of science. The initial split into botany and zoology was followed by further specialization into biochemistry, biophysics, molecular biology, and so on. In ecology, there was something of a split between the population ecologists (e.g., Robert MacArthur) who concentrated on individual populations of organisms, and the systems ecologists (e.g., E. P. and H. T. Odum) who focused on whole ecosystems. But this split never got to the point of separation into distinct departments and disciplines, although many academic programs took on a decided flavor in one direction or the other.

Through all of this, ecologists, more so than those of any other discipline, have maintained communication across most of the natural sciences.

To study ecosystems, one has to integrate hydrology, soil science, geology, climatology, chemistry, botany, zoology, genetics, and many other disciplines. The dividing line for ecologists has been at a particular species—*Homo sapiens*—even though Haeckel's original definition explicitly included humans and many ecologists have argued and worked to operationalize this integration. However, a vast majority of active ecologists consider the study of humans outside their discipline, leaving it to the social sciences. Indeed, most ecologists looked for field sites as remote from human activities as possible to conduct their research. Ecological economics is an attempt to help rectify this tendency to ignore humans in ecology, while at the same time rectifying the parallel tendency to ignore the natural world in the social sciences.

2.3 Reintegration of Ecology and Economics

Ecology and economics have been pursued as separate disciplines through most of the twentieth century. Although each has certainly borrowed theoretical concepts from the other and has shared patterns of thinking from physics and other sciences, each has addressed separate issues, has utilized different assumptions to reach answers, and has supported different interests in the policy process. To be sure, individual scholars kept trying to introduce the issues addressed by natural science into economics, but they were systematically rejected by economists as a group (Martinez-Alier 1987). Indeed, in their popular manifestations as environmentalism and economism, these disciplines became juxtaposed secular religions, preventing the collective interpretation and resolution of the numerous problems at the intersection of human and natural systems.

Ecological economics arose during the 1980s among a group of scholars who realized that improvements in environmental policy and management and protecting the well-being of future generations were dependent on bringing these domains of thought together. Numerous experiments with joint meetings between economists and ecologists were held, particularly in Sweden and the United States, to explore the possibilities of working together (Jansson 1984; Costanza and Daly 1987). Meanwhile, there was also growing discontent with the deficiencies in the system of national accounts that generates measures of economic activity such as gross domestic product (GDP), while ignoring the depletion of natural capital through the mining of resources such as petroleum and through environmental degradation (Hueting 1980). Economists and ecologists joined to encourage the major international agencies to develop accounting systems that included the environment (Ahmad et al. 1989). Buoyed by such initial efforts, the International Society for Ecological Economics (ISEE) was formed during a workshop of ecologists and economists held in Barcelona in late 1987, and the journal, *Ecological Economics*, was launched in 1989. Major international and U.S. conferences of ecologists and economists have been held since then, many ecological economic institutes have been formed around the world, countries have chosen to follow an ecological economics land planning approach (e.g., Peru), and a significant number of books have appeared with the term ecological economics in their titles (e.g., Costanza 1991; Peet 1992; May 1995; Daly and Farley 2004, 2011; Common and Stagl 2005).

Ecological economics is not a single new paradigm based in shared assumptions and theory. It represents a commitment among economists, ecologists, and others, as academics and as practitioners, to learn from each other, to explore new patterns of thinking together, and to facilitate the derivation and implementation of new economic and environmental policies. To date, ecological economics has been deliberately conceptually pluralistic even though particular members may prefer one paradigm over another (Norgaard 1989). One way of looking at it is to view ecological economics as encompassing economics and ecology and their existing links in the form of resource and environmental economics and environmental impact analysis as shown in Figure 2.7. Ecological economists

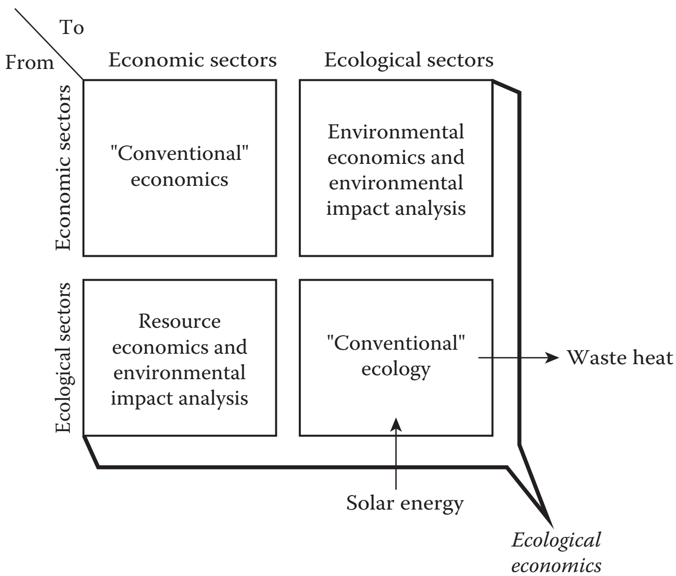

FIGURE 2.7
Relationship of domains of ecological economics, conventional economics, ecology, resource and environmental economics, and environmental impact analysis. (From Costanza, R. et al., *Ecological economics: The science and management of sustainability*, Columbia University Press, New York, 1991.)

	Current Economic Model	Ecological Economics Model
Basic worldview	**Mechanistic, static, atomistic individual tastes and preferences** taken as given and the dominant force. The resource base viewed as essentially limitless due to technical progress and infinite substitutability	**Dynamic, systems, evolutionary human preferences**, understanding, technology, and organization co-evolve to reflect broad ecological opportunities and constraints. Humans are responsible for understanding their role in the larger system and managing it sustainably
Time frame	**Short:** 50 yrs max, 1–4 yrs usually	**Multi-scale:** Days to eons, multiscale synthesis
Primary policy goal	**More:** Economic growth in the conventional sense, as measured by GDP. The assumption is that growth will ultimately allow the solution of all other problems. More is always better	**Better:** Focus must shift from merely growth to "development" in the real sense of improvement in sustainable human well-being, recognizing that growth has significant negative by-products
Primary micro goal	**Max profits (firms) Max utility (individuals)** All agents following micro goals leads to macro goal being fulfilled. External costs and benefits given lip service but usually ignored	**Must be adjusted to reflect system goals** Social organization and cultural institutions at higher levels of the space/time hierarchy ameliorate conflicts produced by myopic pursuit of micro goals at lower levels
Primary measure of progress	GDP	Index of Sustainable Economic Welfare (ISEW), Genuine Progress Indicator (GPI), or other improved measures of real welfare
Space frame	**Local to international:** Framework invarient at increasing spatial scale, basic units change from individuals to firms to countries	**Local to global:** Hierarchy of scales
Species frame	**Human only:** Plants and animals only rarely included for contributory value	**Whole ecosystem:** Including humans. Acknowledges interconnections between humans and rest of nature
Distribution/ poverty	Given lip service, but relegated to "politics" and a "trickle-down" policy: a rising tide lifts all boats	A primary concern, since it directly affects quality of life and social capital and is often exacerbated by growth: a too rapidly rising tide only lifts yachts, while swamping small boats
Economic efficiency/ allocation	The primary concern, but generally including only marketed goods and services (GDP) and market institutions	A primary concern, but including both market and nonmarket goods and services, and effects. Emphasis on the need to incorporate the value of natural and social capital to achieve true allocative efficiency

Property rights	Emphasis on private property and conventional markets	Emphasis on a balance of property rights regimes appropriate to the nature and scale of the system, and a linking of rights with responsibilities. Includes larger role for common-property institutions
Role of government	Government intervention to be minimized and replaced with private and market institutions	Government plays a central role, including new functions as referee, facilitator, and broker in a new suite of common-asset institutions
Principles of governance	Laissez-faire market capitalism	Lisbon principles of sustainable governance
Assumptions about technical progress	Very optimistic	Prudently skeptical
Academic stance	Disciplinary monistic, focus on mathematical tools	Transdisciplinary pluralistic, focus on problems

are rethinking ecology and economics by, for example, extending the materials balance and energetic paradigm of ecology to economic questions (Ayres 1978; Costanza and Herendeen 1984; Hall et al. 1986), applying concepts from economics to better understand the nature of biodiversity (Weitzman 1995), and arguing from biological theory how natural and social systems have coevolved together such that neither can be understood apart from the other (Norgaard 1981).

Today's ecological economists are indebted to particular scholars who, though they have been predominantly ecologists or economists themselves, have maintained and demonstrated the advantages of a transdisciplinary approach. We highlight the new patterns of thinking in the next sections while acknowledging that there are many more who have contributed to the founding of ecological economics in diverse ways.

2.3.1 Ludwig von Bertalanffy and General System Theory

Systems analysis is the study of systems that can be thought of as groups of interacting, interdependent parts linked together by complex exchanges of energy, matter, and information. There is a key distinction between "classical" science and system science. Classical science is based on the resolution, or reduction, of phenomena into isolatable causal trains and on the search for basic, "atomic" units or parts of the system. Reductionist approaches are appropriate if the interaction between the parts is nonexistent, weak, or essentially linear so that they can be added up to describe the behavior of the whole. Although these conditions are met in some physical and simple chemical systems, they are almost never met in more complex living systems. A "living system" is characterized by strong, usually nonlinear, interactions among the parts. Such complex feedbacks make resolution into isolatable causal trains difficult or impossible and also mean that small-scale behavior cannot simply be "added up" to arrive at large-scale results. Of course, this has not prevented scientists from assuming that living systems can be reduced to causal trains and isolatable parts, but this also explains why disciplinary environmental science and economics has produced inappropriate policies and management schemes.

As we noted earlier in our discussion of A. J. Lotka, some scientists have long addressed the difficulties of working with complex systems. Ludwig von Bertalanffy (1901–1972), however, is especially credited with advancing the formal study of systems through a paper he wrote in 1950. This paper drew the attention of others who then chose to explore the field together. In *General System Theory* (1968), von Bertalanffy and his cohorts argued that similar patterns of interaction could be found in quite different systems and ventured the argument that once these basic patterns were understood, all systems could be understood. Although this has not proved to be the case, one participant of the general system theory group, Kenneth Boulding, produced a series of books drawing parallels between economic and ecological systems, inspired other potential ecological economists in their formative years, and then helped in the founding of ecological economics as a formal effort (Boulding 1978, 1985). Ludwig von Bertalanffy (1968) was the first one to suggest a holistic systems approach on the basis that "the whole is much more than just the sum of its parts." Thus, systems theory is an organizational theory, which explains how a system relates and interacts with other systems.

Ecological and economic systems obviously exhibit the characteristics of living systems and hence are not well understood using the methods of classical, reductionist science. Although almost any subdivision of the universe can be thought of as a "system," systems analysts look for boundaries that minimize the interaction between the system under study and the rest of the universe in order to make their job easier. Some systems theorists claim that nature "herself" presents a convenient hierarchy of scales rooted in these interaction-saving boundaries, ranging from atoms to molecules to cells to organs to organisms to populations to communities to ecosystems—including economic, or human-dominated ecosystems—to bioregions to the global system and beyond (Allen and Starr 1982; O'Neill et al. 1986). By studying the similarities and differences among different kinds of systems at different scales and resolutions, one can develop hypotheses and test them against other systems to explore their degree of generality and predictability.

One might define systems analysis as the scientific method applied across and within disciplines, scales, resolutions, and system types; thus, it is transdisciplinary. In other words, it is an integrative manifestation of the scientific method, though most of the traditional or classical scientific disciplines tend to dissect their subjects into smaller and smaller parts hoping to reduce the problem to its essential elements. Thus, systems analysis forms a more natural scientific base and worldview for the inherently integrative transdiscipline of ecological economics than classical, reductionist science.

Beyond this distinction between synthesis and reduction, systems analysis usually applies mathematical modeling to these integrative problems. Although this is neither a necessary nor a sufficient condition for systems analysis, it is a common characteristic, if for no other reason than that systems tend to be complex, and mathematical modeling, especially on computers, is often necessary to handle that complexity. According to von Bertalanffy (1968, 18) "The system problem is essentially the problem of the limitations of analytical procedures in science." Recent years have seen an explosion in our ability to overcome these limitations and to actually model the complex, nonlinear, scale-dependent behavior of systems; hence, the history of systems analysis is now understood to be tightly linked with the history of the computer. Although computers first appeared in the 1950s, their widespread use did not commence until the 1960s and 1970s, and they did not become common until the 1980s. The increased availability, power, and "user-friendliness" of computers made systems analysis feasible. Today, many people can buy a personal computer and relevant software and begin to do practical systems analysis feasible. Now the limitation is clearly the availability of appropriate data.

The possibility for this sort of analysis was recognized early, and practical applications were developed more or less independently by modelers in economics, ecology, industrial management, and what was then called cybernetics (Weiner 1948). Early "systems analysts" in economics included Leontief (1941) and von Neumann and Morgenstern (1953), who mainly focused on static input–output networks and games. Jay Forrester of MIT began modeling complex industrial systems in the early 1960s (Forrester 1961) and has spawned one of the most prolific schools of systems analysis. In ecology, Odum (1971), Patten (1971–1976), and Hannon (1973) were among the early practitioners of dynamic computer simulation and static network analysis. The International Biosphere Program (IBP) was an early large-scale attempt to perform ecological systems analysis for a range of ecosystems (Innis 1978). Students of Jay Forrester developed the world systems model reported in *The Limits to Growth* (Meadows et al. 1972), which launched an impressive debate (Cole et al. 1973; Oltmans 1974) as well as expansions in their analysis (Mesarovic and Pestel 1974; Ehrlich and Holdren 1988; Pestel 1989; Meadows et al. 1992).

2.3.2 Elinor Ostrom and Garret Hardin: Open-Access Resource Management and Commons Institutions

When nature can be divided into separate properties that are individually owned, the owners have an incentive to use the property carefully so that they can continue to use it in the future. When nature cannot be so divided and many people use the resource together, problems can arise. Resources used by multiple users without rules governing their use, and the number of users, will be overexploited. Both traditional and modern societies typically develop rules for the use of resources held in common. The important point is that nature rarely can truly be divided into separate parts—the very premise of systems theory as discussed in the previous section—so the problems raised by collective use of resources must always be addressed. Indeed, as population and material consumption increase, the contradictions between the indivisibility of nature and the use of private property for environmental management become ever more critical.

A. C. Pigou addressed the problem of collective resource use in the 1920s, and subsequent economists have developed formal models. The phenomenon did not become widely understood, however, until it was popularized in an article in *Science* magazine written by Garret Hardin (1915–2003), titled "The Tragedy of the Commons" (Hardin 1968). The problem Hardin addressed is more accurately referred to as "open access" resources rather than "common property." Common ownership is not in itself a tragedy because many resources have been successfully managed as commons.

Open access can develop through the destruction of common institutions regulating the use of resources used jointly by people, leading to tragic consequences. Societies in transition between traditional and modern form frequently experience the tragedy of overuse when neither traditional nor modern forms of common control prevail. Similarly, resources for which access is difficult to restrict, such as frontiers beyond the control of governments, open sea, and wildlife that crosses national boundaries, are frequently overexploited (Berkes 1989). The absence or destruction of institutions regulating commons has led to the extinction of diverse species and to the genetic impoverishment of many.

Gordon (1954) formulated the problem of open-access resources as shown in Figure 2.8. Imagine an open-access fishery with total costs and total revenues from fishing effort as shown. Profits or rents from the fishery are maximized at level of effort E_1, but with unrestricted access, people would put more effort into fishing until the level E_2 was reached where no rent would be earned from fishing and no one would consider additional fishing worth the effort because costs would now be greater than revenues. Because more fish are caught at greater levels of effort, overfishing is more likely to occur in an open-access fishery than in a fishery managed as a commons.

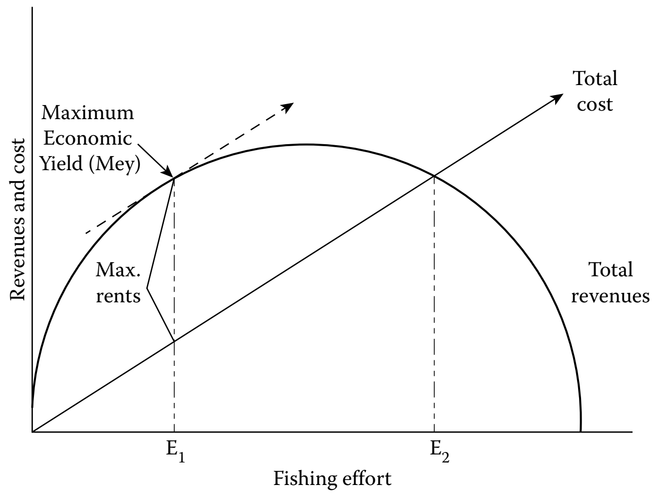

FIGURE 2.8
Excessive fishing effort occurs in an open-access fishery because existing fishermen expand their effort and new fishermen enter the fishery beyond level E_1, the point of maximum profit. Each fisherman continues to make a profit by increased fishing up to level E_2, where the total revenues equal total costs. Further fishing beyond this point is economically counterproductive because costs exceed revenues.

To the extent that biodiversity is manifested as different genetic traits, species, and ecosystems that cannot be owned by individuals and incorporated in market systems, we need common management institutions to conserve biodiversity for our descendants. At the end of the twentieth century, international biodiversity agreements began to be formulated and implemented. In some cases, traditional common property institutions for the protection of biodiversity can be maintained in the face of modernization. In other cases, new institutions will be needed. Common property institutions may be communal, regional, national, or global. The health of institutions at all of these levels will be critical to conserving biological diversity and ecosystem integrity. For this reason, commons institutions are central to the work of many ecological economists (Hanna and Munasinghe 1995a, 1995b). Similarly, it is now well understood that the global climate–regulating system is a common resource in need of common management institutions. For centuries, industrializing nations have dumped carbon dioxide, a by-product of fossil fuel combustion, and other greenhouse gases into the atmosphere without regard for their impacts on the climate system as a whole. Commons institutions for the management of the global climate system are in the process of being agreed to and implemented. An example is the proposed Earth Atmospheric Trust that could reduce carbon emissions and improve inequality. The Trust would embed a global cap-auction-dividend-and-trade system for all greenhouse gas emissions, within a global system that considers the atmosphere a shared asset (Barnes et al. 2008). The concept of the Earth Atmospheric Trust is discussed in more detail in Chapter 4 of this book.

Although Garret Hardin as a biologist "discovered" a phenomenon long understood by economists, Hardin was able to convey the larger meaning of the phenomenon to a broad audience and to alert natural scientists to the importance of institutions for environmental management. His article is still one of the most frequently found among the readings for environmental courses. Hardin, by crossing disciplines and demonstrating the significance to policy of economics and ecology used together, contributed to the rise of ecological economics.

Elinor Ostrom (1933–2012), the only woman to have received the Nobel Prize in Economics (in 2009), is well-known for her work in common pool resources. She is also well-known for challenging Hardin's premise in "Tragedy of the Commons." According to Ostrom (1999), individuals and communities can sustainably manage their own resources, and problems only arise—the tragedy—when outsiders use their power to gain advantage over the resources. She was a firm believer of a bottom-up approach to governing the commons and she developed a set of eight institutional principles for the sustainable governance of common-pool resources (CPRs) (Ostrom 1990):

CPRs must have clearly defined boundaries	Clear rights for resource extraction and capacity to exclude others without the right.
Congruence between appropriation and provision rules and local conditions	Rules such as time and technology are related to local conditions and labor, materials, etc.
Collective action/choice arrangements	Individuals affected by the CPR rules are able to participate in their modification.
Monitoring	CPR rules are enforced through active monitoring, and monitors are accountable to the users and/or are also users.
Graduated sanctions	User's violations of the rules will be punished by graduated sanctions.
Conflict resolution mechanism	Easy to access and low-cost mechanisms to resolve conflicts among users or between users and government officials.
Minimal recognition of rights to organize	Users have the rights to develop their own institutional arrangements (rules and regulations) and these are not challenged by high-level government authorities.
Nested enterprises	Rules are organized and enforced through multiple layers of nested enterprises.

Given the tendency to emphasize the difference between Hardin and Ostrom it is important to recognize their agreement. Note that the first of Ostrom's eight principles is "clearly defined boundaries with the capacity to exclude others who do not have access rights." To avoid the tragedy of open-access, commons requires the existence and enforcement of boundaries—not a "world without borders," however appealing the latter might be on humanitarian grounds.

This framework has been used and applied extensively by many authors (Castello et al. 2009; Schweik and Kitsing 2010; Ararai 2014, among others) in a whole range of situations, and agreement has emerged that the framework works very well. Two decades of use and consideration of the eight-principle framework led to a revised version (Ostrom 2007), which is more flexible, broader, and gives more emphasis to external factors.

2.3.3 Howard T. Odum and Nicholas Georgescu-Roegen: Energetics and Systems

In the year 1971, two influential books were published by two authors who did not yet know of each other, one a noted ecologist and one a noted economist. The books were very different in style and in many other ways, but both books were about energy, entropy, power, systems, and society and both can be said to have made a major contribution to setting the stage for ecological economics. One was from Howard T. Odum (1924–2002): *Environment, Power, and Society* and the other was by Nicholas Georgescu-Roegen (1906–1994): *The Entropy Law and the Economic Process.*

At the time, relatively few people were interested in the overall importance of energy to people in modern economies. But the public's attention was soon galvanized in late 1973 by the Arab oil embargo and the agreement by the Organization of the Petroleum Exporting Countries (OPEC) to significantly increase the price of oil. Subsequent further energy price increases during the Iran–Iraq War in the late 1970s and then a rapid decrease in the price of oil in the mid-1980s seriously perturbed industrial and developing economies. In the process, the role of energy became a central theme in our understanding of economic systems and how we relate to the environment (Odum and Odum 1976; Hall et al. 1986; Hall et al. 2001).

Nicholas Georgescu-Roegen was born in Romania, trained in mathematical statistics in France, assumed academic and government positions in his native country, and fled to the United States after World War II to become an economist, working with Professor Joseph Schumpeter at Harvard. His contributions to the further mathematical refinement of standard neoclassical economics in the areas of utility and consumer choice, production theory, input–output analysis, and development economics were honored by his being designated a distinguished fellow of the American Economic Association. He is most noted, however, for his contributions in the areas of entropy and economics, which still stir considerable controversial discussion among economists.

Georgescu-Roegen argued that all economic processes entail the use of energy and that the second law of thermodynamics, the entropy law, clearly indicates that the available energy in a closed system can only decline. Like others before him, he also noted the parallel between the degradation of the availability of energy and the degradation of the order of materials. Economic processes entail using relatively concentrated iron resources, for example, that are then further concentrated through the use of energy but that ultimately end up being dispersed as rust and waste, less concentrated than the original iron ore. Biodiversity degradation can also be thought of as a parallel problem. New technologies do not "create" new resources, they simply allow us to degrade energy, material order, and biological richness more rapidly and potentially more efficiently.

Critics have argued that the entropy law is not important because the Earth is not a closed system. It receives sunlight daily and is expected to continue to do so for another several billion years. Yet modern industrial economies are fueled by fossil hydrocarbons, accumulations of past solar energy that are clearly limited, while current solar energy is of limited flow and of relatively low concentration.

Georgescu-Roegen's message is controversial, in part, because it conflicts with beliefs in progress that are still strongly held by economists. The message is also difficult to interpret because it does not inform us how quickly we need to make the transition from stock energy resources to flow energy resources. In this sense, we simply need to look at resource constraints as well as the ability of the global system to absorb carbon dioxide and other greenhouse gases; the entropy law itself does not provide additional information. The entropy law, however, does provide a strong bass beat to the sirens being sounded by scientists studying climate change, biodiversity loss, and soil degradation.

Nicholas Georgescu-Roegen not only motivated one of his students, Herman Daly, to address the long-term human predicament (discussed in the next section), but he also inspired many others to ponder the various ways the entropy law helps us understand irreversibility, systems and organization, and our options for the future (see, for example, Chapter 3 of Ayres 1978; and Chapters 6 and 7 in Faber et al. 1996).

The hourglass analogy (see Box 2.3) can be extended by considering the sand in the upper chamber to be the stock of energy in the sun. Solar energy arrives on Earth as a flow whose amount is governed by the constricted middle of the hourglass that limits the rate at which

BOX 2.3 THE HOURGLASS ANALOGY

Many of Georgescu-Roegen's insights can be expressed in terms of his "entropy hourglass analogy."

First, the hourglass is an isolated system: No sand enters, and no sand exits.

Second, within the glass there is neither creation nor destruction of sand, the amount of sand in the glass is constant. This of course is the analog of the first law of thermodynamics—conservation of matter–energy.

Third, there is a continuing running down of sand in the top chamber and an accumulation of sand in the bottom chamber. Sand in the bottom chamber, because it has used up its potential to fall and thereby do work, is high entropy or unavailable matter/energy. Sand in the top chamber still has the potential to fall, thus it is low entropy or available matter/energy. This is the second law of thermodynamics—entropy increases in an isolated system. The hourglass analogy is particularly apt because entropy is time's arrow in the physical world.

One more thing—unlike a real hourglass, this one cannot be turned upside down!

sand falls. Suppose that in ancient geologic ages some of the falling sand had gotten stuck near the top of the bottom chamber, before it had fallen all the way. This becomes a terrestrial dowry of low entropy. We use it by drilling holes into it, allowing the trapped sand to fall to the bottom of the lower chamber. This terrestrial source of low entropy can be used at a rate of our own choosing, unlike the sun whose energy arrives at a fixed flow rate—we cannot "mine" the sun to use tomorrow's sunlight today, but we can mine terrestrial deposits and in a sense use up tomorrow's petroleum today.

There is thus an important asymmetry between our two sources of low entropy. The solar source is stock abundant but flow limited. The terrestrial source is stock limited but flow abundant (temporarily). Peasant societies lived off the solar flow; industrial societies have come to depend on enormous supplements from the unsustainable terrestrial stocks.

Reversing this dependence will be an enormous evolutionary shift. Georgescu-Roegen argued that evolution has in the past consisted of slow adaptations of our endosomatic organs (heart, lungs, etc.), that run on solar energy. Now evolution has shifted to rapid adaptations of our exosomatic organs (cars, airplanes, etc.) that depend on terrestrial low entropy. The uneven ownership of exosomatic organs and the terrestrial low entropy from which they are made, compared to the egalitarian distribution of ownership of endosomatic capital, was for Georgescu-Roegen the root of social conflict in industrial societies.

Howard T. Odum (1924–2002) was born in Durham, North Carolina, the son of Howard W. Odum, a noted sociologist. He was a meteorologist in the American tropics during World War II, received an AB in Zoology from the University of North Carolina in 1947, and a PhD from Yale University in 1951, under ecologist G. Evelyn Hutchinson. He has been concerned with material cycles and energy flow in ecosystems, and he produced one of the first energy flow descriptions of a complete ecosystem in his famous study of Silver Springs, Florida (Odum 1957). He also contributed heavily to his brother Eugene P. Odum's influential textbook, *Fundamentals of Ecology,* first published in 1953 (Odum 1953). This textbook was the standard in ecology for several decades and helped to establish several important ecological concepts, in the profession and in the public consciousness. In particular, the concept of the ecosystem was fully developed and was quantified using units of energy and material flows.

In addition to Hutchinson and his father H. W. Odum, H. T. Odum was influenced in his thinking by Lotka and von Bertalanffy, and he was concerned with many of the same problems as Georgescu-Roegen. His approach was broader than Georgescu-Roegen's, however, and went beyond economics and thermodynamics to include systems in general—from simple physical and chemical systems to biological and ecological systems to economic and social systems. In *Environment, Power, and Society*, he laid out a comprehensive integration of systems with energy flow being the integrating factor. He even developed his own symbolic language (similar in intent and use to Forrester's systems dynamics symbols) to help describe and model the common features of systems. This language was an indispensable aid to the initiated practitioner in helping to understand systems concepts and a barrier to outsiders gaining access to these same concepts.

Odum's work on energy flow through systems and dynamic modeling of systems spawned, or at least paralleled and encouraged, an immense amount of work by his students and others ranging from input–output studies of energy and material flow in ecological and economic systems (Hannon 1973; Ayres 1978; Costanza 1980; Cleveland et al. 1984) to dynamic simulation models of whole ecosystems and integrated ecological economic systems (Costanza et al. 1990; Bockstael et al. 1995). Probably the most concise and complete treatment of the application of many of H. T. Odum's ideas to ecological economics is the 1986 book by C. A. S. Hall, C. Cleveland, and R. Kaufmann titled *Energy and Resource Quality: The Ecology of the Economic Process.*

Both E. P. and H. T. Odum's work has inspired a whole generation of ecologists to study ecology as a systems science and to link it with economics and other disciplines. Although many (if not most) of H. T. Odum's ideas were controversial, they have spawned discussions of what we think are the right questions: How do systems work? How do they evolve and change? How do human systems and ecosystems interact over time? How can we develop an interdisciplinary understanding of systems? What patterns of human development are sustainable? All of these questions were being asked by H. T. and E. P. Odum in the 1950s, 1960s, and 1970s and are among the core questions of ecological economics today (Box 2.4).

2.3.4 Kenneth Boulding and Spaceship Earth and Herman Daly and Steady-State Economics

Kenneth Boulding's classic "The Economics of the Coming Spaceship Earth" (Boulding 1966) was first presented at the Sixth Resources for the Future Forum on Environmental Quality in a Growing Economy in Washington, DC. It set the stage for ecological economics with its description of the transition from the "frontier economics" of the past, where growth in human welfare implied growth in material consumption, to the "spaceship economics" of the future, where growth in welfare can no longer be fueled by growth in material consumption. "Frontier economics" sees the economic system as independent, where natural resources are just inputs to the economic process. In contrast, "spaceship economics" sees the economy as a subsystem within the physical context of the natural and social environment. Basically, Kenneth Boulding (1910–1993) explained the issue of scale, the reason why economic growth could not continue indefinitely over time on a finite planet (Boulding 1966).

Daly (1968, 1991b) elaborated further on this fundamental difference in vision and worldview in recasting economics as a life science—akin to biology and especially ecology, rather than a physical science such as chemistry or physics. The importance of this shift in "pre-analytic vision" (Schumpeter 1950) cannot be overemphasized. It implies a fundamental change in the perception of the problems of resource allocation and how they should be addressed. More particularly, it implies that the focus of analysis should be shifted from marketed resources in the economic system to the biophysical basis of interdependent ecological and economic systems (Clark 1973; Cleveland 1987; Martinez-Alier 1987; Christensen 1989). Daly further elaborated on this theme with his work on "steady state economics" (Daly 1973, 1977, 1991d), which worked out the implications of acknowledging that the Earth is materially finite and nongrowing; hence, rather than maximizing consumption, we should minimize throughput, and that the economy is a subset of this

BOX 2.4 THE MAXIMUM POWER PRINCIPLE

Odum used and elaborated Lotka's energy principle as an evolutionary criterion in systems. He clearly differentiated between energy efficiency (the ratio of useful outputs over total inputs) in systems and power (the rate of doing useful work) and related these two concepts (Odum and Pinkerton 1955). As Figure 2.9 shows, at zero efficiency, power is also zero because no work is being done. But at maximum efficiency, power again is zero because to achieve maximum efficiency one has to run processes reversibly, which for thermodynamic systems means infinitely slowly. Therefore, the rate of doing work goes to zero. It is at some intermediate efficiency (where one is "wasting" a large percentage of the energy) that power is maximized. Consider a simple example—the Atwood's machine. Here, an elevated weight attached to one end of a line over a pulley is used to pull up another weight attached to the other end of the line. When there is no weight at all attached to the lower end, the upper weight descends very rapidly but no work has been done because nothing has been lifted. We are at the zero efficiency side of Figure 2.9. When a weight exactly equal to the elevated weight is attached to the lower end, the system is at maximum efficiency

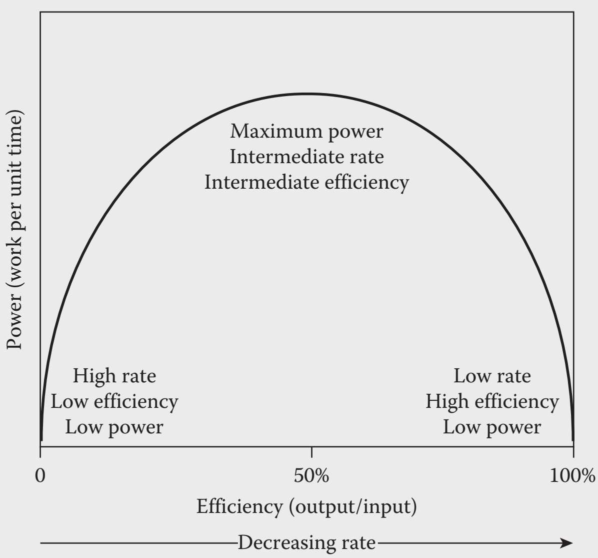

FIGURE 2.9
Trade-off between efficiency and power.

in Figure 2.9 but again the rate of doing work is zero because the lower weight does not move because the weights are perfectly balanced. When the lower weight is at 50% of the upper weight, the system maximizes the rate of doing work or power, as shown in Figure 2.9. The significance of this is that in systems (including ecological and economic systems), those configurations that maximize power, not efficiency, will be at a selective advantage. Entropy dissipation is required for the survival of living systems, and there are limits to the efficiency at which this can go on in dynamic adaptive systems. These efficiency limits are at much lower levels than those theoretically possible at reversible (i.e., infinitely slow) rates. For example, real power plants operate much closer to the maximum *power* efficiency than to the maximum *possible* efficiency.

finite global system. Thus the economy cannot grow forever (at least in a material sense) and ultimately some sort of sustainable steady state is desired. This steady state is not necessarily absolutely stable and unchanging. As in ecosystems, things in a steady-state economy are changing constantly in both periodic and aperiodic ways. The key point is that these changes are bounded and there is no long-term trend in the system. The work of Herman Daly (1938–) in steady-state economics can be seen as one of the direct antecedents of ecological economics.

2.3.5 C. S. Holling and Adaptive Environmental Management

In the late 1970s, Canadian ecologist C. S. Holling (1930–) became director of the International Institute for Applied Systems Analysis (IIASA). His earlier work on spruce budworm outbreaks in northern boreal forests had led him to a complex and dynamic view of ecosystems that eventually took over from the more "equilibrium" concepts that had held sway earlier. He was also concerned with how humans interacted with ecosystems and why their attempts at "management" failed so miserably (the spruce budworm/boreal forest was only one example). This all led to a groundbreaking book titled *Adaptive Environmental Assessment and Management* (Holling 1978).

Adaptive environmental management redraws conventional boundaries by integrating science and management. Holling realized that laboratory and controlled field experiments on parts of ecological systems could not be aggregated to an understanding of the whole. At best, we experiment when we manage ecosystems. Of course, we only learn from experiments if we monitor them well, undertake a fair number of them, and are prepared to learn from them. Thus, environmental management agencies, rather than looking to science to determine for them what is good management practice, must consciously become a part of the experimentation and learning processes. Furthermore, Holling argued, ecosystems do not have a single equilibrium state that they prefer. Rather, they have multiple equilibriums and also evolve over time. This being the case, the scientists and agencies working with ecosystems must constantly adapt their management experiments to understand a changing system (Holling 1978; Walters 1986; Lee 1993; Gunderson et al. 1995). This means that models and policies based on them are not taken as the ultimate answers but rather as guiding an adaptive experimentation process within the regional system. More emphasis is placed on monitoring and feedback to check and improve the model rather than using the model to obfuscate and defend a policy that is not corresponding to reality.

Walters and Holling (1990) distinguished three different types of adaptive management: (1) evolutionary or trial and error; (2) passive—management policies are implemented under the assumption that there is a single best response model and that this model is correct; and (3) active—management policies are viewed as experiments or hypotheses that are implemented and their effectiveness tested by the responses of the ecosystems.

Adaptive environmental management has proved to be an effective approach to understanding and managing complex, changing systems with large uncertainties. Although this approach emerged out of ecology and its application to management, it has tremendous implications for social organization. Environmental managers, people in associated communities, and those in the broader public who are especially interested in environmental issues should question, assist in the monitoring, and share in the learning. This is a very different vision than that of objective scientists determining the truth about environmental systems, managers applying it, and the people being passive beneficiaries. The approach acknowledges the coevolutionary nature of ecological and economic systems (as discussed in the next section) and is a key concept in ecological economics.

2.3.6 Coevolution of Ecological and Economic Systems

One of the strongest barriers to the union of economics and ecology has been the presumption that ecological and economic systems are separable and do not need to be understood together. Economists think of economic systems as separate from nature, while the vast majority of natural scientists think of natural systems as apart from people. Indeed, social scientists generally have thought that all social phenomena are culturally determined. When natural scientists do consider social phenomena, they "naturally" look to natural law to explain it. And so a "line in the sand" is frequently found between cultural and environmental determinists with economists being among the cultural determinists and ecologists being among the environmental determinists. As we have noted, this line reflects historic Western beliefs about systems and about science that had become a part of our problem, an explanation for the unsustainability of modern societies.

Evolutionary ecologists Paul Ehrlich and Peter Raven first alerted the scientific community to the importance of coevolution between species (Ehrlich and Raven 1964). The niche to which species evolve has most frequently been described as a fixed, physical niche. With the characteristics of the niche fixed, evolution acquires a direction, and evolutionary stories usually entail the species progressively fitting the characteristics better and better. Hence, evolutionary stories are frequently stories of progress, with human evolution being the ultimate story of progress. Coevolution is value-free and acknowledges that the characteristics of any one species are selected in the context of the characteristics of other species and vice versa, and the relationships between and among them affect their evolution; species coevolve. Although evolutionary direction and the analog to Western beliefs in progress are lost, coevolution helps explain why species fit together into ecosystems while at the same time species and ecosystems continue to change.

Norgaard (1994) illustrates how understanding the coevolutionary process can help us to understand how natural and social systems interconnect and change. From this, he suggests new directions for social organization to enhance environmental sustainability, social justice, and human dignity. Consider development as a process of coevolution between knowledge, values, organization, technology, and the environment (Figure 2.10). Each of these subsystems is related to each of the others yet each is also

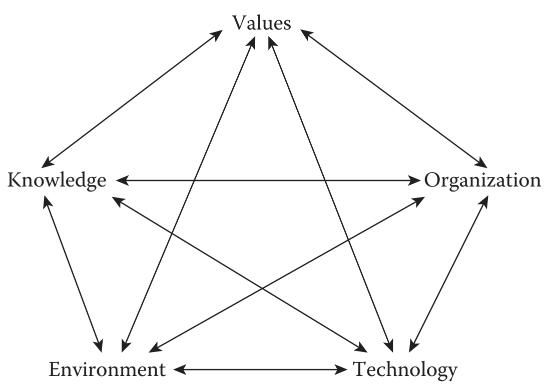

FIGURE 2.10
The coevolutionary development process.

changing and affecting change in the others through selection. Deliberate innovations, chance discoveries, and random changes occur in each subsystem that affect the distribution and qualities of components in each of the other subsystems through natural selection. Whether new components prove fit depends on the characteristics of each of the subsystems at the time. With each subsystem putting selective pressure on each of the others, they coevolve in a manner whereby each reflects the other. Thus everything is coupled, yet everything is changing.

Environmental subsystems are treated symmetrically with the subsystems of values, knowledge, social organization, and technology in this coevolutionary explanation of development. New technologies, for example, exert new selective pressures on species, while newly evolved characteristics of species, in turn, select for different technologies. Similarly, transformations in the biosphere select for new ways of understanding the biosphere. For example, the use of pesticides induces resistance and secondary pest resurgence, selecting both for new pesticides and for more systematic ways of thinking about pest control. Pests, pesticides, pesticide production, pesticide institutions and policy, how we understand pest control, and how we value chemicals in the environment demonstrate an incredibly tight and rapid coevolution in the second half of this century. In the short run, people can be thought of as interacting with the environment in response to market signals or their absence. The coevolutionary model, however, incorporates longer-term evolutionary feedbacks. To emphasize coevolutionary processes is not to deny that people directly intervene in and change the characteristics of environments. The coevolutionary perspective puts its emphasis on the chain of events thereafter, and how different interventions alter the selective pressure and hence the relative dominance of environmental traits that, in turn, select for values, knowledge, organization, and technology and hence subsequent interventions in the environment.

Although the coevolutionary perspective treats changes in the various subsystems symmetrically, let us use this model to address technology in particular. People have interacted with their environments over millennia in diverse ways, many of them sustainable over very long periods, many not. Some traditional agricultural technologies, at the intensities historically employed, probably increased biological diversity. There is general evidence that traditional technologies, again at the level employed, included biodiversity conserving strategies as a part of the process of farming. Technology today, however, is perceived as a leading culprit in the process of biodiversity loss. Modern agricultural technologies override nature but do so only locally and temporarily. They do not "control" nature. Pesticides kill some pests, solving the immediate threat to crops. But the vacant niche left by the pest is soon filled by a second species of pest (or the original pests evolve resistance), pesticides drift to interfere with the agricultural practices of other farmers, and pesticides and their by-products accumulate in soil and groundwater aquifers to plague production and human health for years to come. Each farmer strives to control nature but creates new problems beyond his or her farm and in subsequent seasons for others. Because of all the new problems created beyond the individual farm in space and time, preharvest crop losses due to pests since World War II have remained around 35% while pesticide use has increased dramatically.

New technologies that work with natural processes rather than override them are sorely needed. During the past three centuries, technologies have largely descended from physics, chemistry, and, at best, microbiology. Ecologists and evolutionary biologists were never given the opportunity to systemically review such technologies, nor is it clear that our ecological and evolutionary understanding are sufficient to review them adequately now. A few agricultural technologies, such as the control of pests through the use of other biologicals, have descended from ecological thinking. But research and technological development in biological control was nearly eliminated with the introduction of DDT in agriculture after World War II. Research on and development of agricultural technologies requiring fewer energy and material inputs eventually received considerable support in industrial countries after the rise in energy prices during the 1970s and the farm financial crises in the United States during the early 1980s. Support for agroecology, for technologies based on the management of complementarities between multiple species including soil organisms, however, are only beginning to gain popularity. Learning how to use renewable energy sources will be long and difficult because most of our knowledge has developed to capture the potential of fossil energy. Our universities and other research institutions are still structured around disciplinary rather than systemic thinking, and public understanding of the shortcomings of current technologies and possibilities for ecologically based technologies is still weak. Scientists and technologists reproduce themselves and their institutions through direct control and education; hence science and technology sometimes respond slowly to changes in the social awareness of environmental problems.

From the coevolutionary perspective, we can see more clearly how economies have transformed from coevolving with their ecosystems to coevolving around the combustion of fossil hydrocarbons. In this transformation, people have been freed from the environmental feedbacks on their economic activities that they experienced relatively quickly as individuals and communities. The feedbacks that remain, however, occur over longer periods and greater distances and are experienced collectively—even globally—by many people, making them more difficult to perceive and counteract (Norgaard 1994). By tapping into fossil hydrocarbons, Western societies freed themselves, at least for the short to medium term, from many of the complexities of interacting with environmental systems. Coevolution occurred around fossil hydrocarbons. Tractors replaced animal power, fertilizers replaced the complexities of interplanting crops that were good hosts of nitrogen-fixing bacteria with those that were not, and pesticides replaced the biological controls provided by more complex agroecosystems. Furthermore, inexpensive energy meant crops could be stored for longer periods and transported over greater distances. Social organization coevolved around these new possibilities very quickly. Each of these accomplishments was based on the partial understanding of separate sciences and separate technologies. At least in the short run and "on the farm," separate adjustments of the parts seemed to fit into a coherent, stable whole. Agriculture transformed from an agroecosystem culture of relatively self-sufficient communities to an agroindustrial culture of many separate, distant actors linked by global markets. This progression created a situation in which many countries have become overly dependent on food exports and significantly less self-sufficient. The massive changes in technology and organization gave people the sense of having control over nature and of being able to consciously design their future while in fact problems were merely being shifted beyond the farm and onto future generations.

This coevolutionary explanation of the unsustainability of modern societies then is simply that development based on fossil hydrocarbons allowed individuals to control their immediate environments for the short run while shifting environmental impacts, in ways that have proven difficult to comprehend, to broader and broader publics (ultimately to the entire global polity) and on to future generations. These more distant impacts can select on our social organization as we realize their long-term and global implications and choose to respond in advance, or they can select directly as they are experienced in the future. Working with these collective, longer-term, and more uncertain interrelationships is at least as challenging as environmental management had been historically. People's confidence in the sustainability of development is directly proportional to their confidence in our ability to address these new challenges.

The coevolutionary perspective helps us see that the problem of humans interacting with their environment is not simply a matter of establishing market incentives or appropriate rules about the use of property. Our values, knowledge, and social organization have coevolved around fossil hydrocarbons. Our fossil fuel-driven economy has not simply transformed the environment, it has selected for individualist, materialist values, favored the development of reductionist understanding at the expense of systemic understanding, and preferred a bureaucratic, centralized form of control that works better for steady-state industrial management than for the varied, surprising dynamics of ecosystem management. And the coevolutionary framing highlights how our abilities to perceive and resolve environmental problems within the dominant modes of valuing, thinking, and organizing are severely constrained.

The coevolutionary framework elaborated by Norgaard complements the efforts of cultural ecologists in anthropology (Boyd and Richerson 1985; Durham 1991). It has instigated new developments in thought among political economists (Stokes 1992) and has inspired ecological economics (Gowdy 1994). More recently, Kallis and Norgaard (2010) discuss a coevolutionary agenda for ecological economics and the implications for policy and development.

2.3.7 Role of Neoclassical Economics in Ecological Economics

After all of this description of alternative paradigms, it is important to reiterate that ecological economics is methodologically pluralistic and accepts the framework of analysis of neoclassical economics along with other frameworks. Indeed, neoclassical market analysis is still an important pattern of thinking within ecological economics. There are, however, differences between patterns of thinking and how the patterns are used with particular assumptions. We have already emphasized that most neoclassical economists assume that technological advance will outpace resource scarcity over the long run and that ecological services can also be replaced by new technologies. Ecological economists, on the other hand, assume that resource and ecological limits are critically important and are much less confident that technological advances will arise in response to higher prices generated by scarcities. This difference in worldview, however, does not prevent neoclassical and ecological economists from sharing the same pattern of reasoning.

There is another way in which neoclassical and ecological economists differ even while using the same patterns of thinking. As noted in the previous chapter, neoclassical economists have chosen to ignore how the initial distribution of rights to resources affects how markets subsequently allocate resources between end products and consumers. They have chosen to ignore this relationship since World War II largely for two reasons. First, Karl Marx focused on questions of the distribution of power, and the "other" side of the Cold War, the former USSR, China, and other nations, invoked Marx's name to rationalize their approach to social relations and development. In the West, especially in the United States during the 1950s, questioning the distribution of power was effectively an act of disloyalty. But neoclassical economists also had a second rationale for ignoring equity in the initial distribution of rights to resources. Growing economies could avoid the political difficulties of redistribution by making everyone better off. This became an important argument for increasing the rate of economic growth even in the countries that were already rich.

Furthermore, according to what we decide and want to sustain, two types of sustainability are promoted: weak and strong sustainability. The neoclassical view, the weak sustainability, is interested in preserving the total capital stock. Total capital stock is the sum of human, man-made, and natural capital. The purpose of weak sustainability is to sustain economic output. Weak sustainability is based on the assumption of substitutability among these three types of capital (Gowdy 2000). Weak sustainability assumes that human-made capital is a substitute for natural capital: "That the world can, in effect, get along without natural resources…" (Solow 1974, 11). Thus, as long as total capital is maintained, we are considered to be (weakly) sustainable. On the other hand, strong sustainability is interested in maintaining constant the stock of natural capital over time. Strong sustainability is based on the argument that the three types of capital—natural, man-made, and human—are not substitutes but rather complements. Strong sustainability argues that there is more to happiness than just increased economic output (Goodland 1995; Gowdy 2000).

Concern over sustainability has led to new concerns with equity in an era when Cold War politics have become history. Clearly, sustainability is a matter of transferring assets to future generations. This is a question of equity among generations. To understand sustainability using neoclassical economic reasoning, the distribution of resources among generations, or intergenerational equity, must be central. But sustainability is not simply a matter of intergenerational equity. In a world of very rich and very poor, asset transfer between generations is likely to be at less than a sustainable level. The very rich can be so rich that they do not worry about their progeny having enough. The very poor, on the other hand, can be so poor that each generation has to exploit resources and degrade environmental systems merely to subsist. For many ecological economists, these extremes characterize the world we live in and account for much of the unsustainability. The extremes internationally between rich and poor nations also make it very difficult to reach international understandings on managing the global commons. So sustainability is also a matter of intragenerational and international equity. The conventional stance of neoclassical economists remains that economic growth will provide the conditions to resolve these inequities. But there have been two generations of economic growth since the international development programs were established after World War II, and inequality has increased, not just within many countries but also between developing and developed countries. Thus, the conventional stance is wearing a little thin and is increasingly being questioned.

There is yet a third reason why neoclassical economists historically have not included distribution in their arguments. Once distribution is taken into consideration, there are many possible efficient market allocations depending on how rights to resources are distributed among people.

Since World War II, however, economists have undertaken analyses of the costs and benefits of alternative public projects and other public decisions so as to advise legislatures and public agencies as to which project or decision is best. The legislatures and agencies have asked them for "the" answer assuming the current distribution of rights to resources, not an array of answers depending on alternative distributions of rights to resources. Thus the tradition of not considering equity is firmly rooted in public practice.

The situation, however, is yet more complicated. Neoclassical economics cannot determine whether one distribution of resources among people is better than another. Moral criteria must be invoked and the decision must be made politically. But political decision making is more typically driven by the existing distribution of power than by moral discourse. To a large extent, economists were asked to undertake cost–benefit analysis in order to offset the politics of power. Economists see themselves as acting more in the public interest than the politicians responding to power and pressure groups. Yet, economists have been making their recommendations based on the existing distribution of power as well. So, it is difficult to see how things are going to change. If sustainability requires intergenerational and intragenerational redistribution, there will have to be a serious moral discourse and improvements in democratic politics to achieve sustainability. Paralleling this transition, economists will have to learn how to inform democratic debate with a working sense of trade-offs between options rather than undertaking cost–benefit analyses on behalf of the public.

The realization that economics must work with a more democratic politics complements another research style emerging within ecological economics. Acknowledging that economists need to understand ecology and vice versa further opens the door to asking whether anyone can possibly be excluded from sharing in the search for sustainability. Surely, to the extent that social and ecological systems differ from place to place, local, experiential knowledge will be essential to implementing specific solutions. For this reason, some ecological economists are beginning to experiment with participatory research methods that incorporate lay people with experiential knowledge (e.g., van den Belt et al. 1997).

Ecological economics, as an assemblage of concerned economists and ecologists, is not bound by the historic traditions of neoclassical economics. It uses the framework of neoclassical economics but is not constrained to use only that framework, nor is it constrained by the worldviews, politics, or cultures of economists in the past.

2.3.7.1 Critical Connections

It is difficult to determine where ecological economics ends and other approaches to understanding start. Ecological economists have reached out to other patterns of thinking and pursued a broad range of questions. And people from many fields have reached toward ecological economics. In the future, these connections may prove to be the most important of all, but for now, it is appropriate to describe them as a little less central to the origins of ecological economists.

2.3.7.1.1 Increased Efficiency and Dematerialization

Entrepreneurs and consumers have always had an incentive to get more from less. At the same time, when an individual uses less, he or she typically reaps only a portion of the benefits because of the numerous ways we are connected through ecosystems. Furthermore, choosing to use less must frequently be done collectively through developing new technologies, changing infrastructure to support public transit over automobile use, and adjusting the rules of the game for all. One response to the energy crises of the 1970s was to invest in the development of energy-efficient technologies, to label the efficiency of electric appliances, to mandate increased fuel efficiency for automobiles, and to encourage public utilities to help their customers use less electricity through home insulation. One individual, Amory Lovins, has been especially effective in arguing how the United States could substantially change its course and avoid the environmental consequences of fossil fuel dependence and the risks of nuclear technology by shifting dramatically toward energy efficiency and renewable energy sources (Lovins 1977, 1996).

A group of ecological economists documented the prospects for "dematerialization" at the Wuppertal Institute for Climate, Environment, and Energy in Germany (Hinterberger and Stahel 1996). Their arguments paralleled those of Lovins while also picking up on Herman Daly's argument that we need to stabilize the rate of material throughput in the economy. They calculated the material input per unit of service (or MIPS) for numerous consumption goods and services throughout their life span, making international and intersectorial comparisons possible. MIPS allows for the gathering of information about the direct and indirect resource use efficiency (Schutz and Welfens 2000). Material flows consist of flows of consumer goods and materials such as ores, soil, sand, and gravel, but do not include water and air, which had to be moved to produce the consumer goods. Material flows amounted to about 32 million tons per capita per year in Germany or about 1.2 kg per DM (1.75 lbs. per dollar) spent (Hinterberger and Stahel 1996). But some rather insignificant consumer choices result in significant material flows relative to readily available alternatives; and in other cases, flows could be reduced by increases in the efficiency with which materials are used or by increasing the longevity of the consumer product. Researchers at Wuppertal think material flows can be reduced by as much as a factor of 10. All of this may seem remote from an ecological management perspective, but the counterargument is that we are so far from a level of flow consistent with natural fluxes where management is even possible that the first step is massive reduction in human-induced material flows.

2.3.7.1.2 Ecosystem Health

To a considerable extent, although whole ecosystems have been protected, only individual species have been managed. Models have been derived from principles of population biology that suggest how, for example, Douglas fir trees or salmon can be harvested sustainably. But trees and salmon do not thrive apart from other species and a myriad of other factors that affect ecosystem behavior. For this reason, efforts to manage individual species using these models have proven amazingly ineffective (Holling 1978; Botkin 1990; Meffe 1992). In light of broader concerns with maintaining ecosystems per se and the failures of individual species models, a group of ecologists and social scientists joined together in the early 1990s to study and promote the concept of ecosystem health (Costanza et al. 1992), and they launched the journal *Ecosystem Health* in 1995. This group included many participants from the field of ecological economics and, like ecological economics, is transdisciplinary. "Health," the organizing metaphor, reminds us that for ecosystems, like people, "an ounce of prevention is worth a pound of cure." But it is more than a metaphor once we get serious about defining its meaning, try to agree to preferred states of ecosystems, and set out to develop management criteria across diverse ecosystems in anticipation of multiple possible disturbances (Rapport 1995).

The term "ecosystem integrity" has also been used to make new bridges between biology and policy. "Conservation biology" emerged as a field during the 1980s among biologists who were not content to simply study the decline of biodiversity and who became intent on saving species from extinction. These multiple efforts include scientists who participate in ecological economics as well. They are all examples of groups of scientists who are using science effectively to new ends by shedding the old assumptions about how knowledge fits together and affects progress (Box 2.5).

A healthy ecosystem may be defined in terms of three main features: vigor, resilience, and organization (Costanza et al. 1992; Mageau et al. 1995). In terms of benefits to the human community, a healthy ecosystem is one that provides the ecosystem services supportive of the human community, such as food, fiber, the capacity for assimilating and recycling wastes, potable water, and clean air.

Although the concept of health applied to the level of ecosystems and landscapes is of relatively recent origin (Rapport et al. 1981, 1998a, 1998b;

BOX 2.5 SPECIES EXTINCTION WITHOUT MARKET FAILURE

According to Hotelling's model, even when market prices fully reflect the value of a species, it will be efficient to exploit a species to extinction or to totally degrade an ecosystem if the value of the species or the ecosystem over time is not increasing at least as fast as money deposited in an interest-bearing bank account. Hotelling's logic was distressingly simple. If the value of the biological resource is not increasing as fast as the rate of interest, an individual owner of a biological resource and society at large would be economically better off exploiting the resource faster and putting the returns from the exploitation in the bank where they would be invested in the creation of human-produced capital that earned a return greater than the rate of interest. In this view, biological resources are a form of natural capital that can be converted into human-produced capital and should be so converted if they do not earn as high a return as human-produced capital. This argument describes why economically rational owners of biological resources exploit them to extinction or destruction, and it prescribes that they "should" do so. So long as markets reflect true values, historic and ongoing losses of genetic, species, and ecosystem diversity are efficient and "should" occur. Hotelling's reasoning currently dominates resource economic theory and policy advice from economists, but the section on intergenerational equity shows how Hotelling's argument is inappropriate for most decisions regarding conservation.

Rapport 1989a, 1989b), it has become a guiding framework in many areas, particularly in the evaluation of the large marine ecosystems (Sherman 1995), agroecosystems (Gallopin 1995; Wichert and Rapport 1998), desert ecosystems (Whitford et al. 1996), and others (Rapport 1989a, 1989b).

To appreciate the ecosystem health concept, one must begin by acknowledging that humans are a major component in many (if not most) ecosystems today—although the degree of human interaction varies widely. The human part of the ecosystem includes the humans themselves, their artifacts and manufactured goods (economies), and their institutions and cultures. It is this larger ecosystem (including humans) whose health we need to assess as well as the smaller-scale subsystems of which it is composed.

Based on a survey of health concepts in many fields, Costanza et al. (1992) developed the following three general categories of performance that are usually associated with "well-functioning" in any complex living system at any scale:

1. The vigor of a system is a measure of its activity, metabolism, or primary productivity. Examples include metabolic rate in organisms, gross and net primary productivity in ecological systems, and GNP in economic systems.
2. The organization of a system refers to the number and diversity of interactions among the components of the system. Measures of organization are affected by the diversity of species, and also by the number of pathways and patterns of material and information exchange among the components.
3. The resilience of a system refers to its ability to maintain its structure and pattern of behavior in the presence of stress (Holling 1973). A healthy system is one that possesses adequate resilience to survive various small-scale perturbations. The concept of system resilience has two main components: (1) the length of time it takes for a system to recover from stress (Pimm 1984) and (2) the magnitude of stress from which the system can recover, or the system's specific thresholds for absorbing various stresses (Holling 1973) these two components can be combined into an overall definition of resilience as the ratio of the maximum stress (MS) the system can withstand without flipping to a new state divided by the return time.

2.3.7.1.3 Environmental Epistemology

The field of philosophy that studies how we think we can learn "truth" is known as epistemology. Clearly, if *Homo sapiens* is so special because we are smarter than other animals, then the special problems we have gotten ourselves into relative to other animals must in some sense also be related to how we think. And if we believe that science has indeed driven the technological, and even to some extent the institutional, changes that are behind development, then how we know things scientifically must also be partly responsible for the environmental consequences of development. In this sense, the environmental crises of the latter half of the twentieth century are challenging the underlying premises of the dominant forms of Western science. To argue that separating economics from ecology is a mistake, a dominant premise of ecological economics, is to make an epistemological statement. Realizing this, several ecological economists have explored the history and philosophy of science to directly understand how environmental crises have developed (Norgaard 1989, 1994; Funtowicz and Ravetz 1991; O'Connor et al. 1996). One of the dominant premises of Western science, for example, has been the idea that nature behaves in a predictable manner according to universal principles that once discovered are applicable everywhere. If nature, however, is evolving and, furthermore, has evolved differently in different places, then the expectation that there can be a "physics" of nature can lead people to make a good number of mistakes. If it were such basic premises that are at the root of our crises, then it would be most effective to tackle them directly before trying to create new ways of understanding.

Post-normal science has been proposed as a methodology to manage complex systems—it takes into account uncertainty and values (Funtowicz and Ravetz 1999). Although normal science only gives predictions based on the data, post-normal science steps beyond what normal science is capable of doing. It builds scenarios of possible futures and replaces uncertainties with probabilities, even though the scenarios are not necessarily supported by the data. Thus, it allows for more effective policy decision making by presenting the different alternative scenarios in the future.

2.3.7.1.4 Political Ecology

As noted in the previous chapter, Karl Marx has had an important influence on the social sciences. Besides focusing our attention on power and inequity, Marx has helped us keep our attention on history. The environmental crises of the latter half of the twentieth century have stimulated new critiques of capitalism and development by Marxist anthropologists, economists, historians, and sociologists. From these critiques, a new field known as political ecology has emerged (e.g., Blaikie 1985). Again, the overlap of participants between political ecology and ecological economics is strong (see, e.g., the contributors to O'Connor 1995). Although most of the arguments with respect to equity being made in ecological economics are formally neoclassical (e.g., Howarth and Norgaard 1992), the concern with equity complements research in the area of political ecology on power, poverty, and environmental transformation using Marxian frames of analysis. In ecological economics, work has been done with the two historically separate strands of economic thought being used to inform each other (Martinez-Alier and O'Connor 1996; Gerber et al. 2009).

2.4 Conclusions

Ecological economics continues to evolve through the interaction of diverse patterns of thinking with multiple disciplinary roots. The founding practitioners of ecological economics have combined understandings from multiple fields of thought, questioned historical assumptions, and have risked being ostracized by their disciplinary peers. The opportunity for many more combinations and the questioning of assumptions await whomever would like to join the field. However, disciplinary pressures have not eased yet.

From this point, this introduction to the field of ecological economics pursues one dominant approach to the field. Although ecological economists are certainly diverse, the largest "cluster" works from the initial premise that the Earth has a limited capacity for sustainably supporting people and their artifacts determined by combinations of resource limits and ecological thresholds. To keep the economy operating sustainably within these limits, specific environmental policies need to be established. And so first we document the "pre-analytic vision" of this strain of ecological economics and then we elaborate on potential existing institutions and on new institutions for achieving it.

3

Principles and Objectives of Ecological Economics

As described in the previous chapter, ecological economics is the product of an evolutionary historical development. It is not a static set of answers but a dynamic, constantly changing set of questions. It also advocates a fundamentally different, transdisciplinary vision of the scientific endeavor that emphasizes dialogue and cooperative problem solving. It tries to transcend the definition and protection of intellectual turf that plagues the current disciplinary structure of science. This transdisciplinary vision was the rule in earlier times, but it has been replaced by a more rigid disciplinary vision in recent times.

Figure 3.1 illustrates how this transdisciplinary vision differs from the now standard disciplinary vision. In the upper panel, the standard disciplinary vision is depicted as one that leads to the defining and protecting of disciplinary territories on the intellectual landscape. Sharp boundaries between disciplines, different languages, cultures within disciplines, and lack of any overarching view create problems that cross disciplinary boundaries or that fall in the empty spaces between the territories—very difficult, if not impossible, to deal with. There are also large gaps in the landscape that are not covered by any discipline. Within this vision of how to organize the scientific endeavor, one might think that the main role of ecological economics would be to fill in the empty space between economics and ecology while maintaining sharp boundaries between what is economics, what is ecology, and what is ecological economics. But this is not the vision of ecological economics.

The middle panel in Figure 3.1 illustrates an interdisciplinary vision of the problem. In this vision, the disciplines expand and overlap to fill in the empty spaces in the intellectual landscape but maintain their core territories. There is dialogue and interaction in the overlaps between territories, but the picture begins to look jumbled and incoherent. This vision is of a movement in the direction of a transdisciplinary ecological economics vision, but it is still not quite there.

The bottom panel of Figure 3.1 illustrates the ecological economics vision, where the boundaries between disciplines have been completely eliminated and the problems and questions are seen as a seamless whole

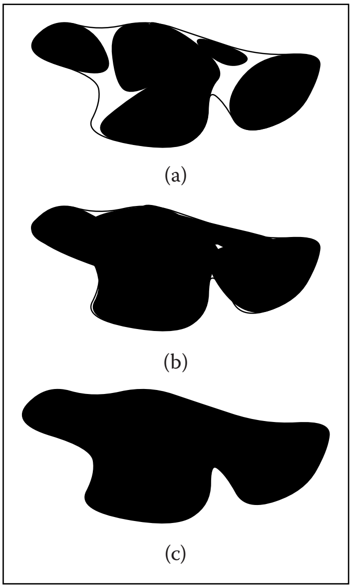

FIGURE 3.1
Disciplinary versus transdisciplinary views: (a) Standard disciplinary view of the problem as "intellectual turf." Sharp boundaries between disciplines, different languages, and cultures within disciplines, and lack of any overarching view make problems that are very difficult for cross-disciplinary boundaries to deal with. (b) Interdisciplinary view where disciplines expand and overlap to fill in the empty spaces in the intellectual landscape. (c) Transdisciplinary approach views the problem as a whole rather than as intellectual turf to be divided up and views the boundaries of the intellectual landscape as porous and changing.

in an intellectual landscape that is also changing and growing. This vision coexists and interacts with the conventional disciplinary structure, which is a necessary and useful way to address many problems. The transdisciplinary view provides an overarching coherence that can tie disciplinary knowledge together and that can address the increasingly important problems that cannot be addressed within the disciplinary structure. In this sense, ecological economics is not an alternative to any of the existing disciplines. Rather it is a new way of looking at the problem that can add value to the existing approaches and that can address some of the deficiencies of the disciplinary approach. It is not a question of "conventional economics" versus "ecological economics" but rather conventional economics as one input (among many) to a broader transdisciplinary synthesis.

We believe that this transdisciplinary way of looking at the world is essential if we are to achieve the three interdependent goals of ecological economics discussed here: sustainable scale, fair distribution, and efficient allocation. This requires the integration of three elements: (1) a practical, shared vision of the way the world works and of the sustainable society we wish to achieve; (2) methods of analysis and modeling that are relevant to the new questions and problems this vision embodies; and (3) new institutions and instruments that can effectively use the analyses to adequately implement the vision.

The importance of the integration of these three components cannot be overstated. Too often when discussing practical applications, we focus only on the implementation element, forgetting that an adequate vision of the world and our goals is often the most practical device for achieving the vision, and that without appropriate methods of analysis even the best vision can be blinded. The importance of communication and education concerning all three elements also cannot be overstated.

The basic points of consensus in the ecological economics vision are as follows:

1. The vision of the Earth as a thermodynamically closed and nonmaterially growing system, with the human economy as a subsystem of the global ecosystem. This implies that there are limits to biophysical throughput of resources from the ecosystem, through the economic subsystem, and back to the ecosystem as wastes.
2. The future vision of a sustainable planet with a high quality of life for all its citizens (humans and other species) within the material constraints imposed by 1.
3. The recognition that in the analysis of complex systems such as the Earth at all space and time scales, fundamental uncertainty is large and irreducible and certain processes are irreversible, requiring a fundamentally precautionary stance.
4. That institutions and management should be proactive rather than reactive and should result in simple, adaptive, and implementable policies based on a sophisticated understanding of the underlying systems that fully acknowledge the underlying uncertainties. This forms the basis for policy implementation, which is itself sustainable.
5. The last point is conceptually pluralistic. This means that even while people writing in ecological economics were trained in a particular discipline (and may prefer that mode of thinking over others), they are open to an appreciation of other modes of thinking and actively seek a constructive dialogue among disciplines (Norgaard 1989). There is not one right approach or model because, like the blind men and the elephant, the subject is just too big and complex to touch all of it with one limited set of perceptual or computational tools.

3.1 Sustainable Scale, Fair Distribution, and Efficient Allocation

One way of characterizing ecological economics is to list the basic problems and the questions it addresses. We see three basic problems: allocation, distribution, and scale. Neoclassical economics deals extensively with allocation, secondarily with distribution, and not at all with scale. Ecological economics deals with all three and accepts much of neoclassical theory regarding allocation. Our emphasis on the scale question is made necessary by its neglect in standard economics. Inclusion of scale is the biggest difference between ecological economics and neoclassical economics.

Allocation refers to the relative division of the resource flow among alternative product uses—how much goes to production of cars, to shoes, to plows, to teapots, and so on. A good allocation is one that is *efficient*, that is, that allocates resources among product end-uses in conformity with individual preferences as weighted by the ability of the individual to pay. The policy instrument that brings about an efficient allocation is relative prices determined by supply and demand in competitive markets.

Distribution refers to the relative division of the resource flow, as embodied in final goods and services, among alternative people. How much goes to you, to me, to others, to future generations. A good distribution is one that is *just* or *fair* or at least one in which the degree of inequality is limited within some acceptable range. The policy instrument for bringing about a more just distribution is transfers, such as taxes and welfare payments.

Scale refers to the physical volume of the throughput, the flow of matter–energy from the environment as low-entropy raw materials and back to the environment as high-entropy wastes (see Figure 1.1). It may be thought of as the product of population times per capita resource use. It is measured in absolute physical units, but its significance is relative to the natural capacities of the ecosystem to regenerate the inputs and to absorb the waste outputs on a sustainable basis. Perhaps the best index of scale of throughput is real gross domestic product (GDP). Although measured in value units (P × Q, where P is price and Q is quantity), real GDP is an index of change in Q. National income accountants go to great lengths to remove the influence of changes in price, both relative prices and the price level. For some purposes, the scale of throughput might better be measured in terms of embodied energy (Costanza 1980; Cleveland et al. 1984). The economy is viewed as an open subsystem of the larger but finite, closed, and nongrowing ecosystem. Its scale is significant relative to the fixed size of the ecosystem. A good scale is one that is at least *sustainable*—that does not erode environmental carrying capacity over time. In other words, future environmental carrying capacity should not be discounted as is done in present value calculations. An optimal scale is at least sustainable, but beyond that it is a scale at which we have not yet sacrificed ecosystem services that are at present worth more at the margin than the production benefits derived from the growth in the scale of resource use.

Scale in this context is not to be confused with the concept of "economies of scale," which refers to the way efficiency changes with the scale or size of production within a firm or industry. Here we are using scale to refer to the overall scale or size of the total macroeconomy and throughput.

Priority of Problems. The problems of efficient allocation, fair distribution, and sustainable scale are highly interrelated but distinct; they are most effectively solved in a particular priority order, and they are best solved with independent policy instruments (Daly 1992). There are an infinite number of efficient allocations but only one for each distribution and scale. Allocative efficiency does not guarantee sustainability (Bishop 1993). It is clear that scale should not be determined by prices but by a social decision reflecting ecological limits. Distribution should not be determined by prices but by a social decision reflecting a just distribution of assets. Subject to these social decisions, individualistic trading in the market is then able to allocate the scarce rights efficiently.

Distribution and scale involve relationships with the poor, future generations, and other species that are fundamentally social in nature rather than individual. *Homo economicus* as the self-contained atom of methodological individualism, or as the pure social being of collectivist theory, is a severe abstraction. Our concrete experience is that of "persons in community." We are individual persons, but our very individual identity is defined by the quality of our social relations. Our relations are not just external, but they are also internal—that is, the nature of the related entities (ourselves in this case) changes when relations among them change. We are related not only by a nexus of individual willingness-to-pay for different things but also by relations of trusteeship for the poor, future generations, and other species. The attempt to abstract from these concrete relations of trusteeship and to reduce everything to a question of individual willingness-to-pay is a distortion of our concrete experience as persons in community—an example of what A. N. Whitehead called "the fallacy of misplaced concreteness" (Daly and Cobb 1989).

The prices that measure the opportunity costs of reallocation are unrelated to measures of the opportunity costs of redistribution or of a change in scale. Any trade-off among the three goals (e.g., an improvement in distribution in exchange for a worsening in scale or allocation, or more unequal distribution in exchange for sharper incentives seen as instrumental to more efficient allocation) involves an ethical judgment about the quality of our social relations rather than a willingness-to-pay calculation. The contrary view, that this choice among basic social goals and the quality of social relations that help to define us as persons should be made on the basis of individual willingness-to-pay, just as the trade-off between chewing gum and shoelaces is made, seems to be dominant in economics today, and it is part of the retrograde modern reduction of all ethical choices to the level of personal tastes weighted by income.

It is instructive to consider the historical attempt of the scholastic economists to subsume distribution under allocation (or more likely they were subsuming allocation under distribution—at any rate they did not make the distinction). This was the famous "just price" doctrine of the Middle Ages that has been totally rejected in economic theory, although it stubbornly survives in the politics of minimum wages, farm price supports, water and electric power subsidies, and so forth. However, we do not, as a general rule, try to internalize the external cost of distributive injustice into market prices. We reject the attempt to correct market prices for their unwanted effects on income distribution. Economists nowadays keep allocation and distribution quite separate, and they argue for letting prices serve only efficiency, while serving justice with the separate policy of transfers. This follows Tinbergen's dictum of equality of policy goals and instruments: one instrument for each policy. The point is that just as we cannot subsume distribution under allocation, neither can we subsume scale under allocation.

It seems clear, then, that we need to address the problems in the following order: first, establish the ecological limits of sustainable scale and establish policies that assure that the throughput of the economy stays within these limits. Second, establish a fair and just distribution of resources using systems of property rights and transfers. These property right systems can cover the full spectrum from individual to government ownership, but intermediate systems of common ownership and systems for dividing the ownership of resources into ownership of particular services need much more attention (Young 1992). Third, once the scale and distribution problems are solved, market-based mechanisms can be used to allocate resources efficiently. This involves extending the existing market to internalize the many environmental goods and services that are currently outside the market. Policy instruments to achieve the three goals of sustainable scale, fair distribution, and efficient allocation are discussed in detail in Chapter 4. First, we delve a little more deeply into the scale and distribution problems.

3.1.1 From Empty-World Economics to Full-World Economics

Ecological economics argues that the evolution of the human economy has passed from an era in which human-made capital was the limiting factor in economic development to an era in which remaining natural capital has become the limiting factor. Economic logic tells us that we should maximize the productivity of the scarcest (limiting) factor, as well as try to increase its supply. This means that economic policy should be designed to increase the productivity of natural capital and its total amount, rather than to increase the productivity of human-made capital and its accumulation, as was appropriate in the past when it was the limiting factor.

The mainstream model of development, sometimes known as the "Washington Consensus," is based on a number of assumptions about the way the world works, what the economy is, and what the economy is for. These assumptions emerged during a period—the early Industrial Revolution—when the world was still relatively empty of humans and their built infrastructure. Natural resources were abundant, social settlements were sparser, and inadequate access to infrastructure represented the main limit on improvements to human well-being. It made sense, at that time, not to worry too much about environmental and social "externalities." They could be assumed to be relatively small and ultimately manageable. It made sense to focus on the growth of the market economy, measured in terms of GDP as a primary means of improving human welfare. It made sense, in that context, to think of the economy as only marketed goods and services and to think of the goal as increasing the amount of goods and services produced and consumed.

The world, however, has changed dramatically since that time. We now live in a world relatively full of humans and their built infrastructure. Since the end of World War II, the planet has experienced what some have called "the great acceleration" in the consumption of fossil fuels and in the growth of market economies. The human footprint has grown so large that, in many cases, limits on the availability of natural resources now constrain real progress more than limits on capital infrastructure do. In this new context, we first have to remember that the goal of an economy is to sustainably improve human well-being and quality of life. Material consumption and GDP are merely means to that end, not ends in themselves. We have to recognize, as both ancient wisdom and new psychological research tell us, that material consumption beyond real need can actually reduce well-being. Such a reorientation leads to specific tasks. We have to identify what really does contribute to human well-being and to recognize and gauge the substantial contributions of natural and social capital, both of which are coming under increasing stress. We have to be able to distinguish between real poverty in terms of low quality of life and merely low monetary income.

Ultimately, we have to create a new vision of what the economy is and what it is for and a new model of development that acknowledges the new full-world context (Costanza 2008).

3.1.2 Reasons the Turning Point Has Not Been Noticed

Why has the transformation from a world that is relatively empty of human beings and human-made capital to a world that is relatively full of these not been noticed by economists? If such a fundamental change in the pattern of scarcity is real, then how could it be overlooked by economists whose job is to pay attention to the pattern of scarcity? Some economists, including Boulding (1966) and Georgescu-Roegen (1971), have indeed signaled the change, but their voices have been largely unheeded.

One reason is the deceptive acceleration of exponential growth. With a constant rate of growth, the world will go from half full to totally full in one doubling period—the same amount of time that it took to go from 1% full to 2% full. Of course, the doubling time itself has shortened, compounding the deceptive acceleration. If we return to our example of the percent appropriation by human beings of the net product of land-based photosynthesis as an index of how full the world is of humans and their capital, then we can say that it is 40% full because we use, directly and indirectly, about 40% of the net primary product of land-based photosynthesis (Vitousek et al. 1986). Taking 40 years as the doubling time of the human scale (i.e., population times per capita resource use) and calculating backward, we go from the present 40% to only 10% full in just two doubling times or in 80 years, which is about an average U.S. lifetime. Also, "full" here is taken as 100% human appropriation of the net product of photosynthesis, which is ecologically unlikely and socially undesirable (only the most recalcitrant species would remain wild; all others would be managed for human benefit). In other words, effective fullness occurs at less than 100% human preemption of net photosynthetic product, and there is much evidence that long-run human carrying capacity is reached at less than the existing 40% (see Chapter 1). The world has rapidly gone from relatively empty (10% full) to relatively full (40% full). Although 40% is less than half, it makes sense to think of it as indicating relative fullness because it is only one doubling time away from 80%, a figure that represents excessive fullness. This change has been faster than the speed with which fundamental economic paradigms shift. According to the physicist Max Planck, a new scientific paradigm triumphs not by convincing the majority of its opponents, but because its opponents eventually die. There has not yet been time for the empty-world economists to die; meanwhile, they have been cloning themselves faster than they are dying by maintaining tight control over their guild. The disciplinary structure of knowledge in modern economics is far tighter than that of the turn-of-the-century physics that was Planck's model. Full-world economics is not yet accepted as academically legitimate, but it is beginning to be seen as a challenge. This book, based on full-world economics, challenges the empty-world economics prevailing today.

3.1.3 Complementarity, Substitutability, and Fundamental Limits

A major reason for failing to note the major change in the pattern of scarcity is that in order to speak of a limiting factor, the factors must be thought of as complementary. If factors are good substitutes, then a shortage of one does not significantly limit the productivity of the other. A standard assumption of neoclassical economics has been that factors of production are highly substitutable. Although other models of production have considered factors as not at all substitutable (e.g., the total complementarity of the Leontief model), the substitutability assumption has dominated. Consequently, the very idea of a limiting factor was pushed into the background. If factors are substitutes rather than complements, then there can be no limiting factor and hence no new era based on a change of the limiting role from one factor to another. It is therefore important to be very clear on the issue of complementarity versus substitutability.

The productivity of human-made capital is more and more limited by the decreasing supply of complementary natural capital. Of course, in the past, when the scale of the human presence in the biosphere was low, human-made capital played the limiting role. The switch from human-made to natural capital as the limiting factor is thus a function of the increasing scale and impact of the human presence. Natural capital is the stock that yields the flow of natural resources—the forest that yields the flow of cut timber; the petroleum deposits that yield the flow of pumped crude oil; the fish populations in the sea that yield the flow of caught fish. The complementary nature of natural and human-made capital is made obvious by asking: what good is a sawmill without a forest? A refinery without petroleum deposits? A fishing boat without populations of fish? Beyond some point in the accumulation of human-made capital, it is clear that the limiting factor on production will be remaining natural capital. For example, the limiting factor determining the fish catch is the reproductive capacity of fish populations, not the number of fishing boats; for gasoline, the limiting factor is petroleum deposits, not refinery capacity; and for many types of wood, it is remaining forests, not sawmill capacity. Costa Rica and Peninsular Malaysia, for example, now must import logs to keep their sawmills employed. One country can accumulate human-made capital and deplete natural capital to a greater extent only if another country does it to a lesser extent—for example, Costa Rica must import logs from somewhere. The demands of complementarity between human-made and natural capital can be evaded within a nation only if they are respected among nations.

Of course, multiplying specific examples of complementarity between natural and human-made capital will never suffice to prove the general case. But the examples given here at least serve to add concreteness to the more general arguments for the complementarity hypothesis given later (Section 3.3).

Because of the complementary relationship between human-made and natural capital, the very accumulation of human-made capital puts pressure on natural capital stocks to supply an increasing flow of natural resources. When that flow reaches a size that can no longer be maintained, there is a big temptation to supply the annual flow unsustainably by liquidation of natural capital stocks, thus postponing the collapse in the value of the complementary human-made capital. Indeed, in the era of empty-world economics, natural resources and natural capital were considered free goods (except for extraction or harvest costs). Consequently, the value of human-made capital was under no threat from scarcity of a complementary factor. In the era of full-world economics, this threat is real and is met by liquidating stocks of natural capital to temporarily keep up the flows of natural resources that support the value of human-made capital—hence, the problem of sustainability.

3.1.4 Policy Implications of the Turning Point

In this new full-world era, investment must shift from human-made capital accumulation toward natural capital preservation and restoration. Also, technology should be aimed at increasing the productivity of natural capital more than human-made capital. If these two things do not happen, then we will be behaving uneconomically, in the most orthodox sense of the word. That is, the emphasis should shift from technologies that increase the productivity of labor and human-made capital to those that increase the productivity of natural capital. This would occur by market forces if the price of natural capital were to rise as it became more scarce. What keeps the price from rising? In most cases, natural capital is unowned and consequently nonmarketed. Therefore, it has no explicit price and is exploited as if its price were zero. Even where prices exist on natural capital, the market tends to be myopic and excessively discounts the costs of future scarcity, especially when under the influence of economists who teach that accumulating capital is a near-perfect substitute for depleting natural resources!

Natural capital productivity is increased by: (1) increasing the flow (net growth) of natural resources per unit of natural stock (limited by biological growth rates); (2) increasing product output per unit of resource input (limited by mass balance); and especially by (3) increasing the end-use efficiency with which the resulting product yields services to the final user (limited by technology). We have already argued that complementarity severely limits what we should expect from (2), and complex ecological interrelations and the law of conservation of matter–energy limits the increase from (1). Therefore, the ecological economics focus should be mainly on (3).

The aforementioned factors limit productivity from the supply side. From the demand side, preferences may limit the economic productivity of natural capital more stringently than the limit of biological productivity. For example, game ranching and fruit and nut gathering in a natural tropical forest may, in terms of biomass, be more productive than cattle ranching. But undeveloped tastes for game meat and tropical fruit may make this use less profitable than the biologically less productive use of cattle ranching. In this case, a change in tastes can increase the biological productivity with which the land is used.

Because human-made capital is owned by the capitalist, we can expect that it will be maintained with an interest toward increasing its productivity. Labor power, which is a stock that yields the useful services of labor, can be treated in the same way as human-made capital. Labor power is human made and is owned by the laborer who has an interest in maintaining it and enhancing its productivity. But nonmarketed natural capital (the water cycle, the ozone layer, the atmosphere, etc.) is not subject to ownership, and no self-interested social class can be relied upon to protect it from overexploitation.

If the thesis argued here was accepted by development economists, what policy implications would follow? In the new era, the role of economic development banks would be increasingly to make investments that replenish the stock and that increase the productivity of natural capital. In the past, development investments have largely aimed at increasing the stock and productivity of human-made capital. Instead of investing mainly in sawmills, fishing boats, and refineries, development should now focus on reforestation, restocking of fish populations, and renewable substitutes for dwindling reserves of petroleum. The latter should include investment in energy efficiency because it is impossible to restock petroleum deposits. Because natural capacity to absorb wastes is also vital, resource investments that preserve that capacity (e.g., pollution reduction) also increase in priority. For marketed natural capital, this will not represent a revolutionary change. For nonmarketed natural capital, it will be more difficult, but even here economic development can focus on complementary public goods such as education, legal systems, public infrastructure, and population prudence. Investments in limiting the rate of growth of the human population are of the greatest importance in managing a world that has become relatively full. Like human-made capital, human-made labor power is also complementary with natural resources, and its growth can increase demand for natural resources beyond the capacity of natural capital to supply sustainably.

The clearest policy implication of the full-world thesis is that the level of per capita resource use of the rich countries cannot be generalized to the poor, which has been the case for the past few decades due to population growth. Present total resource use levels are already unsustainable, and multiplying them by a factor of five to ten as envisaged in the *Brundtland Report*, albeit with considerable qualification, is ecologically impossible.

In 2008, the prestigious Commission on Growth and Development released its final 180-page report, "The Growth Report," which is a product of 18 blue ribbon contributors from 16 countries, under the leadership of economics Nobelists Michael Spence and Robert Solow and World Bank vice president Danny Leipziger. The report stated that "sustained growth" means that the global economy is to grow at 7% for 25 years (duplicating the experience of the 13 star performers), which means the economy will increase by a factor of 5.4. At the end of 25 years will that be enough, or might we need two five-year encores? We are not told, but inasmuch as the concept of "enough" is absent from the analysis, one expects a series of encores. A "mere" quintupling of the scale of the economic subsystem relative to the scale of the nongrowing and containing ecosystem should by itself trigger a few questions. Are remaining environmental sources and sinks sufficient to regenerate the resources and to absorb the wastes of the larger metabolic flow (resource throughput) necessary to sustain the quintupled global economy? Did perhaps the rapidly growing 13 states use more than their share of the world's remaining sources and sinks, including the most accessible ones, effectively precluding the generalized repetition of their accomplishment? Indeed, even at the present scale, what makes this blue ribbon commission believe that the extra ecological and social costs of growth are not already larger than the extra production benefits? For a report that claims that growth is the sine qua non of most good things, one would expect some careful analysis of the concept and measurement of growth. Is growth a temporary process necessary to arrive at some desired, sufficient state, which thereafter is maintained, like the stationary state of J. S. Mill? Or is it the process of growth itself that is permanently desirable and presumably limitless? This question gets no consideration at all. The assumption seems to be growth forever. Because the report's subtitle refers to both "growth" and "development," one would expect some useful distinction, such as ecological economists have introduced, namely that growth is quantitative physical increase while development is qualitative improvement (Daly 2008).

As a policy of growth becomes less possible, the importance of redistribution and population prudence as measures to combat poverty increases correspondingly. In a full world, human numbers and per capita resource use must be constrained. Poor countries cannot cut per capita resource use; indeed, they must increase it to reach a sufficiency, so their focus must be mainly on population control. Rich countries can cut both, and for those that have already reached demographic equilibrium, the focus would be more on limiting per capita consumption to make resources available for transfer to help bring the poor up to sufficiency. Investments in the areas of population control and redistribution therefore increase in priority for development.

Investing in natural capital (nonmarketed) is essentially an infrastructure investment on a grand scale and in the most fundamental sense of infrastructure—that is, the biophysical infrastructure of the entire human niche, not just the within-niche public investments that support the productivity of the private investments. Rather we are now talking about investments in biophysical infrastructure (infra-infrastructure) to maintain the productivity of all previous economic investments in human-made capital—be they public or private—by investing in rebuilding the remaining natural capital stocks, which have come to be limitative. Because our actual ability to re-create natural capital is very limited, such investments will have to be indirect—that is, they must conserve the remaining natural capital and encourage its natural growth by reducing our level of current exploitation. Investments in waiting (e.g., fallow) have been respectable and accepted since Alfred Marshall in 1890. This includes investing in projects that relieve the pressure on these natural capital stocks by expanding cultivated natural capital (plantation forests to relieve pressure on natural forests) and by increasing end-use efficiency of products.

The difficulty with infrastructure investments is that their productivity shows up in the enhanced return on other investments and is therefore difficult to calculate and to collect for loan repayment. Also, in the present context, these ecological infrastructure investments are defensive and restorative in nature—that is, they will protect existing rates of return from falling more rapidly than otherwise, rather than raising their rate of return to a higher level. This circumstance will dampen the political enthusiasm for such investments but will not alter the economic logic favoring them. Past high rates of return to human-made capital were possible only with unsustainable rates of use of natural resources and consequent (uncounted) liquidation of natural capital. We are now learning to deduct natural capital liquidation from our measure of national income (see Ahmad et al. 1989). The new era of sustainable development will not permit natural capital liquidation to count as an income and will consequently require that we become accustomed to lower rates of return on human-made capital—rates on the order of magnitude of the biological growth rates of natural capital—because that will be the limiting factor.

Once investments in natural capital have resulted in equilibrium stocks that are maintained but not expanded (yielding a constant total resource flow), then all further increases in economic welfare would have to come from increases in pure efficiency resulting from improvements in technology and clarification of priorities. Certainly investments are being made in increasing biological growth rates, and the advent of genetic engineering may add greatly to this thrust. However, experience to date (e.g., the green revolution) indicates that higher biological yield rates usually require the sacrifice of some other useful quality (disease resistance, flavor, strength of stalk). In any case, the law of conservation of matter–energy cannot be evaded by genetics: more food from a plant or animal implies either more inputs or less matter–energy going to the non-food structures and functions of the organism (Cleveland 1994). To carry the arguments for infrastructure investments into the area of biophysical/environmental infrastructure or natural capital replenishment will require new thinking by development economists. Because much natural capital is not only public but also globally public in nature, the United Nations seems indicated to take a leadership role.

Consider some specific cases of biospheric infrastructure investments and the difficulties they present.

1. A largely deforested country will need reforestation to keep the complementary human-made capital of sawmills (carpentry, cabinetry skills, etc.) from losing their value. Of course, the deforested country could for a time resort to importing logs. To protect the human-made capital of dams from silting up the reservoirs behind them, the water catchment areas feeding the lakes must be reforested or original forests must be protected to prevent erosion and sedimentation. Agricultural investments depending on irrigation can become worthless without forested water catchment areas that recharge aquifers.
2. At a global level, enormous stocks of human-made capital and natural capital are threatened by depletion of the ozone layer, although the exact consequences are too uncertain to be predicted.
3. The greenhouse effect is a threat to the value of all coastally located and climatically dependent capital (such as agriculture), be it human made (port cities, wharves, beach resorts) or natural (estuarine breeding grounds for fish and shrimp). And if the natural capital of fish populations diminishes due to loss of breeding grounds, then the value of the human-made capital of fishing boats and canneries will also be diminished in value, as will the labor power (specialized human capital) devoted to fishing, canning, and so on.

We have begun to adjust national accounts for the liquidation of natural capital but have not yet recognized that the value of complementary human-made capital must also be written down as the natural capital that it was designed to exploit disappears. Eventually, the market will automatically lower the valuation of fishing boats as fish disappear, so perhaps no accounting adjustments are called for. But ex ante policy adjustments aimed at avoiding the ex post writing down of complementary human-made capital, whether by market or accountant, are certainly overdue.

3.1.5 Initial Policy Response to the Historical Turning Point

Although there is no indication of the degree to which development economists would agree with the fundamental thesis argued here, three major international agencies (the World Bank, the United Nations Environment Programme [UNEP], and UNDP) have embarked on a project of biospheric infrastructure investment known as the Global Environmental Facility (GEF). The facility provides concessional funding for programs investing in: climate change, protection of international water resources, protection of biodiversity, protection against persistent organic pollutants and land degradation, and multifocal areas of integrated ecosystem management. If the thesis argued here is correct, then investments of this type should eventually become very important in development economics. It would seem that the "new era" thesis merits serious discussion, especially because it appears that our practical policy response to the reality of the new era has already outrun our theoretical understanding of it. We need a much deeper understanding of natural capital and the ecosystem services it provides. The current status of this understanding is discussed in the following section.

3.2 Ecosystems, Biodiversity, and Ecosystem Services

An *ecosystem* consists of plants, animals, and microorganisms that live in biological communities and that interact with each other, with the physical and chemical environment, with adjacent ecosystems, and with the atmosphere. The structure and functioning of an ecosystem is sustained by synergistic feedbacks between organisms and their environment. For example, the physical environment puts constraints on the growth and development of biological subsystems, which, in turn, modify their physical environment.

Solar energy is the driving force of ecosystems, enabling the cyclic use of materials and compounds required for system organization and maintenance. Ecosystems capture solar energy through photosynthesis by plants. This is necessary for the conversion, cycling, and transfer of energy to other systems of materials and critical chemicals that affect growth and production, that is, biogeochemical cycling. Energy flow and biogeochemical cycling set an upper limit on the quantity and number of organisms and on the number of trophic levels that can exist in an ecosystem (Odum 1989).

Holling (1987) has described ecosystem behavior as the dynamic sequential interaction among four basic system functions: exploitation, conservation, release, and reorganization. The first two are similar to traditional ecological succession. *Exploitation* is represented by those ecosystem processes that are responsible for rapid colonization of disturbed ecosystems during which organisms capture easily accessible resources. *Conservation* occurs when the slow resource accumulation builds and stores increasingly complex structures. Connectedness and stability increase during the slow sequence from exploitation to conservation and a "capital" of biomass is slowly accumulated. *Release* or *creative destruction* takes place when the conservation phase has built elaborate and tightly bound structures that have become "overconnected," so that a rapid change is triggered. The system has become *brittle*. The stored capital is then suddenly released, and the tight organization is lost. The abrupt destruction is created internally but caused by an external disturbance such as fire, disease, or grazing pressure. This process of change both destroys and releases opportunity for the fourth stage, *reorganization,* where released materials are mobilized to become available for the next exploitative phase.

The stability and productivity of the system are determined by the slow exploitation and conservation sequence. *Resilience,* the system's capacity to recover after disturbance or its capacity to absorb stress, is determined by the effectiveness of the last two system functions. The self-organizing ability of the system, or more particularly the resilience of that self-organization, determines its capacity to respond to the stresses and shocks imposed by predation or pollution from external sources.

Some natural disturbances, such as fire, wind, and herbivores, are an inherent part of the internal dynamics of ecosystems and in many cases set the timing of successional cycles (Holling et al. 1995). Natural perturbations are parts of ecosystem development and evolution and seem to be crucial for ecosystem resilience and integrity. If they are not allowed to enter the ecosystem, it will become even more brittle and thereby even larger perturbations will be invited with the risk of massive and widespread destruction. For example, small fires in a forest ecosystem release nutrients stored in the trees and support a spurt of new growth without destroying all the old growth. Subsystems in the forest are affected but the forest remains. If small fires are blocked out from a forest ecosystem, forest biomass will build up to high levels and when the fire does come it will wipe out the whole forest. Such events may flip the system to a totally new state that will not generate the same level of ecological functions and services as before (Holling et al. 1995; Lenton et al. 2008). These sorts of flips may occur in many ecosystems. For example, savanna ecosystems

(Perrings and Walker 1995), coral reef systems (Knowlton 1992), and shallow lakes (Scheffer et al. 1993) all can exhibit this kind of behavior. The flip from one state to another is often induced by human activity; for example, cattle ranching in savanna systems can lead to completely different grass species assemblages; nutrient enrichment and physical disturbance around coral reefs can lead to replacement with algae-dominated systems; and nutrient additions can lead to eutrophication of lakes.

Natural ecosystems including human-dominated systems have been called "complex adaptive systems." Because these systems are evolutionary rather than mechanistic, they exhibit a limited degree of predictability. Understanding the problems and constraints these evolutionary dynamics pose for ecosystems is a key component in managing them sustainably (Costanza et al. 1993).

BOX 3.1 COLLECTIVELY SEEING COMPLEX SYSTEMS

RICHARD B. NORGAARD

Economists use multiple patterns of thinking to understand economies: market models, Marxist arguments, Keynesian and monetary theories, institutional analysis, and other forms. There is no more general model that unites the more specific models. Similarly, ecologists understand ecosystems through models emphasizing food webs, material and energy flows, population dynamics and species interactions, evolutionary processes, and spatial patterns. Divisions in scientific understanding also arise through the different spatial and temporal bounds scientists put on their analyses as well as through the different assumptions they make about how the parts of reality they are studying relate to the whole. For example, most economists, if they consider the environment at all, make very simple assumptions about ecosystems, while most ecologists, if they consider the economy at all, make very simple assumptions about economies and human behavior. Thus, scientific understanding of the interactions between economic and ecological systems is very fractured and disconnected. This is why students cannot simply take a few courses in economics and a few courses in ecology and then see the full complexities of reality clearly.

Seeing the full complexity of economic and ecological interactions was, however, the goal of the Millennium Ecosystem Assessment (2005). About 1,400 scientists from multiple environmental and social science disciplines from around the world worked together over a period of five years. They agreed on a general model and then assessed the available scientific literature and data to create a more systemic understanding of the changes taking place around the globe. What they discovered, of course, was that the studies undertaken using specific models did not fit into their general model. Ecologists had not included linkages to the economy in their studies; economists had not included linkages to ecosystems. Some studies were conducted at one scale, others at another. The same words were used but with different meanings in the different studies they assessed. The quality of environmental data from monitoring varied tremendously between heavily populated and unpopulated regions as well as between rich and poor countries.

Nevertheless, a full picture was developed through discussions among ever-changing combinations of scientists participating in the Millennium Ecosystem Assessment. The discussions drew on the scientific and experiential knowledge of the scientists. Scientists participating in a group working on one part of the assessment had to connect with scientists from other groups to make sure the linkages they were beginning to understand were consistent across groups. Judgment calls were repeatedly made, contested by other participants, and fine-tuned again. In short, an understanding of the complex interactions between people and nature, of how ecosystem degradation occurred, and of what this meant for future peoples was constructed through a long, complex discursive process that took place in some 50 meetings over the five years, in numerous e-mail exchanges, and in international conference calls as well, all in the context of writing the text of the assessment.

We understand complex system dynamics through a collective discursive learning process. Ecological economists were among the most effective participants in the arduous process of the Millennium Ecosystem Assessment because they were already accustomed to working with other scientists across the models of economics, ecology, and other disciplines. Although there are still possibilities for solitary thinkers to make breakthroughs in ecological economics, some of the most effective ecological economics is accomplished through a discursive learning process with others.

3.2.1 Biodiversity and Ecosystems

Species diversity appears to have two major roles in the self-organization of large-scale ecosystems. First, it provides the units through which energy and materials flow, giving the system its functional properties. There is some experimental evidence (Naeem et al. 1994) that species diversity increases the productivity of ecosystems by utilizing more of the possible pathways for energy flow and nutrient cycling. Second, diversity provides the ecosystem with the resilience to respond to unpredictable surprises (Tilman and Downing 1994; Holling et al. 1995).

"Keystone" species are those that control the system during the exploitation and conservation phases. The species that keep the system resilient by absorbing perturbation are important in the release and reorganization phases. The latter group can be thought of as a form of ecosystem "insurance" (Barbier et al. 1994). The insurance aspect includes the reservoirs of genetic material necessary for the evolution of microbial, plant, animal, and human life. Genes preserve information about what works and what worked in the past. Genes thereby constrain the self-organization process to those options that have a higher probability of success. They are the record of successful self-organization (Schneider and Kay 1994). Günther and Folke (1993) distinguish between working and latent information in terms of the function of genes. Similarly, the organisms or groups of organisms that are controlling the ecosystem during the exploitation and conservation phases could be looked upon as working information and those with the ability to take over the system during the release and reorganization phases, that is, those who keep the system resilient, as latent information. Both are part of functional diversity.

Hence, it is the number of organisms involved in the structuring set of processes during the different stages of ecosystem development—and at different spatial and temporal scales—that determines functional diversity. This number is not necessarily the same as the number of all organisms in the system (Holling et al. 1995). Therefore, it is not simply the diversity of species that is important, it is how that diversity is organized into a coherent whole system. The degree of organization of a system is contained in the network of interactions among the component parts (see further along in this section and Ulanowicz 1980, 1986), and it is this organization, along with system resilience and productivity (or vigor), that jointly determines the overall health of the system (Mageau et al. 1995).

3.2.2 Ecosystem Services

Ecological systems play a fundamental role in supporting life on Earth at all hierarchical scales. They form the life-support system without which economic activity would not be possible. They are essential in global material cycles such as the carbon and water cycles. Ecosystems produce renewable resources and services. For example, a fish in the sea is produced by several other "ecological sectors" in the food web of the sea. The fish is a part of the ecological system in which it is produced, and the interactions that produce and sustain the fish are inherently complex.

BOX 3.2 THE VALUE OF THE WORLD'S ECOSYSTEM SERVICES: THE INFLUENCE OF A SINGLE PAPER

ROBERT COSTANZA

In 1997, myself and 12 colleagues published a paper in *Nature* that estimated the value of the world's ecosystem services (Costanza et al. 1997). The paper was a global synthesis of information about how important natural ecosystems are to supporting human welfare. It was unique in that it not only asserted that ecosystems are important but quantified how important they are in units (dollars) that were easy to compare with other things that support human welfare. The paper acknowledged the many difficulties, limitations, and controversies surrounding such an exercise, but it concluded that solving these problems would lead to even larger values. It also came up with a range of values—$16 to $54 trillion/year (with a mean of $33 trillion/year in 1994)—as the estimated total annual nonmarketed contribution of ecosystems to human welfare. Because this number was significantly larger than global GNP and was obviously still an underestimate, it led to the inescapable conclusion that ecosystems are much more important to human welfare than had been previously assumed by many, and that they therefore deserved much more attention. A main goal of the paper was to encourage further discussion and research. Since its publication, the paper has been cited in the scientific literature almost 5,000 times (In the ISI web of science as of August 2014), making it the second most highly cited article in the ecology/environment field in the last decade. This high citation rate indicates that the paper achieved its goal of encouraging further discussion and research.

The paper has influenced several fields in slightly different ways. The environment/ecology field has embraced the concept of ecosystem services as a way of effectively making the link between ecosystem functioning and human welfare. The Millennium Ecosystem Assessment is just one of several initiatives that have been organized around the concept of ecosystem services. This field has also been more open to alternative valuation methods for ecosystem services, but there is a significant subset of people that are skeptical of any attempt to value ecosystem services. This is partly due to the misconception that valuing nonmarketed ecosystem services (which are mainly public goods—nonrival and nonexcludable) is the same as privatizing and commodifying them as if they were private goods. This is simply not the case.

Some professional economists have been less positive, largely for the wrong reasons. They have argued with the paper's methods, but, as noted earlier, these objections were duly noted in the paper itself and only make the results more conservative. I think the deeper (unstated) objection is that they feel that if ecosystems are really as important as the paper shows, then what they have been studying all these years is less important.

The field of ecological economics has been guardedly supportive, wishing to acknowledge the importance of ecosystems and to emphasize the limitations of the study's methods. In all cases, however, the paper has stimulated significant discussion of these issues and that has been a positive factor.

Since the publication of this paper, there has been an explosion of research on the value of ecosystem services. A random sample includes: (1) a follow-up working group at the National Center for Ecological Analysis and Synthesis produced a special issue of *Ecological Economics* delving into many of the questions that the original paper raised (Costanza and Farber 2002); (2) the National Science Foundation now lists ecosystem services and their valuation as a core item on the environmental research agenda; (3) the ISI Web of Science now lists more than 12,000 papers when one enters the term "ecosystem services" in the topic search field; (4) a growing number of research projects and policy initiatives are being undertaken using ecosystem services as a core organizing principle, including the Ecosystem Services Partnership, a global group of several thousand members. A recent paper from Costanza et al. has updated the 1997 paper and concluded that between 1997 and 2011 we have lost more than $20 Trillion in the value of ecosystem services due to land use change.

In the next 10 years, I expect the concepts of ecosystem services and natural capital to become core concepts in how we think about and manage humanity's relationship with the rest of nature.

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Ecosystem services are the ecological characteristics, functions, or processes that directly or indirectly contribute to human well-being—the benefits people derive from functioning ecosystems (Costanza et al. 1997; MEA 2005). Ecosystem processes and functions may contribute to ecosystem services, but they are not synonymous. Ecosystem processes and functions describe biophysical relationships and exist regardless of whether or not humans benefit (Granek et al. 2010). Ecosystem services, on the other hand, only exist if they contribute to human well-being, and they cannot be defined independently.

The following categorization of ecosystem services has been used by the Millennium Ecosystem Assessment (MEA 2005):

a. *Provisioning services*: Ecosystem services that combine with built, human, and social capital to produce food, timber, fiber, or other "provisioning" benefits. For example, fish delivered to people as food require fishing boats (built capital), fisher-folk (human capital), and fishing communities (social capital) to produce.
b. *Regulating services*: Services that regulate different aspects of the integrated system. These are services that combine with the other three capitals to produce flood control, storm protection, water regulation, human disease regulation, water purification, air quality maintenance, pollination, pest control, and climate control. For example, storm protection by coastal wetlands requires built infrastructure, people, and communities to be protected. These services are generally not marketed but have clear value to society.
c. *Cultural services*: Ecosystem services that combine with built, human, and social capital to produce recreation, aesthetic, scientific, cultural identity, sense of place, or other "cultural" benefits. For example, to produce a recreational benefit requires a beautiful natural asset (a lake), in combination with built infrastructure (a road, trail, dock, etc.), human capital (people able to appreciate the lake experience), and social capital (family, friends, and institutions that make the lake accessible and safe). Even "existence" and other "nonuse" values require people (human capital) and their cultures (social and built capital) to appreciate.
d. *Supporting "services"*: Services that maintain basic ecosystem processes and functions such as soil formation, primary productivity, biogeochemistry, and provisioning of habitat. These services affect human well-being *indirectly* by maintaining processes necessary for provisioning, regulating, and cultural services. They also refer to the ecosystem services that have not yet, or may never be, intentionally combined with built, human, and social

capital to produce human benefits but that support or underlie these benefits and may sometimes be used as proxies for benefits when the benefits cannot be easily measured directly. For example, net primary production (NPP) is an ecosystem function that supports carbon sequestration and removal from the atmosphere, which combines with built, human, and social capital to provide the benefit of climate regulation. Some would argue that these "supporting" services should rightly be defined as ecosystem "functions" because they may not yet have interacted with the other three forms of capital to create benefits. We agree with this in principle but recognize that supporting services/functions may sometimes be used as proxies for services in the other categories.

This categorization suggests a very broad definition of services, limited only by the requirement of a contribution to human well-being. Even without any subsequent valuation, explicitly listing the services derived from an ecosystem can help ensure appropriate recognition of the full range of potential impacts of a given policy option. This can help make the analysis of ecological systems more transparent and can help inform decision makers of the relative merits of different options before them (Costanza et al. 2011).

Examples of these services include the maintenance of the composition of the atmosphere, amelioration and stability of climate, flood controls and drinking water supply, waste assimilation, recycling of nutrients, generation of soils, pollination of crops, provision of food, maintenance of species and a vast genetic library, and also maintenance of the scenery of the landscape, recreational sites, and aesthetic and amenity values (Figure 3.2) (Ehrlich and Mooney 1983; Folke 1991; de Groot 1992; Ehrlich and Ehrlich 1992; Costanza et al. 1997; de Groot et al. 2002). Biodiversity at genetic, species, population, and ecosystem levels all contribute in maintaining these functions and services (Worm et al. 2006). Cairns and Pratt (1995) argue that a highly environmentally literate society would probably accept the assertion that most, if not all, ecosystem functions are in the long term beneficial to society.

Many ecosystem services are public goods. This means they are nonexcludable, and multiple users can simultaneously benefit from using them. This creates circumstances where individual choices are not the most appropriate approach to valuation. Instead, some form of community or group choice process is needed. Furthermore, ecosystem services (being public goods) are generally not traded in markets. We therefore need to develop other methods to assess their value.

There are a number of methods that can be used to estimate or measure benefits from ecosystems. Valuation can be expressed in multiple

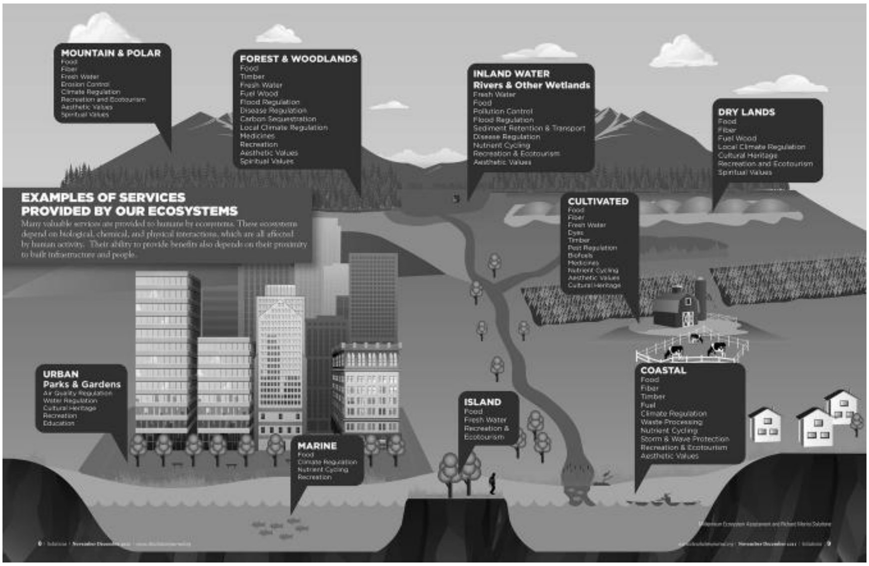


FIGURE 3.2
Ecosystem services: the benefits people derive from functioning ecosystems.

ways, including monetary units, physical units, or indices. Economists have developed a number of valuation methods that typically use metrics expressed in monetary units (see Freeman 2003) while ecologists and others have developed measures or indices expressed in a variety of non-monetary units such as biophysical trade-offs (cf. Costanza 2004).

The study of ecosystem services has grown exponentially in the past few decades as seen through publication records (Costanza and Kubiszewski 2012). The most influential of these studies was published in 1997 by Costanza and colleagues, which estimated the global monetary value of ecosystems in a *Nature* article, "The Value of the World's Ecosystem Services and Natural Capital" (Costanza et al. 1997). This paper estimated the value of 17 ecosystem services for 16 biomes to be in the range of US$16–$54 trillion per year, with an average of US$33 trillion per year, a figure that was larger than annual GDP at the time. This area of publication has grown exponentially. In this study, estimates of global ecosystem services were derived from a synthesis of previous studies that utilized a wide variety of techniques such as those mentioned earlier to value specific ecosystem services in specific biomes. This technique, called "benefit transfer," uses studies that have been done at other locations or in different contexts but that can be applied with some modification. Such a methodology, although useful as an initial estimate, is just a first cut; much progress has been made since then (cf. USEPA SAB 2009).

More recently, the concept of ecosystem services gained attention with a broader academic audience and with the public when the Millennium Ecosystem Assessment (MEA) was published (MEA 2005). The MEA was a four-year, 1,300-scientist study commissioned by the United Nations in 2005. The report analyzed the state of the world's ecosystems and provided recommendations for policymakers. It determined that human actions have depleted the world's natural capital to the point that the ability of a majority of the globe's ecosystems to sustain future generations can no longer be taken for granted.

In 2008, a second international study was published on The Economics of Ecosystems and Biodiversity (TEEB), hosted by UNEP. TEEB's primary purpose was to draw attention to the global economic benefits of biodiversity, to highlight the growing costs of biodiversity loss and ecosystem degradation, and to draw together expertise from the fields of science, economics, and policy to enable practical actions moving forward. The TEEB report was picked up extensively by the mass media, bringing ecosystem services to a broad audience.

With such high profile reports being published, ecosystem services have entered not only the public media but also into business. Dow Chemical recently established a $10 million collaboration with The Nature Conservatory to tally up the ecosystem costs and benefits of every business decision (Walsh 2011). Such collaboration will provide a significant addition to ecosystem services valuation knowledge and techniques. However, there is significant research that is still required.

Hundreds of projects and groups are currently working toward better understanding, modeling, valuation, and management of ecosystem services and natural capital. It would be impossible to list all of them here, but the new Ecosystem Services Partnership (ESP; http://www.es-partnership.org) is a global network that does just that and helps to coordinate the activity and build consensus. The following lays out the research agenda as agreed to by a group of 30 participants at a meeting in Salzau, Germany, in June 2010, at the launch of the ESP.

3.2.3 Defining and Predicting Sustainability in Ecological Terms

The most well-known definition of sustainability, or sustainable development in this case, was first presented by the Brundtland Commission and stated that "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987).

The problem with this definition (or any definition of sustainability) is that, like "fitness" in evolutionary biology, determinations can only be made *after the fact*. An organism alive right now is fit to the extent that its progeny survive and contribute to the gene pool of future generations.

The assessment of fitness today must wait until tomorrow. The assessment of sustainability must also wait until after the fact.

What often pass as *definitions* of sustainability are therefore usually *predictions* based on actions taken today that one hopes will lead to sustainability. For example, keeping harvest rates of a resource below natural renewal rates should, one could argue, lead to a sustainable extraction system—but that is a prediction, not a definition. It is, in fact, the foundation of maximum sustainable yield (MSY) theory, for many years the basis for management of exploited wildlife and fisheries populations (Roedel 1975). As learned in these fields, a system can only be known to be sustainable after there has been time to observe if the prediction holds true. Usually there is so much uncertainty in estimating natural rates of renewal and in observing and regulating harvest rates, that a simple prediction such as this is always highly suspect, especially if it is erroneously thought of as a definition (Ludwig et al. 1993).

The second problem is that when one says a system has achieved sustainability, one does not mean an infinite life span but rather a life span that is consistent with its time and space scale. Figure 3.3 indicates this relationship by plotting a hypothetical curve of system life expectancy on the y-axis versus time and space scale on the x-axis.

We expect a cell in an organism to have a relatively short life span, the organism to have a longer life span, the species to have an even longer life span, and the planet to have a longer life span. But no system (even the universe itself in the extreme case) is expected to have an infinite life span.

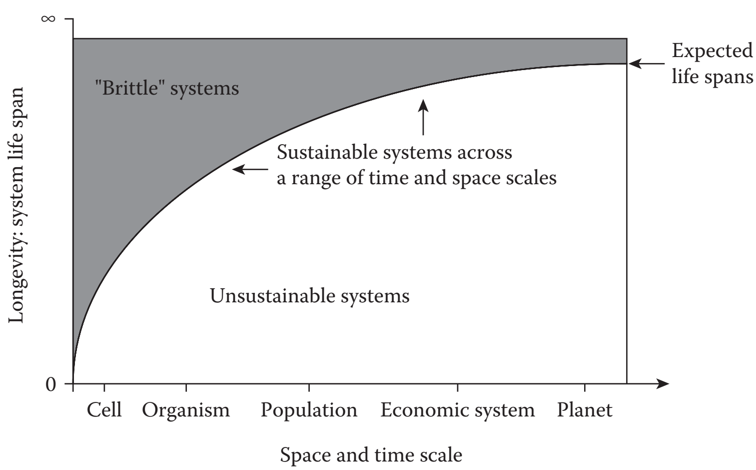


FIGURE 3.3
Sustainability as scale- (time- and space-) dependent concepts. (From Costanza, R., and B. C. Patten, *Ecological Economics*, 15, 193–196, 1995.)

A sustainable system in this context is thus one that attains its full expected life span.

Individual humans are sustainable in this context if they achieve their "normal" maximum life span. At the population level, average life expectancy is often used as an indicator of the health and well-being of the population, but the population itself is expected to have a much longer life span than any individual and would not be considered to be sustainable if it were to crash prematurely, even if all the individuals in the population were living out their full "sustainable" life spans.

Because ecosystems experience succession as a result of changing climatic conditions and internal developmental changes, they have a limited (albeit fairly long) life span. The key is differentiating between changes due to normal life span limits and changes that cut short the life span of the system. Things that cut short the life span of humans are obviously contributors to poor health. Cancer, AIDS, and a host of other ailments do just this. Human-induced eutrophication in aquatic ecosystems causes a radical change in the nature of the system (ending the life span of the more oligotrophic system while beginning the life span of a more eutrophic system). We would have to call this process "unsustainable" using the aforementioned definitions because the life span of the first system was cut "unnaturally" short. It may have gone eutrophic eventually, but the anthropogenic stress caused this transition to occur "too soon."

More formally, this aspect of sustainability can be thought of in terms of the longevity of the system and its component parts:

- A system is sustainable if, and only if, it persists in nominal behavioral states as long as, or longer than, its expected natural longevity or existence time.
- Neither component- nor system-level sustainability, as assessed by the longevity criterion, confers sustainability to the other level.

Within this context, one can begin to see the subtle balance between longevity and evolutionary adaptation across a range of scales that is necessary for overall sustainability. Evolution cannot occur unless there is limited longevity of the component parts so that new alternatives can be selected. And this longevity has to be increasing hierarchically with scale as shown schematically in Figure 3.3. Larger systems can attain longer life spans because their component parts have shorter life spans and can adapt to changing conditions. Systems with an improper balance of longevity across scales can become either "brittle" when their parts last too long and they cannot adapt fast enough (Holling 1987) or "unsustainable" when their parts do not last long enough and the higher level system's longevity is cut unnecessarily short.

3.2.4 Ecosystems as Sustainable Systems

Ecological systems are our best current models of sustainable systems. Better understanding of ecological systems and how they function and maintain themselves can thus yield insights into designing and managing sustainable economic systems. For example, in mature ecosystems all waste and by-products are recycled and used somewhere in the system or are fully dissipated. This implies that one characteristic of sustainable economic systems should be a "closing of the cycle" by productively recycling currently discarded material, rather than simply storing it, diluting it, or changing its state, and allowing it to disrupt other existing ecosystems and economic systems that cannot effectively use it.

Ecosystems have had eons of trial and error to evolve closed loops of organic matter, nutrients, and other materials globally. In thermodynamics terminology, the Earth is a "closed" system—closed to material inputs, except for a small amount of meteoritic matter, but open to energy inputs from the sun and outputs of waste heat to space. A general characteristic of closing the loops and building organized nonpolluting natural systems is that the process can take a significant amount of time. The connections, or feedback mechanisms, in the system must evolve, and there are characteristics of systems that enhance or retard evolutionary change. Humans have the special ability to perceive this process and (potentially) to enhance and accelerate it. The current economic system needs to better develop the decomposer function of ecological systems to allow more complete recycling.

The first by-product, or pollutant, of the activity of one part of the system that had a disruptive effect on another part of the system was probably oxygen, an unintentional by-product of photosynthesis that was very disruptive to anaerobic respiration. There was so much of this "pollution" that the Earth's atmosphere eventually became saturated with it and new species evolved that could use this by-product as a productive input in aerobic respiration. The current biosphere represents a balance between these processes that has evolved over millions of years to ensure that the formerly unintentional by-product is now an absolutely integral component process in the system.

Eutrophication and toxic stress are two current forms of by-products that result from the inability of the affected systems to evolve fast enough to convert the "pollution" into useful products and processes. Eutrophication is the introduction of high levels of nutrients into formerly lower nutrient systems. The species of primary producers (and the assemblages of animals that depend on them) that were adapted to the lower nutrient conditions are outcompeted by faster growing species adapted to the higher nutrient conditions. But the shift in nutrient regime is so sudden that only the primary producers are changed, resulting in a disorganized collection of species with much internal disruption (i.e., plankton blooms, fish kills). This can rightly be called pollution. The introduction of high levels of nutrients into a system not adapted to them causes pollution (called eutrophication in this case), whereas the introduction of the same nutrients into a system that *is* adapted to them (i.e., marshes and swamps) would be a positive input. We can minimize the negative effects of such by-products by finding the places in the ecosystem where they represent a positive input and placing them there. In many cases, what we think of as waste are resources in the wrong place.

Toxic chemicals represent a form of pollution because there are *no* existing natural systems that have experienced them before, and so there are no existing systems to which they represent a positive input. The places where toxic chemicals can most readily find a productive use are probably in other industrial processes, not in natural ecosystems. The solution in this case is to encourage the evolution of industrial processes that can use toxic wastes as productive inputs or to encourage alternative production processes, which do not produce the wastes in the first place.

3.3 Substitutability versus Complementarity of Natural, Human, Social, and Built Capital

The upshot of these considerations is that natural capital (natural resources) and human-made capital are complements rather than substitutes. The neoclassical assumption of near perfect substitutability between natural resources and human-made capital is a serious distortion of reality, the excuse of "analytical convenience" notwithstanding. To see *how* serious, imagine human-made capital being a perfect substitute for natural resources. Then it would also be the case that natural resources would be a perfect substitute for human-made capital. Yet, if that were so, then we would have had no reason whatsoever to accumulate human-made capital because we were already endowed by nature with a perfect substitute! Historically, of course, we did accumulate human-made capital long before natural capital was depleted, precisely because we needed human-made capital to make effective use of the natural capital (complementarity!). It is amazing that the substitutability dogma should be held with such tenacity in the face of such an easy *reduction ad absurdum*. Add to that the fact that capital itself requires natural resources for its production—that is, the substitute itself requires the very input being substituted for—and it is quite clear that human-made capital and natural resources are fundamentally complements, not substitutes. Substitutability of capital for resources is limited to reducing waste of materials in process, for example, collecting sawdust and using a press (capital) to make particleboard. And no amount of substitution of capital for resources can ever reduce the mass of material resource inputs below the mass of the outputs, given the law of conservation of matter–energy.

Substitutability of capital for resources in aggregate production functions reflects largely a change in the total product mix from resource-intensive to different capital-intensive products. It is an artifact of product aggregation, not factor substitution (i.e., along a given product isoquant). It is important to emphasize that it is this latter meaning of substitution that is under attack here—producing a given physical product with less natural resources and more capital. No one denies that it is possible to produce a different product or a different product mix with less resources. Indeed, new products may be designed to provide the same or better service while using fewer resources, and sometimes less labor and less capital as well. This is technical improvement, not substitution of capital for resources. Light bulbs that give more lumens per watt represent technical progress, qualitative improvement in the state of the art, not the substitution of a quantity of capital for a quantity of natural resource in the production of a given quantity of a product.

It may be that economists are speaking loosely and metaphorically when they claim that capital is a near perfect substitute for natural resources. Perhaps they are counting as "capital" all improvements in knowledge, technology, managerial skill, and so on—in short, anything that would increase the efficiency with which resources are used. If this is the usage, then "capital" and resources would by definition be substitutes in the same sense that more efficient use of a resource is a substitute for using more of the resource. But to define capital as efficiency would make a mockery of the neoclassical theory of production, where efficiency is a ratio of output to input, and capital is a quantity of input.

The productivity of human-made capital is more and more limited by the decreasing supply of complementary natural capital. Of course, in the past when the scale of the human presence in the biosphere was low, human-made capital played the limiting role. The switch from human-made to natural capital as the limiting factor is thus a function of the increasing scale of the human presence.

3.3.1 Growth versus Development

Improvement in human welfare can come about by pushing more matter–energy through the economy or by squeezing more human want satisfaction out of each unit of matter–energy that passes through. These two processes are so different in their effect on the environment that we must stop conflating them. Better to refer to throughput increase as *growth* and efficiency increase as *development*.* Growth is destructive of natural capital and beyond some point will cost us more than it is worth—that is, sacrificed natural capital will be worth more than the extra man-made capital whose production necessitated the sacrifice. At this point, growth has become anti-economic, impoverishing rather than enriching. Development, or qualitative improvement, is not at the expense of natural capital. There are clear economic limits to growth but not to development. This is not to assert that there are no limits to development, only that they are not as clear as the limits to growth; consequently, there is room for a wide range of opinion on how far we can go in increasing human welfare without increasing resource throughput. How far can development substitute for growth? This is the relevant question—not how far can human-made capital substitute for natural capital, the answer to which, as we have seen, is "hardly at all."

Still, great uncertainty and debate exists as to whether economic growth promotes overall well-being. This uncertainty is critical because economic growth policies, also known as neoliberal policies, are being disseminated to all developing countries around the world. The promotion of economic growth is based on the assumption that increases in wealth and material consumption lead to increases in well-being (Samuelson 1947; Easterlin 1995; Oswald 1997; Goklany 2002; Layard 2005; Kusago 2007).

After 20 years of implementing neoliberal policies, many countries have experienced economic growth (Edwards 1992; Amann and Baer 2002); there have also been decreases in poverty levels in certain countries (Londoño and Székely 2000) and increases in well-being through improvements in living standards (as measured by GDP) and life expectancy, as well as decreases in child mortality (Krueger 1997; Goklany 2002).

However, these neoliberal policies have also brought about high economic, social, and environmental costs, often outweighing the improvements in well-being. Chile, often considered as the perfect model of neoliberal growth, has experienced negative effects due to these policies (Green 1996; Schurman 1996; Altieri and Rojas 1999; Baer and Maloney 2003; Homedes and Ugalde 2005). In recent years, economic growth has either declined or become stagnant in many developing nations (Muradian and Martinez-Alier 2001; Mahon 2003; Held 2005). Subjective well-being has decreased in many developed countries such as the United States, Japan, and most countries in Europe, as well as most recently in China (Oswald 1997; Layard 2003; Kahneman and Krueger 2006). The inequality gap within and among countries continues to increase

* This distinction is explicit in the dictionary's first definition of each term. *To grow* means literally "to increase naturally in size by the addition of material through assimilation or accretion." *To develop* means "to expand or realize the potentialities of; bring gradually to a fuller, greater, or better state" (*The American Heritage Dictionary of the English Language*).

(Londoño and Székely 2000; Naim 2000; Muradian and Martinez-Alier 2001; Wade 2004). Poverty is still a major problem in many countries around the world, and there is controversy regarding the magnitude of the poverty reduction that has occurred (Londoño and Székely 2000; Wade 2004; Held 2005). Also, increased dependency on degrading (especially primary) natural resources has exacerbated environmental pressures and increased the rate of species extinction (Kessler and Van Dorp 1998; Muradian and Martinez-Alier 2001; Paus 2003; McCarthy and Prudham 2004).

Some people believe that there are truly enormous possibilities for development without growth. Energy efficiency, they argue, can be vastly increased (Lovins 1977; Lovins and Lovins 1987); likewise for the efficiency of water use. Other materials are not so clear. Others (Costanza 1980; Cleveland et al. 1984; Gever et al. 1986; Hall et al. 1986) believe that the bond between growth and energy use is not so loose. This issue arises in the *Brundtland Commission Report* (WCED 1987) where on the one hand, there is a recognition that the scale of the human economy is already unsustainable in the sense that it requires the consumption of natural capital, and yet on the other hand, there is a call for further economic expansion by a factor of five to ten in order to improve the lot of the poor without having to appeal too much to the "politically impossible" alternatives of serious population control and redistribution of wealth. The big question is: how much of this called for expansion can come from development, and how much must come from growth? This question is not addressed by the commission. But statements by secretary MacNeil (1990) of the World Commission on Environment and Development (WCED), were that "The link between growth and its impact on the environment has also been severed" (13), and "the maxim for sustainable development is not 'limits to growth'; it is 'the growth of limits'," indicate that WCED expects the lion's share of that factor of five to ten to come from development, not growth. They confusingly use the word "growth" to refer to both cases, saying that future growth must be qualitatively very different from past growth. When things are qualitatively different it is best to call them by different names, hence our distinction between growth and development. Our own view is that WCED is too optimistic—that a factor of five to ten increase cannot come from development alone, and that if it comes mainly from growth it will be devastatingly unsustainable. Therefore, the welfare of the poor, and indeed of the rich as well, depends much more on population control, consumption control, and redistribution than on the technical fix of a five- to tenfold increase in total factor productivity.

We acknowledge, however, that there is vast uncertainty on this critical issue of the scope for economic development from increasing efficiency. We have therefore devised a policy that should be sustainable regardless of who is right in this debate. We save its full description for the final chapter in this book. For now we mention only the basic logic: protect the pessimists against their worst fears and encourage the optimists to pursue their dreams by the same policy; namely, limit throughput. First, following are some general principles of sustainable development.

3.3.2 Can Built Capital Substitute for Natural Capital?

The main issue is the relation between natural capital, which yields a flow of natural resources and services that enter the process of production, and the human-made capital that serves as an agent in the process for transforming the resource inflow into a product outflow. Is the flow of natural resources (and the stock of natural capital that yields that flow) substitutable by human-made capital? Clearly, one resource can substitute for another—we can transform aluminum instead of copper into electric wire. We can also substitute labor for capital, or capital for labor, to a significant degree even though the characteristic of complementarity is also important. For example, we can have fewer carpenters and more power saws, or fewer power saws and more carpenters and still build the same house. In other words, one resource can substitute for another, albeit imperfectly, because both play the same qualitative role in production: both are raw materials undergoing transformation into a product. Likewise, capital and labor are substitutable to a significant degree because both play the role of agent of transformation of resource inputs into product outputs. However, when we come to substitution across the roles of transforming agent and material undergoing transformation (efficient cause and material cause), the possibilities of substitution become very limited and the characteristic of complementarity is dominant. For example, we cannot make the same house with half the lumber no matter how many extra power saws or carpenters we try to substitute. Of course, we might substitute brick for lumber, but then we face the analogous limitation—we cannot substitute masons and trowels for bricks.

3.3.3 Natural Capital

Thinking of the natural environment as "natural capital" is in some ways unsatisfactory, but useful within limits. We may define capital broadly as a stock of something that yields a flow of useful goods or services. Traditionally capital was defined as produced means of production, which we call here human-made capital, as distinct from natural capital which, though not made by man, is nevertheless functionally a stock that yields a flow of useful goods and services. We can distinguish renewable from nonrenewable natural capital and marketed from nonmarketed natural capital, giving four cross-categories. Pricing natural capital, especially nonmarketable natural capital, is so far an intractable problem, but one that need not be faced here. All that need be recognized for the argument at hand is that natural capital consists of physical stocks that are complementary to human-made capital. We have learned to use the concept of human capital (i.e., skills, education), which departs even more fundamentally from the standard definition of capital. Human capital cannot be bought and sold, although it can be rented. Although it can be accumulated, it cannot be inherited without effort by bequest as can ordinary human-made capital, but it must be re-learned anew by each generation. Natural capital, however, is more like traditional human-made capital in that it can be bequeathed. Overall the concept of natural capital is less a departure from the traditional definition of capital than is the commonly used notion of human capital.

There is a large subcategory of marketed natural capital that is intermediate between natural and human made, which we might refer to as "cultivated natural capital." This consists of such things as plantation forests, herds of livestock, agricultural crops, fish bred in ponds, and so on. Cultivated natural capital supplies the raw material input complementary to human-made capital but does not provide the wide range of natural ecological services characteristic of natural capital proper (e.g., eucalyptus plantations supply timber to the sawmill, and may even reduce erosion, but do not provide a wildlife habitat or conserve biodiversity). Investment in the cultivated natural capital of a plantation forest, however, is useful not only for the lumber but as a way of easing the pressure of lumber interests on the remaining true natural capital of natural forests.

Marketed natural capital can, subject to the important social corrections for common property and myopic discounting, be left to the market. Nonmarketed natural capital, both renewable and nonrenewable, will be the most troublesome category. Remaining natural forests should in many cases be treated as nonmarketed natural capital and only replanted areas treated as marketed natural capital. In neoclassical terms, the external benefits of remaining natural forests might be considered "infinite" thus removing them from market competition with other (inferior) uses. Most neoclassical economists, however, have a strong aversion to any imputation of an "infinite" or prohibitive price to anything.

3.3.4 Sustainability and Maintaining Natural Capital

Solutions to the problems of sustainability will only be robust and effective if they are fair and equitable. Philosopher Rawls (1987) has argued that policies that represent an overlapping consensus of the interest groups involved in a problem will most likely be fair, effective, and resilient. The normal political process tends to accentuate conflict, and majority voting often sidetracks efforts to find overlapping consensus. The policies resulting from majority voting often are unfair to the minority and are not resilient because the minority spends all of its time fighting the decision and trying to build a new majority to overthrow the previous majority. In addition, interest groups important to global, long-run decisions (such as future generations and other species) are given little if any representation in the process.

There is, however, a growing, global, overlapping consensus that attempts to acknowledge the interests of future generations and other species. The consensus is that the appropriate long-term social goal is sustainability (WCED 1987; AGENDA 21 1992). Consensus on *exactly* what is meant by sustainability is still being discussed (WCED 1987; Costanza 1991; Goodland and Daly 1996), but we interpret this as healthy disagreement over the means not the ends. The goal is a system that will survive indefinitely and in good shape, and one can only be sure one has achieved that goal in retrospect. In prospect, there is disagreement over which current policies will achieve the goal and, as discussed earlier, we need to be especially cognizant of the inherent uncertainty of our ability to predict the future. The "precautionary principle" is beginning to achieve a degree of consensus as the basic approach to uncertainty (Bodansky 1991). For this reason, the focus should be on policies that are aimed at assuring sustainability over as wide a range of future conditions as possible.

For example, a sustainable system is one with "sustainable income," defined in a Hicksian sense as the amount of consumption that can be sustained indefinitely without degrading capital stocks, including "natural capital" stocks (Pearce and Turner 1989; El Serafy 1991; Costanza and Daly 1992). Because "capital" is traditionally defined as produced (manufactured) means of production, the term "natural capital" needs explanation. It is based on a more functional definition of capital as "a stock that yields a flow of valuable goods or services into the future." What is functionally important is the relation of a stock yielding a flow; whether the stock is manufactured or natural is in this view a distinction among kinds of capital and not a defining characteristic of capital itself. For example, a stock or population of trees or fish provides a flow or annual yield of new trees or fish (along with other services), a flow which can be sustainable year after year. The sustainable flow is "natural income," the stock that yields the sustainable flow is "natural capital." Natural capital may also provide services such as recycling waste materials or water catchment and erosion control, which are also counted as natural income. Because the flow of services from ecosystems requires that they function essentially as whole systems, the structure and biodiversity of the ecosystem is a critical component in natural capital.

To achieve sustainability, we must therefore incorporate natural capital, and the ecosystem goods and services that it provides, into our economic and social accounting and into our systems of social choice. In estimating these values, we must consider how much of our ecological life-support systems we can afford to lose. To what extent can we substitute manufactured for natural capital, and how much of our natural capital is irreplaceable? For example, could we replace the radiation screening services of the ozone layer if it were destroyed?

Daly (1990b) has developed three basic criteria for the maintenance of natural capital and ecological sustainability.

1. For renewable resources, the rate of harvest should not exceed the rate of regeneration (sustainable yield).
2. The rates of waste generation from projects should not exceed the assimilative capacity of the environment (sustainable waste disposal).
3. For nonrenewable resources, the depletion of the nonrenewable resources should require comparable development of renewable substitutes for that resource.

3.4 Population and Carrying Capacity

A primary question is: Are there limits to the carrying capacity of the Earth system for human populations? Ecological economics gives an unequivocal *yes.* Where doubt sets in is on the precise number of people that can be supported, the standard of living of the population, and the way in which food production will reach the limit imposed by the carrying capacity. These issues must be the priority research topics for the next decades.

Various estimates of the Earth's global carrying capacity for people have appeared in the literature ranging from 7.5 billion (Bernard Gilliand, as cited in Demeny 1988, 224–225) to 12 billion (Clark 1958), 40 billion (Revelle 1976), and 50 billion (Brown 1954). However, many authors are skeptical about the criteria—amount of food, or kilocalories—used as a basis for these estimates. "For humans, a physical definition of needs may be irrelevant. Human needs and aspirations are culturally determined: they can and do grow to encompass an increasing amount of 'goods,' well beyond what is necessary for mere survival" (Demeny 1988, 215–216). For a long and careful if somewhat inconclusive discussion of the population issue, see Cohen (1995).

Cultural evolution has a profound effect on human impacts on the environment. By changing the learned behavior of humans and incorporating tools and artifacts, it allows individual human resource requirements and their impacts on their resident ecosystems to vary over several orders of magnitude. Thus, it does not make sense to talk about the "carrying capacity" of humans in the same way as the "carrying capacity" of other species

(Blaikie and Brookfield 1987) because, in terms of their carrying capacity, humans are many subspecies. Each subspecies would have to be culturally defined to determine levels of resource use and carrying capacity. For example, the global carrying capacity for *Homo americanus* would be much lower than the carrying capacity for *Homo indus* because each American consumes much more than each Indian does. And the speed of cultural adaptation makes thinking of species (which are inherently slow changing) misleading anyway. *Homo americanus* could change its resource consumption patterns drastically in only a few years, while *Homo sapiens* remains relatively unchanged. We think it best to follow the lead of Daly (1977) in this and speak of the product of population and per capita resource use as the total impact of the human population. It is this total impact that the Earth has a capacity to carry, and it is up to society to decide how to divide it between numbers of people and per capita resource use. This complicates population policy enormously because one cannot simply state a maximum population but rather must state a maximum number of impact units. How many impact units the Earth can sustain and how to distribute these impact units over the population is a dicey problem indeed, but one that must be the focus of research in this area.

Many case studies indicate that "there is no linear relation between growing population and density, and such pressures toward land degradation and desertification" (Caldwell 1984). In fact, one study found that land degradation can occur under rising pressure of population on resources (PPR), under declining PPR, and without PPR (Blaikie and Brookfield 1987). Therefore, the scientific agenda must look toward more complex, systemic models where the effects of population pressures can be analyzed in their relationships with other factors. This would allow us to differentiate population as a "proximate" cause of environmental degradation from the concatenation of effects of population with other factors as the "ultimate" cause of such degradation.

Research can begin by exploring methods for more precisely estimating the total impact of population times per capita resource use. For example, the "Ehrlich identity" (Pollution/Area = People/Area × Economic Production/People × Pollution/Economic Production) can be operationalized as (CO_2 Emissions/km = Population/km × GDP/Population × CO_2 Emissions/GDP). Thus, no single factor dominates the changing patterns of total impact across time. This points to the need for local studies of causal relations among specific combinations of populations, consumption, and production, noting that these local studies need to aim for a general theory that will account for the great variety of local experience.

Another research priority is to look at the effect adding a new person has on resources, according to consumption levels and the effect that efficiency has on rising levels of consumption. Decreasing energy consumption in developed countries could dramatically decrease CO_2

emissions globally. It is only under a scenario of severe constraints on emissions in the developed countries that population growth in the less developed ones plays a major global role in emissions growth. If energy efficiency could be improved in the latter as well as in the former, then population increase would play a much smaller role.

Research priority should also look at situations where demand (either subsistence or commercial) becomes large relative to the maximum sustainable yield of the resource, or where the regenerative capacity of the resource is relatively low, or where the incentives and restraints facing the exploiters of the resource are such as to induce them to value present gains much more highly than future gains.

Some authors single out a high rate of population growth as a root cause of environmental degradation and of overload of the planet's carrying capacity. Consequently, the policy instrument is obviously population control. Ehrlich and his colleagues maintain that "There is no time to be lost in moving toward population shrinkage as rapidly as is humanly possible" (Ehrlich 1989, 20). But, as Ehrlich himself fully recognizes, the policy of focusing solely on population control is known to be insufficient. It has repeatedly been shown that this is not easily achieved in and of itself, and that important social and economic transformations must also accompany it, such as the reduction of poverty. Even in those cases where population growth has been relatively successfully controlled, as in China, the welfare of the people has not necessarily improved and the environment is not necessarily exposed to lower rates of hazard.

The opposite position is taken by those who see high rates of population growth as stimulating economic development through inducing technological and organizational changes (Boserup 1965) or as a phenomenon that can be solved through technological change (Simon 1990).

Such positions, however, ignore the dangers of environmental depletion implicit in unchecked economic growth: consumption increases and rapidly growing populations can put a very real burden upon the resources of the Earth and can bring about social and political strife for control of such resources. This position also assumes that technological creativity will have the same outcomes in the future as in the past, and in the South as in the North, a questionable assumption. In particular, it assumes that new technology solves old problems without creating new ones that may be even worse. Finally, it heavily discounts the importance of the loss of biodiversity—a loss that is irreversible and whose human consequences are as yet unknown.

According to a World Bank study of 64 countries, when the income of the poor rises by 1%, general fertility rates drop by 3% (Lappe and Schurman 1988). In contrast, other authors state that "population is not a relevant variable" in terms of resource depletion and stress that resource consumption, particularly overconsumption by the affluent, is the key factor (Durning 1992). Organisation for Economic Co-operation and Development (OECD) countries represent only 18% of the world's population (OECD library) and 24% of the world's land area, but their economies account for about 59% of the world gross product, 78% of road vehicles, and more than 50% of global energy use. They generate about 76% of world trade, 73% of chemical product exports, and 73% of forest product imports and account for one-third of global greenhouse gas emissions. The main policy instrument in this case, in the short term, is reducing consumption, and this can be most easily achieved in those areas where consumption per capita is highest.

With a world population that is surpassing 7 billion, increasing food and energy prices due to lack of resources (Brown 2011), slowing of development in already underdeveloped countries due to overpopulation (Birdsall et al. 2003; Bloom and Canning 2004), and with a lack of jobs (Cincotta et al. 2003), there has been a refocusing on population stability, often in the form of family-planning policies. Family planning has been proven to be very cost-effective (Singh et al. 2010): for every dollar spent on family planning, the United Nations has found that two to six dollars can be saved in the future on other development goals Department of Economic and Social Affairs UN (2009). Recently, the United States and the United Kingdom once again increased their foreign aid funding toward international family planning (UN DESA 2009).

An estimated one-third of global births are the result of unintended pregnancy (Bongaarts 2009). More than 200 million women in developing countries would prefer to delay their next pregnancy or not have any more children at all (Singh et al. 2003). However, several barriers prevent many of these women from making a conscious choice: lack of access to contraceptives, risk of side effects, cultural values, or opposition from family members (Carr and Khan 2004; Sedgh et al. 2007).

One of the major factors of such population growth is the negative impact it is having on the Earth's life-supporting ecosystem services (Ehrlich and Ehrlich 1991; Wilson 2003; Speidel et al. 2009). It has been estimated that about half of the productivity of the Earth's biosystems has been diverted to human use (Brown and Earth Policy Institute 2008; Jackson 2009). As population continues to increase, competition for these increasingly scarce resources will intensify globally. The disconnect between the "haves" and the "have nots" will also become more visible as living standards drop below survival level (Schor 2005).

Thus, a new framework should expand the definitions of issues. The focus should not only be on population size, density, rate of increase, age distribution, and sex ratios but also on access to resources, livelihoods, social dimensions of gender, and structures of power. New models have to be explored in which population control is not simply a question of family planning but of economic, ecological, social, and political planning;

in which the wasteful use of resources is not simply a question of finding new substitutes but of reshaping affluent lifestyles; and in which sustainability is seen not only as a global aggregate process but also as one having to do with sustainable livelihoods for a majority of local peoples.

3.5 Measuring Welfare and Well-Being

Getting a better handle on how to measure the well-being and health of both ecological and economic systems, and the welfare of humans within them, is critical. This section looks at the conventional macroeconomic measures of welfare (GDP and related measures) with an eye toward how to improve them to better reflect human well-being.

3.5.1 Quality of Life, Happiness, Well-Being, and Welfare

There is a substantial body of new research on what contributes to human well-being and quality of life. Although there is still much ongoing debate, this new science clearly demonstrates the limits of conventional economic income and consumption in contributing to well-being. For example, psychologist Tim Kasser, in his 2003 book, *The High Price of Materialism* (Kasser 2003), points out that people who focus on material consumption as a path to well-being are actually less satisfied with their lives and even suffer higher rates of physical and mental illness than those who do not focus so much on material consumption. Material consumption beyond real need is a form of psychological "junk food" that only satisfies for the moment and ultimately leads to depression, Kasser says.

Economist Richard Easterlin has shown that well-being tends to correlate well with health, level of education, and marital status and shows sharply diminishing returns to income beyond a fairly low threshold. He concludes (Easterlin 2003, p. 11182) that

> People make decisions assuming that more income, comfort, and positional goods will make them happier, failing to recognize that hedonic adaptation and social comparison will come into play, raise their aspirations to about the same extent as their actual gains, and leave them feeling no happier than before. As a result, most individuals spend a disproportionate amount of their lives working to make money, and sacrifice family life and health, domains in which aspirations remain fairly constant as actual circumstances change, and where the attainment of one's goals has a more lasting impact on happiness. Hence, a reallocation of time in favor of family life and health would, on average, increase individual happiness.

British economist Richard Layard synthesizes many of these ideas and concludes that current economic policies are not improving well-being and happiness and that "happiness should become the goal of policy, and the progress of national happiness should be measured and analyzed as closely as the growth of GDP [gross domestic product]" (Layard 2005).

Economist Robert Frank, in his book *Luxury Fever* (Frank 1999), also concludes that some nations would be better off—that is, overall national well-being would be higher—if we actually consumed less and spent more time with family and friends, working for our communities, maintaining our physical and mental health, and enjoying nature.

On this last point, there is substantial and growing evidence that natural systems contribute heavily to human well-being. In a paper published in the journal *Nature* (Costanza et al. 1997), the annual, nonmarket value of the Earth's ecosystem services was estimated to be substantially larger than global GDP. This estimate was admittedly a rough first cut, but the goal of this paper was to stimulate interest and research on the topic of natural capital and ecosystem services.

So, if we want to assess the "real" economy—all the things that contribute to real, sustainable, human well-being—as opposed to only the "market" economy, we have to measure and include the nonmarketed contributions to human well-being from nature; from family, friends, and other social relationships at many scales; and from health and education. What does such a more comprehensive, integrative definition of well-being and quality of life look like?

3.5.1.1 An Integrative Definition of Quality of Life and Well-Being

When we evaluate the state of human affairs or propose policies to improve it, we typically proceed from assumptions about the characteristics of a good life and strategies for achieving them. We might suppose, for example, that access to particular resources is a part of a good life and, therefore, that increasing economic production per capita is an appropriate goal. Unfortunately, our underlying assumptions are rarely tested and established. We therefore need a more basic approach to defining well-being or quality of life (QOL) that, in turn, can guide our efforts to improve humans' experience. Examinations of QOL often fall under two headings:

1. So-called objective indicators of QOL include, for example, indices of economic production (i.e., GDP), literacy rates, life expectancy, and other data that can be gathered without a subjective evaluation being made by the individual being assessed (although, of course, we must acknowledge that subjective judgments of the

researcher are involved in the process of defining and gathering "objective" measures as seen in the case, for example, of selecting a proxy for "literacy"). Objective indicators may be used singly or in combination to form summary indexes, as in the United Nations Human Development Index (HDI) (UNDP 1998), the Index of Sustainable Economic Welfare, or in the Genuine Progress Indicator (GPI). To the extent that such a measure can be shown to be valid and reliable across assessment contexts (admittedly a difficult task), these relatively objective measures may help us gather standardized data that are less vulnerable to social comparison and local adaptation. For example, a valid measure should minimize the degree to which QOL is largely a function of comparing one's life to others' in one's locale, in the media, or in some other narrowly construed group; a person's QOL should not be considered high simply because others in the locale are more miserable.

2. Subjective indicators of QOL gain their impetus, in part, from the observation that many objective indicators merely assess the opportunities that individuals have to improve QOL rather than assessing QOL itself. Thus, economic production may best be seen as a *means* to a potentially (but not necessarily) improved QOL rather than an end in itself. In addition, unlike most objective measures of QOL, subjective measures typically rely on survey or interview tools to gather respondents' own assessments of their lived experiences in the form of self-reports of satisfaction, happiness, well-being, or some other near-synonym. Rather than presume the importance of various life domains (e.g., life expectancy or material goods), subjective measures can also tap the perceived significance of the domain (or "need") to the respondent. Diener and Suh (2003) provide convincing evidence that subjective indicators are valid measures of what people perceive to be important to their happiness and well-being. Nevertheless, there are individuals who cannot provide subjective reports or whose subjective reports may not be as trustworthy in reflecting their true welfare because of the internalization of cultural norms (Nussbaum and Glover 1995), mental illness, lack of information, or other reasons.

What seems best, then, is to attempt an approach to QOL that combines objective and subjective approaches. Our integrative definition of QOL is as follows: QOL is the extent to which objective human needs are fulfilled in relation to personal or group perceptions of subjective well-being. Human needs are basic needs for subsistence, reproduction, security, affection, and so on. Subjective well-being (SWB) is assessed by individuals' or groups' responses to questions about happiness, life satisfaction, utility, or welfare. The relation between specific human needs and perceived satisfaction with each need can be affected by mental capacity, cultural context, information, education, temperament, and the like, often in quite complex ways. Moreover, the relation between the fulfillment of human needs and overall subjective well-being is affected by the (time-varying) weights individuals, groups, and cultures give to fulfilling each of the human needs relative to the others. SWB measures are important because: (1) SWB is an important and valuable component of overall well-being; (2) well-being is a multidimensional concept and requires more than just material consumption; (3) SWB assessments add to current objective measures of well-being because objective and subjective well-being are considered as separate entities and objective measures cannot adequately assess feelings of happiness; (4) SWB helps assess the effects of public policies and guides future policy decisions when used in conjunction with other key objective measures of well-being indicators such as the HDI and environmental measures (Oswald 1997; Frey and Stutzer 2002; Diener, Oishi, and Lucas 2003; Gowdy 2005; Layard 2005).

With this definition, the role of policy is to create opportunities for human needs to be met, understanding that there exists a diversity of ways to meet any particular need. Built, human, social, and natural capitals each represent one way of categorizing those opportunities. Time is also an independent constraint on the achievement of human needs.

Social norms affect the weights given to various human needs when aggregating them to overall individual or social assessments of SWB and also policy decisions about social investments in improving opportunities. Social norms evolve over time due to collective population behavior (Azar 2004). The evolution of social norms can be affected by conscious shared envisioning of preferred states of the world (Costanza 2000b).

As we have said, one convenient way to summarize the opportunities for meeting human needs is to group them into four basic types of assets or "capital" that are necessary to support the real, human-well-being-producing economy: built capital, human capital, social capital, and natural capital.

We refer to these assets as "capital" in the sense of a stock or accumulation or heritage—a patrimony received from the past that contributes to the welfare of the present and future. Clearly our use of the term "capital" is much broader than that associated with capitalism. These assets, which overlap and interact in complex ways to produce all benefits, are generally defined as follows:

- *Natural capital*: The natural environment and its biodiversity. Among other things, natural capital is needed to provide ecosystem goods and services. These goods and services are essential to basic human needs such as survival, climate regulation, habitat for other species, water supply, food, fiber, fuel, recreation, cultural amenities, and the raw materials required for all economic production.

- *Social and cultural capital*: The web of interpersonal connections, social networks, cultural heritage, traditional knowledge, and trust, and the institutional arrangements, rules, norms, and values that facilitate human interactions and cooperation between people. These contribute to social cohesion; strong, vibrant, and secure communities; and good governance and help fulfill basic human needs such as participation, affection, and a sense of belonging.
- *Human capital*: Human beings and their attributes, including physical and mental health, knowledge, and other capacities that enable people to be productive members of society. This involves the balanced use of time to fulfill basic human needs such as satisfying employment, spirituality, understanding, skills development, creativity, and freedom.
- *Built capital*: Buildings, machinery, transportation infrastructure, and all other human artifacts and services that fulfill basic human needs such as shelter, subsistence, mobility, and communications.

We recognize that human, social, and produced assets depend entirely on the natural world, and that natural capital is therefore ultimately nonsubstitutable. Sustainability therefore requires that we live off the interest (sustainable yields) generated by natural capital without depleting the capital itself.

To think of nature, the biosphere, the Earth as a form of capital is a way of recognizing its importance to the economy, an importance that is often overlooked. Ecological economics understands economies as embedded in cultures and societies, which are embedded in the geobiosphere. This means that economies rely on the geobiosphere to provide materials and energy and to accommodate all the wastes that economic activity inevitably produces. Natural capital is similar to built capital (buildings, machines, infrastructure, warehouses) in that it provides goods (e.g., minerals, fossil fuels) and services (e.g., pollination, flood control) without which economies could not function.

In speaking of "natural capital," we are using the term "capital" in its physical not financial sense (e.g., a carpenter's stock of tools or a factory assembly line). A herd of livestock is a capital stock that yields a flow of new members. The physical herd converts grass, water, and so forth, into new animals. The net increment is income or sustainable yield.

The constant herd is capital, reproducing stock. This is a physical stock–flow relation independent of financial arrangements. Indeed, the word "capital" derives from "capitas," the number of heads the herdsman has in his live stock. Similar stock–flow relationships hold for forests, fisheries, and other populations. The problems arise when the physical descriptive term "natural capital" is converted into financial monetary terms and especially when natural growth rates are converted into monetary yields of different physical stocks and then are compared with the rate of interest on a stock of money in the bank. But reasonable rejection of financialization of nature should not keep us from recognizing the physical importance of natural capital as a stock that yields desired flows.

But natural capital is also very different from built capital. First of all, built capital is made from natural capital. In other words, nature can exist without built capital, but built capital cannot exist without nature. There is an essential hierarchy limiting the extent to which built capital can substitute for natural capital, and they are better thought of as complements than substitutes.

Second, built capital represents a "fund" that provides a "service," as, for example, a lathe provides a service when it is used to shape wood. The lathe does not end up embodied in the wood. Natural capital can also be a fund that provides services, such as when a forest provides habitat for forest creatures. But natural capital can also be a stock out of which a supply of material flows. So the forest that provides habitat as a fund-service is also a stock of trees that supplies a flow of wood (the very wood used on the lathe.) Services do not deplete funds. Flows do deplete stocks, which can however be regenerated if renewable. Because materials flowing from natural capital are usually sold through markets, and ecosystem services often are not, there is an ever-present tendency to overuse natural capital for the flows it can provide to the detriment of its capacity to provide services.

A third and more profound reason for differentiating between natural and built capital is that built capital is simply an object for the benefit of humans. That is why it exists. When built capital no long provides a useful service, it is demolished. Nature, of which humans are an integral part, is much more than that. Nature is populated by countless species, many of whom are sentient, experience a range of emotions, learn, and live in communities of their own making. Reverence for all life acknowledges that the rest of nature has rights and that a fair distribution of resources needs to acknowledge those rights. Thus, thinking of built capital and natural capital as substitutes is not appropriate, as a common designation of both of them as forms of capital might otherwise suggest.

With these caveats in mind, we employ the concept of natural capital in this report cognizant of its limitations (Third World Network 2012).

3.5.2 Gross Domestic Product and Its Political Importance

Economists want the market to perform well. They are deeply convinced that when the market performs well, people in general benefit. Most of their research is geared, in one way or another, to understanding what makes the market function well.

Although many of their theories about healthy market functioning are deductive, economists are also interested in measurement of market success, both in particular sectors of the market and the market as a whole. The single most important measure in most countries is GDP. Most economists view growth in GDP, or GDP per capita, as a sign of a healthy market, which means for them a healthy economy, and then human well-being.

With respect to some aspects of economic teaching, such as opposition to government intervention in the labor market, economists are regularly overruled by public consensus. But with respect to growth as measured by GDP, there has been no major public dissent. Only recently conversations about alternative indicators have begun in academic and political circles. Even so, all political parties are committed to economic growth, and that means an increased GDP. When alarm is expressed about the difficulty of stimulating adequate growth, the meaning is that the policies adopted have not sufficiently increased the GDP. The general public also accepts this view of economic health and human well-being and is more likely to keep a party in power when it believes the economy—and that means chiefly the GDP—is growing.

Other countries also measure their domestic products. Although complete standardization has not been attained and difficulties in inter-country comparisons are recognized, GDP measurements are also used by international financial agencies to measure the comparative success of development programs. Both the World Bank and the International Monetary Fund (IMF) shape their policies by this indicator. Successful economic development means that the rate of increase of per capita GDP is satisfactory.

Humanitarians also often cite GDP figures. Their objective is to arouse our sympathy for the people whose income is very low. They usually imply that the countries with high per capita GDP should find means of transferring some of their wealth to countries with low per capita GDP. In short, GDP as the standard measure of economic success is widely accepted by economists, politicians, financiers, humanitarians, and the general public. It is enormously important and merits closer examination.

All groups assume that GDP measures something of importance to the economy and most assume that this is closely bound up with human welfare. As shown earlier in this chapter, human welfare has dimensions other than the economic one. But it is rightly held that the economic element in welfare is very important, and that the stronger the economy the greater the contribution to human welfare. It is also often thought that the economy is the major area of welfare subject to political influence. In any case, there is little consensus on any other measure, so that none of the others that have been proposed exert even a remotely comparable influence on public policy.

The tendency to forget that GDP measures only some aspects of welfare and to treat it as a general index of national well-being is, of course, a typical instance of the fallacy of misplaced concreteness, as devastatingly shown by Daly and Cobb (1989). It can be countered by giving increasing visibility to other indicators, such as the HDI, ecological footprint, GPI, and others. Indicators of ecological health should also be developed and publicized (Costanza et al. 1992). Although not stated in the form of statistical indexes, Lester Brown's annual *State of the World* (Brown 1997a) volumes and the annual *Vital Signs* (Brown 1997b) scorecards help in this regard.

The assumption that economic welfare as measured by GDP can simply be added to other elements of welfare generally reflects the reductionist view of reality. The whole is found by putting together the parts into which it was divided for study. That assumes that the parts are in fact unchanged by their abstraction from the whole, which is clearly not true. Hence the first question to ask is whether growth in the economy as measured by GDP actually contributes to the total well-being of people.

Until recently, this question was hardly raised, and even today it is not taken seriously in most economic and political circles. Nevertheless, the question is now before the world. There is a mounting chorus of critics who point out how high the cost of growth of GDP has been in psychological, sociological, and ecological terms (Wachtel 1983). The relation of GDP to total human welfare is discussed further later in this chapter.

But there is also a question about the relation of GDP to economic welfare itself. This question is familiar to economists. Indeed, no knowledgeable economist supposes that the GDP is a perfect measure of economic welfare. Most recognize that market activity, as measured by GDP, has social costs that it ignores and that it counts positively market activity devoted to countering these same social costs. Obviously GDP overstates welfare! There are other weaknesses that make it vulnerable to ridicule, but there is a widespread assumption that these are minor weaknesses and that what GDP measures comes close enough to economic welfare that it can be used without further ado in a whole range of practical contexts. When economists or political leaders forget that what is measured by GDP is quite distinct from economic welfare, and when they then draw conclusions from the GDP about economic welfare, the fallacy of misplaced concreteness appears again.

Although economists quickly acknowledge this, they also quickly deny its importance. Our task will be to examine more closely the discussion of GDP and economic welfare to determine whether this wide consensus among economists is justified or whether the fallacy, in this instance, is more important than they suppose. We will discuss three moves away from GDP. First, we consider a move toward a conceptually more correct concept of income (Hicksian income). The issue here is not to measure economic welfare at all but to do a better job of measuring income. Of course, there is a relation between income and welfare, and a better measure of income is likely to be a better index of welfare also, but Hicksian income does not directly address the relation to economic welfare in general. The second move away from GDP is toward a measure of economic welfare, component by component. The third is a move toward a more comprehensive measure of total human welfare in which economic welfare is only one component.

3.5.3 Gross Domestic Product: Concepts and Measurement

The definition of GDP has remained fairly consistent over the years. This is one of its appeals. There is a long historical record. Sherman (1966) defines GDP as follows:

> The gross domestic product (GDP) may be calculated in two different ways, corresponding to the money flow from households to business or the equal money flow from business to households. In the first way, we examine the aggregate money demand for all products. This is the flow of money spending on consumer goods, investment goods, government expenditure, and net export spending.
>
> The second way is to add up the money paid out by businesses for all of its costs of production. Most of these costs of production constitute flows of money income to households. These incomes include wages paid for services of labor, rent for the use of land, interest for the use of borrowed capital, and profit for capital invested (pp. 30–31).

The text notes that depreciation and excise taxes must be added to the second way. When this is done, the first and second ways must attain identical results. Equality between the spending and income streams is guaranteed by the residual nature of profit. Any difference between the two streams appears as either profit or loss, which when added to the income stream guarantees the equality of the two flows.

Sherman goes on to show that by subtracting depreciation from GDP one arrives at net national product (NNP); by subtracting retained corporate profits, corporate income taxes, and contributions for social insurance and adding government transfer payments at net interest paid by government, one arrives at personal income; and by subtracting personal income taxes from this, one arrives at disposable personal income.

If Sherman were asked directly whether GDP is a measure of economic welfare, we are not sure what he would answer. But that he regards it as such for practical purposes and communicates this regard to his readers, there can be no doubt. After having cautioned that each industry's contribution to the national product is only the value added rather than the total value of its output, Sherman (1966) writes:

> A second qualification is necessary if we wish to measure accurately the year-to-year improvement *in national welfare*.... We must always deflate the changes in the money value of the national product by the price changes to find the real amount of change in the national product.
>
> Lastly, we may not be interested in the total national product but in the national product per person of the population.... Therefore, if we wish to measure the improvement in *individual welfare*, we must always deflate the increase in our total national product by the increase in our population. (emphasis added; 52–53)

One would expect from this textbook account that the actual measure of the GDP in the national income accounts was a straight measure of market activity only. There are those who would find this limitation beneficial in their work (Eckstein 1983). However, this has never been the case.

The reason that GDP has never been based on market activity alone is that this would distort the actual economic situation drastically. From the beginning of the accounts, two major additions to market activity have been food and fuel produced and consumed by farm families and the rental value of owner-occupied dwellings. The reason for including these is obvious. Consider a scenario: suppose someone lives in a home he rents from someone else while owning a house elsewhere that he rents out to another party. Both rentals constitute market activity. If, he then moves into his own home, market activity is reduced, and if only market activity is counted then the GDP is reduced. Yet intuitively, no one feels that the economy has been damaged. (Also imputed have been the value of food and clothing provided to the military, and banking services rendered to depositors without payment; Ruggles 1983.)

Our point is that from the beginning there has been a tension in the consideration of what it is that GDP measures. The tension is visible in textbooks. On the one hand, the emphasis is on market activity. On the other hand, there is a concern about making judgments about improvement in welfare. The GDP has emphasized the market but has made modest adjustments in the direction of welfare by imputing a rental value for owner-occupied housing. But the same logic that justifies the inclusion of these items would justify the inclusion of many others.

Accordingly, many proposals have been advanced to impute additional values in computing the GDP. Thus far, none have been adopted. As Otto Eckstein (1983) comments

> NIPA (National Income and Product Accounts) has many purposes; to gauge economic performance, compare economic welfare over time and across countries, measure the mix of resources used between private and public sectors and between consumption and investment, and to identify the functional distribution of income and of the tax burden. Inevitably, these purposes clash and the accounts must be a compromise (p. 316).

A compromise cannot be completely satisfactory to anyone. Our concern, however, is not whether the compromise will slightly warp comparisons of "economic welfare over time and across countries" but whether GDP, which remains primarily a measure of market activity, is in general a useful measure of economic welfare at all. Might it not be better to have a measure of market activity that works well for the more technical purposes and makes no adjustments in the direction of measuring welfare? Then the question of how much correlation exists between increasing market activity and economic welfare of people could be asked more clearly and neutrally.

There is a second respect in which the GDP fails to be a pure measure of market activity. At some point, it also concerns itself with wealth; specifically, capital. This is apparent where depreciation factors into the cost of doing business. This operates in a rather odd way—the greater the depreciation of capital assets of a business in a given year, the greater the GDP (all other things being equal). The decline in the value of a factory and its equipment increases the GDP. The fact that this decline is not a contribution to economic welfare is recognized through the deletion of this figure in calculating the NNP and the national income. But we must remember that it is GDP rather than these other figures that factors into most comparative studies of economic welfare.

This indicates that although depreciation of capital assets does enter into GDP figures, it does so in a way that is opposite to its relation to national wealth. Some of the figures in the GDP do indicate a positive relation to the increase in national wealth, others are neutral, and some, as we have seen, are negative. It is possible to ask whether measures of national wealth might not correlate more highly with national economic welfare than do either market activity or GDP. In fact, one great economist, Irving Fisher, argued strongly that this is the case (Fisher 1906). In Fisher's view, nearly all consumer goods are classed as capital or as wealth, and their consumption represents depreciation. For Fisher, welfare is the service (the psychic sense of want satisfaction) rendered by this capital and, for the most part, would have to be imputed. For example, the value of the annual service of your overcoat is what it would cost you to rent it. This is the same imputation as with owner-occupied houses but is more difficult to determine because we have no rental markets for overcoats. But the logic is the same. It is at least essential that no one supposes that GDP measures national wealth or has any necessary correlation with its increase or decrease.

None of these comments are intended to imply that the NIPA of the U.S. government or similar accounts in other countries are of no use. Our concern here is with one particular use: namely, their use as a measure of economic welfare. Until we understand exactly what GDP does and does not measure, we cannot make reasonable judgments on these questions.

Like most of what happens in the world, the explanation of why the GDP measures what it does is historical rather than systematic. The Commerce Department began reporting statistics on the net product of the national economy in 1934. But it has been noted that

> It was the mobilization for World War II and the consequent demand for data relating to the economy as a whole that was primarily responsible for shaping the accounts. The central questions posed by the war were how much defense output could be produced and what impact defense production would have upon the economy as a whole. (Ruggles 1983, 17)

Similar developments were occurring in other countries, and the United States compared its approach with those of the British and Canadians during 1944. The next year the League of Nations convened a meeting on national income accounting. So, by 1947, the United States was ready to publish its newly developed national accounting system. Although this was supplemented in various ways in later years and revised in 1958 and 1965, with respect to our concerns it has remained basically unchanged.

There have, however, been critical discussions of the national income accounts that raised questions relevant to our concerns. This was especially true of the 1971 Conference on Income and Wealth, which did concern itself with welfare questions. It became clear that:

> Many users considered that the present emphasis of the national income and product accounts on market transactions led to a perspective that was too narrow for the measurement of economic and social performance. It was cogently argued that additional information was required on non-market activity, on the services of consumer and government durables and intangible investment, and on environmental costs and benefits. (Ruggles 1983, 332)

There was some discussion of the evaluation of leisure. But such considerations involved large imputation that would render the accounts less useful to "Those who used the national accounts for the analysis of economic activity in the short run, with a focus on inflation, the business cycle, and fiscal policy" (Ruggles 1983, 332). For this reason, the concerns of those interested in measuring long-term economic and social performance have not been dealt with in the accounts.

On the other hand, the Bureau of Economic Analysis (BEA) has established a new program to develop measures of nonmarket activity within the framework of GDP accounts. In part, this work is a response to the emphasis put on this topic at the 1971 Conference on Income and Wealth, but it also reflects the strong interest in environmental studies within the Department of Commerce. The federal government's concern with the measurement of the costs of pollution control and environmental damage has stimulated work in this area. The BEA's current program, however, includes not only environmental questions but also (1) time spent in nonmarket work and leisure, (2) the services of consumer durables, and (3) the services of government capital. The close relationship to the national income accounting system in this work is stressed, but as yet it has not been formally integrated (Ruggles 1983).

The tension we have noted between a measure of market activity and a measure of economic welfare is clearly being felt by those responsible for national income accounts. The problem seems to be insoluble as long as the effort is to have a single summary figure, such as GDP.

Ruggles (1983), whose historical account we have been following, concludes:

> There is no well-defined universe of nonmarket activities and imputations to be covered. The set of all possible imputations is unbounded. The only criterion that can be employed is whether the imputations are considered to be useful and necessary for the particular purpose at hand….
>
> For all these reasons, an explicit separation of market transactions from imputations in the national accounts would seem highly desirable.... It would be recognized, however, that imputations alone cannot meet the information needs for measuring economic and social performance.... No amount of imputation can convert a one-dimensional summary measure such as the GDP into an adequate or appropriate measure of social welfare (pp. 41–43).

In 1992, the Earth Summit recommended that countries implement environmental economic accounts at the earliest date. This led the United Nations Statistical Division (UNSD) to publish the "interim" handbook of national accounting, called the System of Environmental and Economic Accounting (SEEA). As the discussions around concepts and methods continued, several developing and developed countries started experimenting on the compilation of SEEA. The continued research and country experimentation led to the publication of an operational manual in 2000. SEEA was updated and republished in 2003 to include much more of the consensus around concepts, definitions, and methods. However, because it did not include strict accounting guidelines and methods, but left options for countries, it was never recognized as a statistical system. However, because many countries were already independently attempting to implement SEEA and the growing recognition that natural capital needed to be included in national accounts, the UN began a second revision. In 2012, the United Nations Statistical Commission adopted the SEEA as a statistical standard. The World Bank, through their Wealth Accounting and the Valuation of Ecosystem Services (WAVES) program has begun to assist countries in implementing the new SEEA.

3.5.4 From Gross Domestic Product to Hicksian Income and Sustainable Development

Not only is GDP a poor measure of welfare, it is also a poor measure of income. In subsequent sections, we discuss the effort to move from GDP toward a measure of welfare. This is a very difficult task involving many controversial issues. In this section, the focus is on the less controversial issue of converting GDP into a better measure of income. Unlike welfare, the concept of income has a fairly clear theoretical definition, although there are big problems in making that definition operational. In measuring welfare, one cannot avoid—to a large extent—implicitly defining the concept by one's very measure of it. With income, we have an explicit independent definition to which our measurements may to a greater or lesser degree correspond. With welfare, we have no such independent theoretical definition. It is therefore useful to keep these two departures quite separate from GDP.

The central criterion for defining the concept of income has been well stated by Sir John Hicks in *Value and Capital* (1948):

> The purpose of income calculations in practical affairs is to give people an indication of the amount which they can consume without impoverishing themselves. Following out this idea, it would seem that we ought to define a man's income as the maximum value which he can consume during a week, and still expect to be as well off at the end of the week as he was at the beginning. Thus when a person saves he plans to be better off in the future; when he lives beyond his income he plans to be worse off. Remembering that the practical purpose of income is to serve as a guide for prudent conduct, I think it is fairly clear that this is what the central meaning must be (p. 172).

The same basic idea of income holds at the national level and for annual time periods. Income is not a precise theoretical concept but rather a practical rule-of-thumb guide to the maximum amount that can be consumed by a nation without eventual impoverishment. We all know that we cannot consume the entire GDP without eventually impoverishing ourselves, so we subtract depreciation to get NNP, which is usually taken as income in Hicks's sense. Note that the central defining characteristic of income is *sustainability*. The term "sustainable income" ought therefore to be considered a redundancy. The fact that it is not is a measure of how far we have strayed from the central meaning of income and, consequently, the need for correction.

But could we really consume even NNP year after year without impoverishing ourselves? No, we could not, for two reasons: first, because the production of NNP at the present scale requires supporting biophysical transformations (environmental extractions and insertions) that are not ecologically sustainable; and second, because NNP overestimates net product available for consumption by counting many defensive expenditures (expenditures necessary to defend ourselves from the unwanted side effects of production) as final products rather than as intermediate costs of production. Consequently, NNP increasingly fails as a guide to prudent conduct by nations.

For example, a developing country may obtain 6% of its GDP from timber exports. Perhaps 2% is based on sustained yield exploitation and the remaining 4% is based on deforestation. The maximum sustainable consumption has been overestimated by 4%, not even counting the loss of unpriced ecosystem services of the forest. That may sound small, but in an economy whose conventional GDP was growing at 3%, a 4% reduction is the difference between growth and decline, which makes a very big qualitative difference in a nation's perception of itself and its policies, and indeed, of its leaders. The last difference is one reason for resistance to this change in income accounting. No politician wants to be known as the minister under whom the country went from growth to decline in one year. Yet there is an opportunity for someone to become known as the leader who introduced the income accounting system that saved the nation from eventual impoverishment.

Two adjustments to NNP are necessary to arrive at a good approximation to Hicksian income and a better guide to prudent behavior. One adjustment is a straightforward extension of the principle of depreciation to cover consumption of natural capital stocks depleted as a consequence of production. The other is to subtract (regrettably necessary) defensive expenditures made to defend ourselves from the unwanted side effects of growing aggregate production and consumption. Defensive expenditures are intermediate goods, which means they are costs of production rather than final products available for consumption. Defensive expenditures include policing, door locks, window bars, increased frequency of painting property to prevent damage from acid rain corrosion, and so on. To correct for having counted defensive expenditures in NNP, their magnitude must be estimated and subtracted in order to arrive at an estimate of sustainable consumption or a true income.

To summarize, let us define our corrected income concept, Hicksian income (HI), as net national product (NNP) minus defensive expenditures (DE) and depreciation of natural capital (DNC). Thus, HI = NNP – DE – DNC.

No interference whatsoever with the current national accounts (or loss of historical continuity or comparability) is entailed in this suggestion. Two additional adjustment accounts are introduced, not for frivolous or trendy reasons, but to gain a better approximation of the central and well-established meaning of income. Because these two adjustment accounts are also relevant to our attempt to measure welfare, they will be discussed in that context and are not further considered here.

What deserves some mention in this context is the recent surge of interest in "sustainable growth" or "sustainable development" within development agencies and third world countries following the publication of the *Brundtland Report* (WCED 1987). Although the two terms are used synonymously, we suggest a distinction. As discussed earlier, "growth" should refer to quantitative expansion in the scale of the physical dimensions of the economic system, while "development" should refer to the qualitative change of a physically nongrowing economic system in dynamic equilibrium with the environment. By this definition the Earth is not growing but is developing. Any physical subsystem of a finite and nongrowing Earth must itself also eventually become nongrowing. Therefore, growth will become unsustainable eventually and the term "sustainable growth" would then be self-contradictory. But sustainable development does not become self-contradictory. Now that these terms have become buzzwords among the development agencies, it is important to make this distinction and even more important to define sustainable development in operational terms. If we had defined development operationally as an increase in Hicksian income rather than as an increase in GDP, then sustainability would have been guaranteed, as we have seen.

The main operational implication of Hicksian income is to keep capital intact. Our problem is that the category of capital we have endeavored to maintain intact is only humanly created capital. The natural capital is left out as are human capital, such as the skills, education, and health of workers, and social capital, such as relationships and volunteer work. Indeed, they are left out by definition as long as one defines capital as "(humanly) produced means of production." We suggest a functional definition of capital as a stock that yields a flow of goods or services. As we have discussed before, there are then two categories of capital, natural and built. Natural capital is the nonproduced means of producing a flow of natural resources and services. Only human-made capital has been maintained intact, along with some natural capital stocks that are privately owned (herds of cattle, plantation forests).

Another approach that is relevant to making GDP a better measure of income and to operationalizing the definition of sustainable development has been advanced by El Serafy (1988). El Serafy tackles the difficult issue of how to treat receipts from nonrenewable resources in defining income. Or, what comes to the same thing, how can a community leave its nonrenewable resources forever in the ground unused yet not allow their exploitation to deflect the community from the path of sustainable development? He argues that receipts from a nonrenewable resource can be divided into an income and a capital component. The income component is that portion of the receipts that could be consumed annually in perpetuity on the assumption that the remainders of the receipts were invested in renewable assets. The return on the renewable assets and the amount invested each year are such that when the nonrenewable resource is exhausted the new renewable assets will be yielding an amount equal to the income component of the receipts.

The basic logic underlying El Serafy's method is that

> The finite series of earnings from the resource, say a 10-year series of annual extraction leading to the extinction of the resource, has to be converted to an infinite series of true income such that the capitalized value of the two series are equal. An income portion has to be identified from the annual earnings from sales that is capable of being spent on consumption; the remainder, the capital element, is set aside year after year to be invested in order to create a perpetual stream of income that would sustain the same level of *true* income, during the life of the resource as well as after the resource has been exhausted.

To make the separation into income and capital components, one needs to know only the rate of discount (which must ultimately be related to the rate of growth of renewable resources and the rate of growth of factor productivity, although this relation is not discussed by El Serafy) and the life expectancy of the nonrenewable resource (total reserve stock divided by the annual extraction rate). Social choices or assumptions about these magnitudes will allow the calculation of the percentage of the nonrenewable resource receipts that should be counted as income. For example, if the life expectancy of a nonrenewable resource is 10 years and the discount rate is 5%, then it can be shown that 42% of current receipts is income and the remaining 58% is the capital content that must be reinvested. Alternatively, if the discount rate was 10% and the life expectancy remained at 10 years, the income component would be 65%. A discount rate of 10% and a life expectancy of 50 years would result in a 99% income component.

El Serafy's method is elegant and parsimonious in terms of its information requirements. The effect of rising costs of extraction can be taken into account as a reduction of reserves. The whole calculation can be redone on the assumption of rising relative price of resources rather than on the assumption of constant prices used for simplicity. As a correction of GDP, El Serafy's method is more radical than the subtraction of depletion of natural capital from NNP because it would change the very calculation of GDP itself. Instead of keeping the present overestimate of Hicksian income and then subtracting an adjustment figure, El Serafy's method would avoid the overestimate from the beginning by calculating GDP differently. Although this is logically neater, it is politically more difficult to convince national income accountants to do this because it sacrifices historical continuity in the way accounts are kept. But even if the estimation of a natural capital depreciation adjustment account was favored for this reason, El Serafy's method would still be useful in calculating natural resource depreciation, which would still be receipts in excess of the income component, assuming this amount was being consumed rather than invested.

If a development bank or agency takes sustainable development as its guiding principle, then, ideally, each of the projects it finances should be sustainable. Whenever this is not possible, such as with the exploitation of a nonrenewable resource, there should be a complementary project that would ensure sustainability for the two taken together. The receipts from the nonrenewable extraction should be divided into an income and capital component as discussed earlier, with the capital component invested each year in the renewable complement (long-run replacement). Furthermore, if projects or combinations of projects must be sustainable, then it is inappropriate to calculate the net benefits of a project or policy alternative by comparing it with an unsustainable option—that is, by using a discount rate that reflects rates of return on alternative uses of capital that are themselves unsustainable. For example, if a sustainably managed forest can yield 4% and is judged an uneconomic use of land on the basis of a 6% discount rate, which on closer inspection turns out to be based on unsustainable uses of resources, including perhaps the unsustainable clearing of that same forest, then clearly the decision simply boils down to sustainable versus unsustainable use. If we have already adopted a policy of sustainable development, then of course we choose the sustainable alternative, and the fact that it has a negative present value when calculated at a nonsustainable discount rate is simply irrelevant. The present value criterion itself is not irrelevant because we are still interested in efficiency—in choosing the best sustainable alternative. But the discount rate must then reflect only *sustainable* alternative uses of capital. The allocation rule for attaining a goal efficiently (maximize present value) cannot be allowed to subvert the very goal of sustainable development that it is supposed to be serving! Use of an unsustainable discount rate would do just that. We suspect that discount rates in excess of 5% often reflect unsustainable alternatives. At least one should be required to give, say, five concrete examples of sustainable projects that yield 10% before one uses that figure as a discount rate.

Given acceptance of the goal of sustainable development, there still remains the question of the level of community at which to seek this goal. International trade allows one country to draw on the ecological carrying capacity of another country and thus be unsustainable in isolation—even though it is sustainable as part of a larger trading bloc. The trade issue again raises the question of complementarity versus substitutability of natural and human-made capital. If we follow the path of strong sustainability, then this complementarity must be respected either at the national or international level. A single country may substitute human-made capital for natural capital to a high degree if it can import the products of natural capital (the flow of natural resources and services) from other countries that have retained their natural capital to a greater degree. In other words, the demands of complementarity can be evaded at the national level but only if they are respected at the international level. One country's ability to substitute human-made capital for natural capital to a high degree depends on some other country's making the opposite (complementary) choice.

One reason for the unanimity of support given to the phrase "sustainable development" is precisely that it has been left rather vague—development is not distinguished from growth in the *Brundtland Report*, nor is there any distinction between strong and weak sustainability. Politically this was wise on the part of the authors. They managed to put high on the international agenda a concept whose unstated implications were too radical for consensus at that time. But in so doing they have guaranteed eventual discussion of these radical implications. Consider, for example, two questions immediately raised by any attempt to operationalize their definition of sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs." First, there is the question of distinguishing "needs" from extravagant luxuries or impossible desires. If "needs" includes an automobile for each of a billion Chinese, then sustainable development is impossible. The whole issue of *sufficiency* can no longer be avoided. Second, the question of not compromising "the ability of future generations to meet their own needs" requires an estimate of that ability. It may be estimated on the basis of either strong or weak sustainability, depending on assumptions about substitutability between natural and built capital. This will force deeper discussion of the substitutability issue, which lies near the heart of present economic theory.

The Brundtland Commission legitimated the concept of sustainable development and made it easier for others to press the issue further. Although a lot of progress has been made around the concept of sustainability, sustainable growth is still a term that is often used by governmental agencies. GDP is still considered the primary indicator of progress and well-being, and the difference between development and growth is rarely understood.

3.5.5 From Gross Domestic Product to a Measure of Economic Welfare

Without claiming to devise a comprehensive measure of social welfare, it may still be possible to develop a measure that incorporates the positive contribution of the economy to social welfare. This was the goal of Nordhaus and Tobin (1972) in their construction of a measure of economic welfare (MEW). However, this was a means to demonstrate that the consensus among economists was correct, that the existing GDP correlates sufficiently well with economic welfare to make it unnecessary to use the instrument they devise! This is their clear conclusion despite their earlier statement that "maximization of GDP is not a proper objective of policy" (Nordhaus and Tobin 1972, 4). We will ignore this puzzling contradiction and describe their careful work on the MEW—in which they "attempt to allow for the more obvious discrepancies between GDP and economic welfare" (6).

Nordhaus and Tobin begin with the GDP and make three types of adjustments: "Reclassification of GNP [gross national product] expenditures as consumption, investment, and intermediate; imputation for the services of consumer capital, for leisure, and for the product of household work; correction for some of the disamenities of urbanization" (5). With the exception of environmental costs and benefits, they covered all the questions raised in the 1971 Conference on Income and Wealth mentioned earlier. We will follow their argument in summary.

GDP is a measure of production, not consumption, whereas economic welfare is a matter of consumption. Hence, the first task was to separate consumption from investment and intermediate expenditures. This entailed the deletion of depreciation, as was already accomplished in the NNP. Beyond this, Nordhaus and Tobin considered the effects of treating all durables as capital goods but found that this had little effect. More importantly, it allowed for government capital and reclassification of education and health expenditures as capital investments.

An especially interesting adjustment followed from the recognition that welfare correlates with per capita consumption rather than with gross consumption. To sustain per capita consumption for a rising population, some portion of the NNP must be reinvested. Nordhaus and Tobin (1972) accordingly subtracted from NNP for this purpose to gain a "sustainable" per capita consumption figure. We quote only these sustainable MEW figures.

The authors also noted that some expenditure were regrettable necessities rather than contributions to welfare. In this category, they placed the costs of commuting to work, police services, sanitation services, road maintenance, and national defense. The assumption was that when more people spent longer periods driving to work, the increase in the

GDP did not indicate an increase in well-being (and so with the others). These figures were, accordingly, subtracted.

The second task was to make appropriate imputations for capital services, leisure, and nonmarket work. The latter two had a very large effect on the statistics, and there was no one indisputable method for valuing them. Nordhaus and Tobin proposed three methods. The question was whether leisure and nonmarket activity were affected by technological progress. The authors preferred the measure that left the value of leisure unaffected by technical progress even though nonmarket productive activity was so affected. We report only the statistics generated by this choice.

The third task was to consider urban disamenities. Nordhaus and Tobin recognized that there were negative "externalities" connected with economic growth and suggested that these were most apparent in urban life. "Some portion of the higher earnings of urban residents may be simply compensation for the disamenities of urban life and work. If so we should not count as a sign of welfare the full increments of NNP that result from moving a man from farm or small town to city" (Nordhaus and Tobin 1972, 13).

They now had before them the full range of adjustments. One or another may have appeared inappropriate to some. For example, it may have been argued that police protection was a contribution to welfare, and that it should not be deleted. The counterargument, however, is convincing if our purpose is to compare welfare over time. The increasing cost of police protection did not imply that we were less vulnerable to crime than in the past. Should the social a situation change so that much less protection was needed, this should not have been regarded as a reduction of economic welfare.

The real question was whether the list of regrettable necessities was sufficiently inclusive. As Nordhaus and Tobin (1972) recognize

> The line between final and instrumental outlays is very hard to draw. For example, the philosophical problems raised by the malleability of consumer wants are too deep to be resolved in economic accounting. Consumers are susceptible to efforts of producers. Maybe all our wants are just regrettable necessities; maybe productive activity does no better than to satisfy the wants which it generates; maybe our net welfare product is tautologically zero (pp. 8–9).

Having said this, they ignored the problem. The same problem has been briefly considered and dismissed by Denison and Jaszi, who believed that regrettables or defensive expenditures *should* be counted as final consumption, as was currently the case (Jaszi 1973). All expenditures, they argue, were basically defensive; thus food expenditures were a defense against hunger, clothing and housing expenditures defended against the cold and rain, and so forth—and even expenditures on churches defended against the devil! Clever though this riposte may have been, it missed the point—namely, that "defensive" meant a defense against the *unwanted side effects of other production*, not a defense against normal baseline environmental conditions of cold, rain, and so on. It was not the case that "our net welfare product is tautologically zero" (Nordhaus and Tobin 1972, 8–9). Defensive expenditures were only those that were "regrettably made necessary" by other acts of production and, consequently, should have been counted as costs of that other production; that is to say, counted as intermediate rather than final goods.

We are now ready to consider the results of Nordhaus and Tobin's MEW. What is of special interest to us is how it correlates with GDP because the question of whether growth of GDP indicates improved economic welfare motivated the whole study. First, we quote the conclusion of Nordhaus and Tobin (1972), and then we examine the figures on the basis of which they make their judgment:

> Although the numbers presented here are very tentative, they do suggest the following observations. First, MEW is quite different from conventional output measures. Some consumption items omitted from GDP are of substantial quantitative importance. Second, our preferred variant of per capita MEW has been growing more slowly than per capita NNP (1.1% for MEW as against 1.7% for NNP, at annual rates over the period 1929–1965). Yet MEW has been growing. The progress indicated by conventional national accounts is not just a myth that evaporates when a welfare-oriented measure is substituted (p. 17).*

When their findings are more carefully examined for time frames other than the full period from 1929–1965, the relatively close association between growth of per capita GDP and MEW disappears.† For example, between 1945 and 1947, per capita GDP fell about 15% (from $2,528 to $2,142) while per capita sustainable MEW rose by more than 16% (from $5,098 to $5,934). Of course, this is the period of demobilization after World War II, so no conclusions should be drawn from this short-term

* In fact, the growth rate of per capita MEW from 1929 to 1965 was only 1.0% per year, as opposed to 1.1%. The correct evaluation can be found in Table 18 of Nordhaus and Tobin's study (1972, 56).

† We have chosen to compare per capita MEW with per capita GDP rather than with per capita NNP as Nordhaus and Tobin (1972) have done. We do this for the sake of consistency with other studies (especially the one by Zoltas [1981], discussed here). The differences in annual growth rates are not large, though the growth of per capital NNP is slightly slower than for per capita GDP.

negative relationship. Yet the presumption that the growth of GDP could be used as a reasonable proxy for MEW growth does not find confirmation in other periods either. From 1935 to 1945, per capita GDP rose almost 90% (from $1,332 to $2,528), while per capita sustainable MEW rose only about 13% (from $4,504 to $5,098). More significantly, during the postwar period 1947–1965, when neither depression nor war nor recovery had a major impact on growth rates, per capita GDP rose about six times as fast as per capita sustainable MEW (per capita GDP grew by 48% or about 2.2% per year, while per capita sustainable MEW grew by 7.5% or about 0.4% per year).* Moreover, if we assume, as Nordhaus and Tobin (1972) did in one of their options, that the productivity of housework has not increased at the same rate as the productivity of market activities, then per capita sustainable MEW actually registers a decline of 2% during the period 1947–1965. Alternatively, we might consider the growth of per capita sustainable MEW in the absence of any imputation for leisure or household production because, as Nordhaus and Tobin admit, "Imputation of the consumption value of leisure and nonmarket work presents severe conceptual and statistical problems. Since the magnitudes are large, differences in resolution of these problems make big differences in overall MEW estimates" (Nordhaus and Tobin 1972, 39).

If that imputation is omitted, per capita sustainable MEW grows by 2% from 1947 to 1965. In any case, whether the appropriate figure for the change during that period in per capita sustainable MEW is 7.5%, 2%, or –2%, each of these results suggest that in fact "the progress indicated by conventional national accounts is ... just a myth that evaporates when a welfare-oriented measure is substituted" (Nordhaus and Tobin 1972, 13). With their own figures, Nordhaus and Tobin shed doubt on the thesis that national income accounts serve as a good proxy measure of economic welfare.

Nordhaus reflected again on the significance of his work with Tobin five years later. His interpretation of the results was unchanged: "Although GDP and other national income aggregates are imperfect measures of the economic standard of living, the broad picture of secular progress that they convey remains after correction for their most obvious deficiencies" (Nordhaus 1972, p. 197).

He failed to remark upon the lack of similarity between the growth of MEW and GDP during the last 18 years of the period that he and Tobin had reviewed.

* Interestingly, though Nordhaus and Tobin (1972) calculate the growth rate of per capita NNP and per capita sustainable MEW for the periods 1929–1947 and 1947–1965 (see Table 18 on page 56 of their text), they never refer to the remarkable difference between those two periods in their discussion. To do so would have required them to explain why the growth rate for per capita sustainable MEW had flattened out, even as per capita NNP kept rising.

3.5.6 The Index of Sustainable Economic Welfare and the Genuine Progress Indicator

We have shown that the domestic product, whether gross or net, is not identical with true national income and that subtracting indirect business taxes from NNP (as is done in the national income accounts to arrive at "national income") still does not give us a true measure of national income. True income is sustainable, and to calculate this Hicksian income would require a quite different approach.

We have also shown that there is a marked difference between what GDP measures and economic welfare, and that the latter has been growing much more slowly than the former as measured by the two proposals that have been made for judging the U.S. economy. A defender of the continuing use of GDP as a guide to policy could argue that, even so, economic welfare *has* advanced along with GDP. If *any* advance in the welfare measure is truly a gain, it is still desirable to increase GDP. The recognition that it takes a great deal of increase in GDP to achieve a small improvement in real economic welfare could be used to argue that ever greater efforts are needed for the increase of GDP.

To counter such a claim two points need to be made. First, there are social and ecological indicators that are adversely affected by growth of GDP. Not all of these are dealt with in any of the welfare measures. This is especially true of many of the pervasive externalities.

Second, GDP interprets every expense as positive and does not distinguish welfare-enhancing activity from welfare-reducing activity (Cobb et al. 1995; Talberth et al. 2007). For example, an oil spill increases GDP because of the associated cost of cleanup and remediation, but it obviously detracts from overall well-being (Costanza et al. 2004). GDP also leaves out many components that enhance welfare but that do not involve monetary transactions and therefore fall outside the market. For example, the act of picking vegetables from a garden and cooking them for family or friends is not included in GDP. Yet buying a similar meal in the frozen food aisle of the grocery store involves an exchange of money and a subsequent GDP increase. GDP also does not account for the distribution of income among individuals, which has considerable effect on individual and social well-being (Wilkinson and Pickett 2009).

A more comprehensive indicator would consolidate economic, environmental, and social elements into a common framework to show net progress (Costanza et al. 2004). A number of researchers have proposed alternatives to GDP that make one or more of these adjustments with varying components and metrics (Smith 2013). Some have also noted the dangers of relying on a single indicator and have proposed a "dashboard" approach with multiple indicators.

In an effort to address these issues (while remaining mindful of the pitfalls), Daly and Cobb (1989) developed an Index of Sustainable Economic Welfare (ISEW). The ISEW takes the MEW of Nordhaus and Tobin and the Economic Aspects of Welfare (EAW) of Zoltas (1981) as starting points, but it incorporates the sustainability issues that EAW ignores and the environmental issues that MEW ignores. Rather than revising and bringing up to date the existing measures, they decided to create a new one that includes some of the elements not dealt with by any of the three indices already discussed, as well as fresh ways of treating topics that were included in them. To summarize these changes, ISEW:

1. Factors in income distribution on the assumption that an additional dollar's worth of income adds more to the welfare of a poor family than a rich one.
2. Considerably alters what Nordhaus and Tobin (1972) did in the calculation of changes in net capital stock. Specifically, it includes only changes in the stock of fixed reproducible capital and excludes natural and human capital in this calculation.
3. Updates Zoltas's (1981) estimates using more recent data for air and water pollution and adds an estimate of noise pollution.
4. Includes estimates of costs of the loss of wetlands and farmlands, depletion of nonrenewable resources, commuting, urbanization, auto accidents, advertising, and long-term environmental damage.
5. Omits any imputation of the value of leisure.
6. Includes imputed values for the value of unpaid household labor.

Since then, the ISEW has been renamed the Genuine Progress Indicator (GPI) (Talberth, Cobb and Slattery, 2007). Like ISEW, GPI starts with personal consumption expenditures (a major component of GDP) but makes adjustments using approximately 25 different components, including income distribution, environmental costs, and negative activities such as crime and pollution, among others. GPI also adds positive components left out of GDP, including the benefits of volunteering and household work (Talberth et al. 2007). By separating activities that diminish welfare from those that enhance it, GPI better approximates sustainable economic welfare (Posner and Costanza 2011). GPI is not meant to be an indicator of sustainability. It is a measure of economic welfare that needs to be viewed alongside biophysical and other indicators. In the end, because one only knows if a system is sustainable after the fact, there can be no direct indicators of sustainability, only predictors (Costanza and Patten 1995).

GPI and ISEW have been calculated for various countries around the world. These studies have indicated that in many countries, beyond a certain point, GDP growth no longer correlates with increased economic welfare.

A global GPI was also estimated using GPI and ISEW data from 17 countries (Figure 3.4) that contain approximately 53% of the world's population and 59% of the global GDP (Kubiszewski et al. 2013). On the global level, GPI/capita peaked in 1978 (Figure 3.5). Interestingly, 1978 is also around the time that the human ecological footprint exceeded the Earth's capacity to support humanity. Other global indicators, such as surveys of life satisfaction, also began to level off around this time.

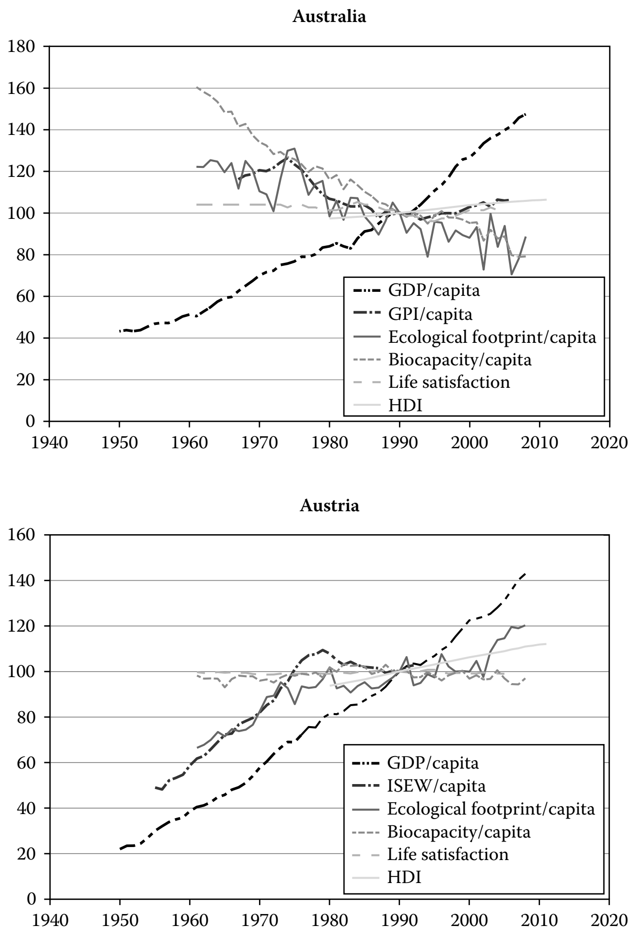


FIGURE 3.4
Comparison with other indicators. The 17 countries used in this study comparing indexed trends for GPI/capita, GDP/capita, Ecological footprint/capita, Biocapacity/capita, HDI, Life Satisfaction, and the Gini coefficient. All graphs are indexed to 1990 = 100. (From Kubiszewski, I., R. Costanza, C. Franco, P. Lawn, J. Talberth, T. Jackson, and C. Aylmer, *Ecological Economics* 93, 57–68, 2013.)

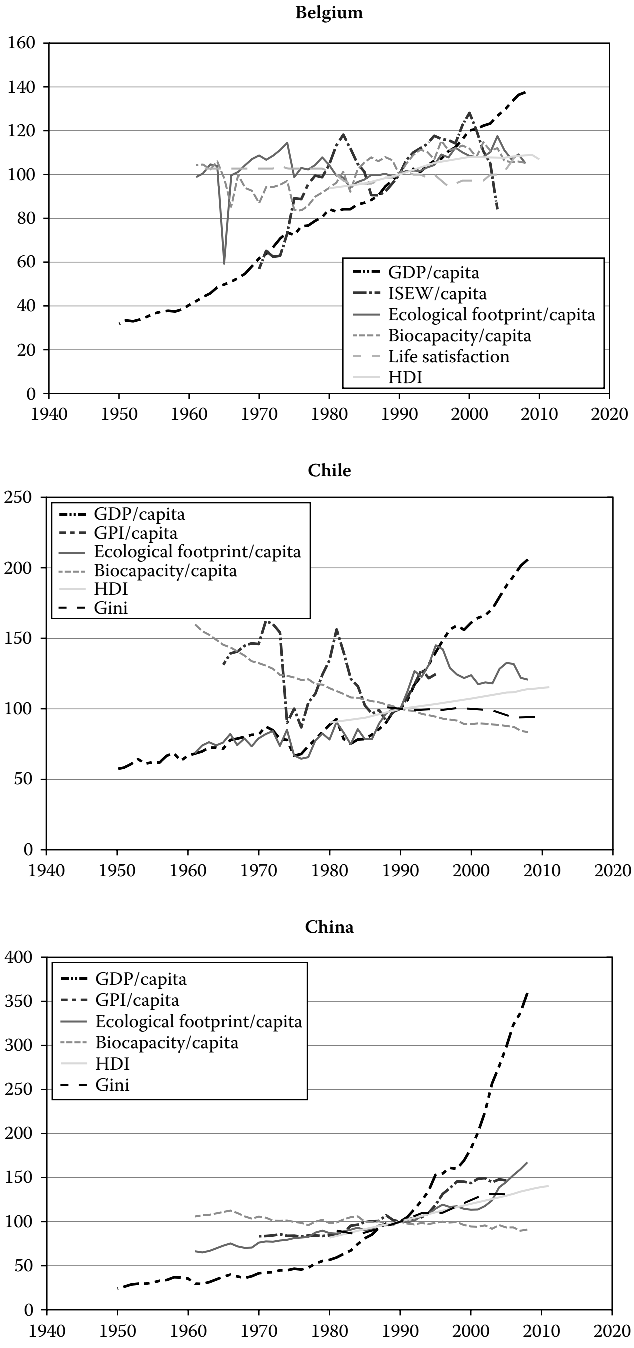
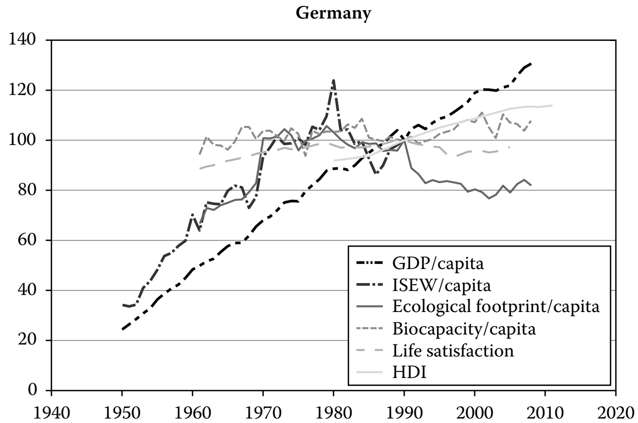
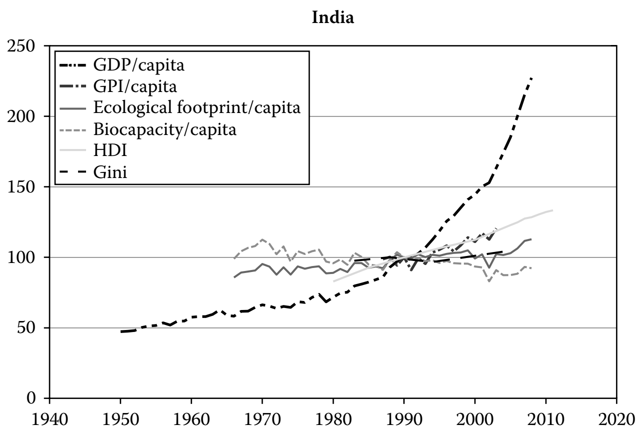
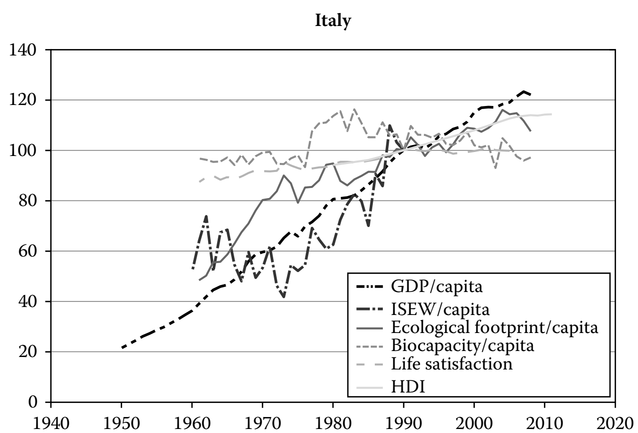


FIGURE 3.4 (*Continued*)







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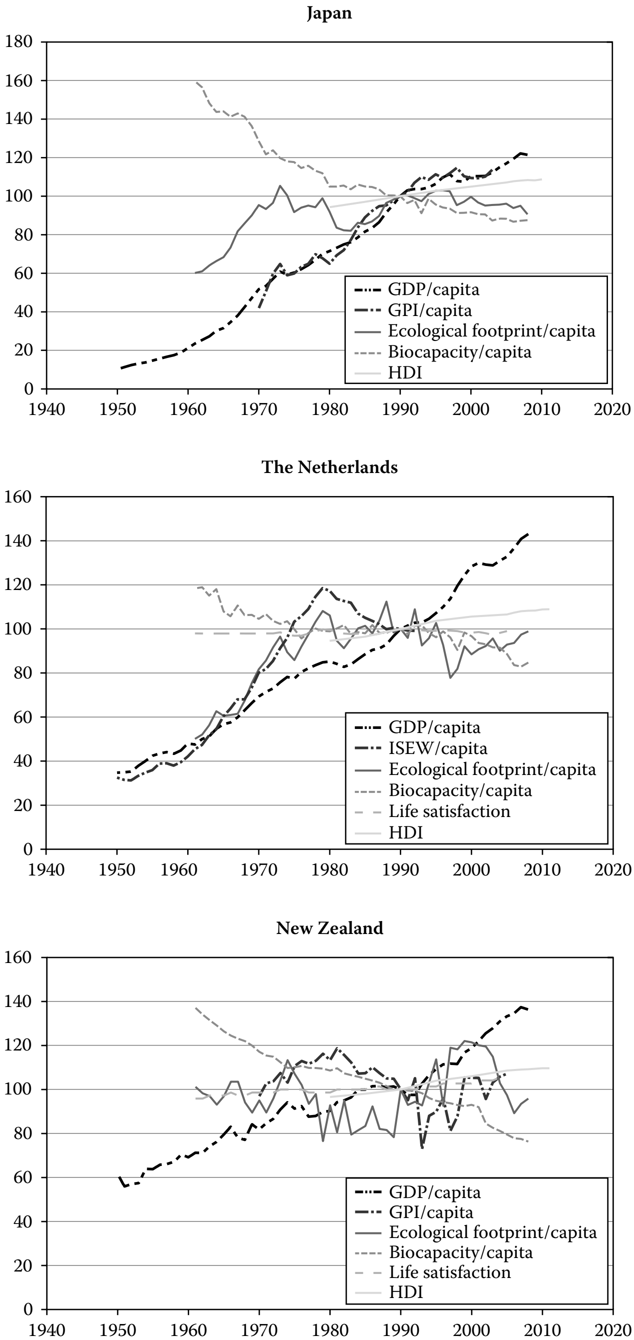

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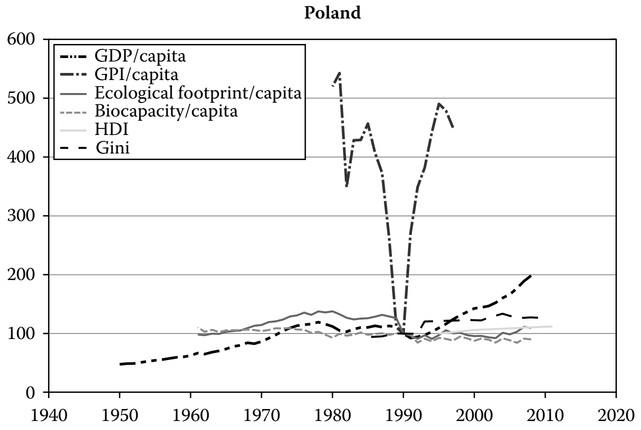

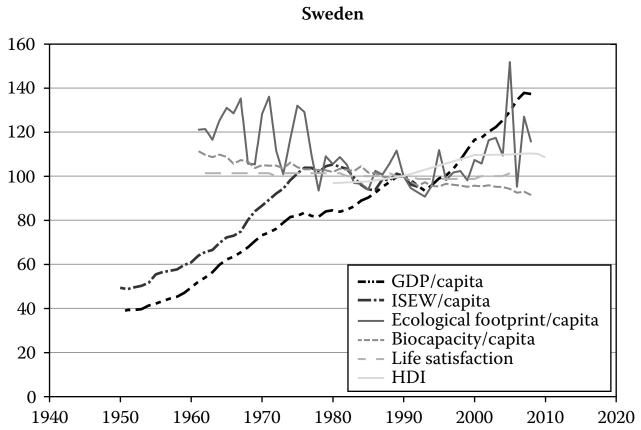

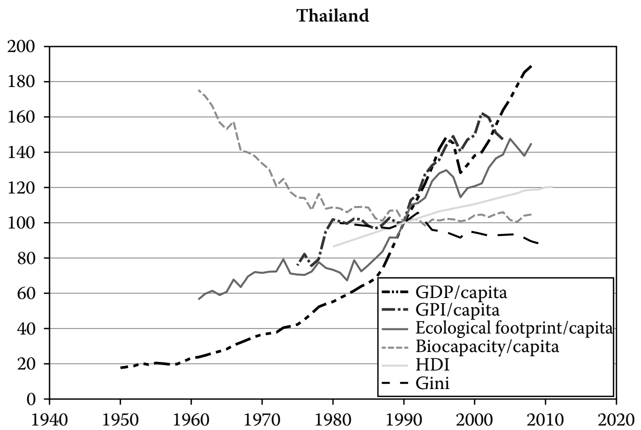

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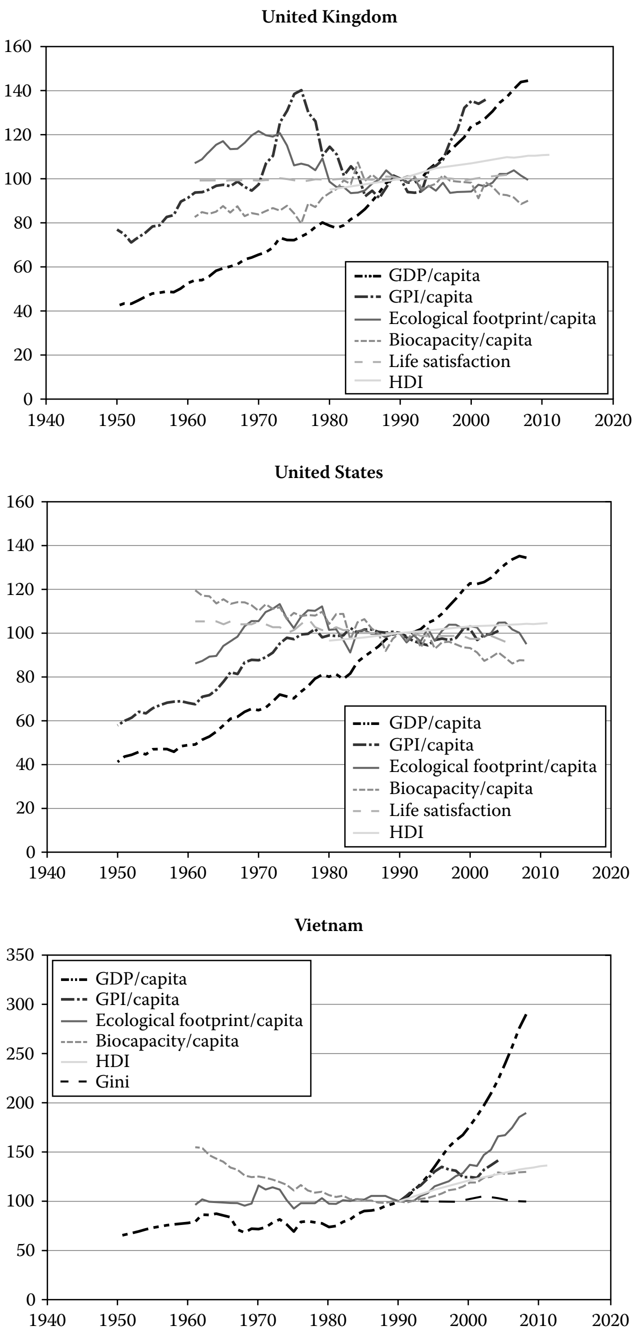

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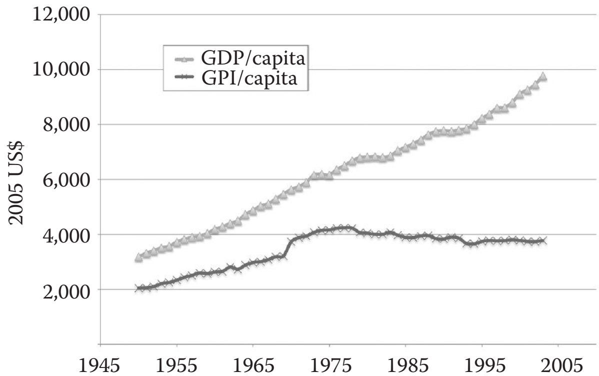

FIGURE 3.5
Global GPI per capita and GDP per capita.

An important function of GPI is to send up a red flag at that point. Because it is made up of many benefit and cost components, it also allows for the identification of which factors increase or decrease economic welfare. Other indicators are better guides of specific aspects. For example, life satisfaction is a better measure of overall self-reported happiness. By observing the change in individual benefit and cost components, GPI reveals which factors cause economic welfare to rise or fall even if it does not always indicate what the driving forces are behind this. It can account for the underlying patterns of resource consumption, for example, but may not pick up the self-reinforcing evolution of markets or political power that drives change.

Recently, two state governments in the United States have adopted GPI as an official indicator—Maryland and Vermont. In addition, the data necessary to estimate GPI is becoming more available in many countries and regions. For example, remote sensing data allow better estimates of changes in natural capital, and surveys of individuals about their time use and life satisfaction are becoming more routine. The bottom line is that the costs of estimating GPI are not particularly high, the data limitations can be overcome, and it can be relatively easily estimated in most countries. Alternatively, a simplified version of GPI can also be calculated as an initial step in the process (Bleys 2007).

3.5.7 Toward a Measure of Total Human Welfare

Although the GPI goes a long way toward providing a better measure of economic welfare, it is certainly not a perfect measure of economic welfare and it falls far short of measuring *total* welfare. GPI is still based on measuring how much is being produced and consumed, with the tacit assumption that more consumption leads to greater welfare. GPI at least adjusts for the sustainability of this consumption, its negative impacts on natural capital, and its distribution across income classes, and makes other reasonable adjustments. This is a huge improvement over GDP and one that tells a very different story about recent changes in aggregate economic welfare.

A completely different approach, however, would be to look directly at the actual well-being that is achieved—to separate the means (consumption) from the ends (well-being) without assuming that one is correlated with the other. Some authors have begun to look at the problem from this perspective. For example, Max-Neef (1992) has developed a matrix of human needs and has attempted to address well-being from this alternative perspective. Although human needs can be classified according to many criteria, Max-Neef organized them into two categories: existential and axiological, which he arranges as a matrix. He lists nine categories of axiological human needs that must be satisfied in order to achieve well-being: (1) subsistence, (2) protection, (3) affection, (4) understanding, (5) participation, (6) leisure, (7) creation, (8) identity, and (9) freedom. These are arrayed against the existential needs of (1) having, as in consuming; (2) being, as in being a passive part of without necessarily having; (3) doing, as in actively participating in the work process; and (4) relating, as in interacting in social and organizational structures. The key idea here is that humans do not have primary needs for the products of the economy. The economy is only a means to an end. The end is the satisfaction of primary human needs. Food and shelter are ways of satisfying the need for subsistence. Insurance systems are ways to meet the need for protection. Religion is a way to meet the need for identity. And so on. Max-Neef summarizes as:

> Having established a difference between the concepts of needs and satisfiers it is possible to state two postulates: first, fundamental human needs are finite, few and classifiable; second, fundamental human needs (such as those contained in the system proposed) are the same in all cultures and in all historical periods. What changes, both over time and through cultures, is the way or the means by which the needs are satisfied (pp. 199–200).

This is a very different conceptual framework from conventional economics, which assumes that human desires are infinite and that, all else being equal, more is always better. According to this alternative conceptual framework, we should be measuring how well basic human needs are being satisfied if we want to assess well-being, not how much we are consuming, because the two are not necessarily correlated (see the earlier section 3.5.1.1 that discusses subjective well-being measures).

3.5.8 Alternative Models of Wealth and Utility

We can summarize the foregoing discussion with reference to two alternative models of wealth and utility, based loosely on the ideas of Ekins (1992). Figure 3.6a and b shows these relationships diagrammatically. Model 1 (Figure 3.6a) shows the conventional economic view of the process. The primary factors of land, labor, and capital combined in the economic process to produce goods and services (GDP), which is divided into consumption (the sole contributor to individual utility and welfare) and investment (goes into maintaining and increasing the capital stocks). Preferences are fixed. In this model, the primary factors are perfect substitutes for each other so land has been downplayed, and

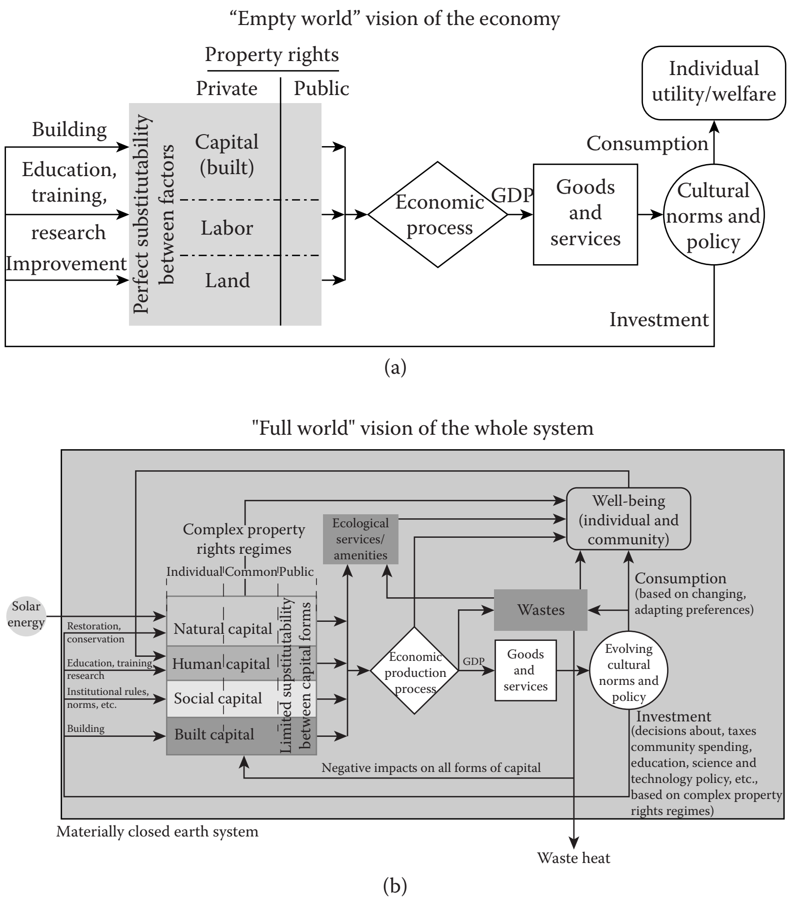

FIGURE 3.6
Alternative models of economic activity. (From Ekins, P., in T. O'Riordan, ed., *Ecotaxation*, Earthscan Publications, 1995.)

the lines between all the forms of capital are fuzzy. Property rights are usually simplified to either private or public and their distribution is usually taken as fixed and given.

Model 2 (Figure 3.6b) shows the alternative ecological economics view of the process. Notice that the key elements of the conventional view are still present but more has been added and some priorities have changed. There is limited substitutability among the three basic forms of capital in this model: natural, human, and build, and property rights regimes are complex and flexible, spanning the range from individual to common to public property. Natural capital captures solar energy and behaves as an autonomous complex system. Economic goods and services and ecological services and amenities are produced and both contribute in different ways to satisfying basic human needs and to creating individual and community well-being. There is also waste production by the economic process, which contributes negatively to well-being and has a negative impact on capital and ecosystem services. Preferences are adapting and changing but basic human needs are constant.

As Ekins (1992) points out:

> It must be stressed that that the complexities and feedbacks of model 2 are not simply glosses on model 1's simpler portrayal of reality. They fundamentally alter the perceived nature of that reality and in ignoring them conventional analysis produces serious errors.... (151)

In the remaining sections, we elaborate on the various implications of these distinctions.

3.5.9 Sustainable and Desirable "Doughnut"

A new model of the economy consistent with our new full-world context would be based clearly on the goal of sustainable human well-being. It would use measures of progress that clearly acknowledge this goal (e.g., GPI instead of GDP). It would acknowledge the importance of ecological sustainability, social fairness, and real economic efficiency.

Ecological sustainability implies recognizing that natural and social capitals are not infinitely substitutable by built and human capital and that real biophysical limits and planetary boundaries exist to the expansion of the market economy. Climate change is perhaps the most obvious and compelling of these limits.

Social fairness implies recognizing that the distribution of wealth is an important determinant of social capital and quality of life. The conventional economic model, although explicitly aimed at reducing poverty, has bought into the assumption that the best way to do this is through growth in GDP. This has not proved to be the case, and explicit attention to distribution issues is sorely needed. As Robert Frank argued (Frank 2007), economic growth beyond a certain point sets up a "positional arms race" that changes the consumption context and forces everyone to consume too much of positional goods (such as houses and cars) at the expense of nonmarketed, nonpositional goods and services from natural and social capital. Increasing inequality of income actually reduces overall societal well-being, not just for the poor but across the income spectrum. Wilkinson and Pickett (2009) have produced empirical data that show a strong correlation between income inequality in OECD countries and a whole range of health and social problems. Large income inequality is as detrimental to the well-being of the rich as it is to the poor.

Real economic efficiency implies including all resources that affect sustainable human well-being in the allocation and management system. Our current market-focused allocation system excludes most nonmarketed natural and social capital assets and services that are huge contributors to human well-being. The current economic model ignores this and therefore does not achieve real economic efficiency. A new, sustainable model would measure and include the contributions of natural and social capital in ways that go well beyond the market. This would better approximate real economic efficiency.

The new model would also acknowledge that a complex set of property rights regimes is necessary to adequately manage the full range of resources that contribute to human well-being. For example, most natural and social capital assets are part of the commons. Making them private property does not work well. When a resource is nonrival (meaning that use by one person does not leave less for others to use), then market prices will ration access to those who can afford to pay, even though additional use incurs no additional costs. The clearest example of this is information. In fact, for information that protects the environment or provides other social benefits—for example, an inexpensive, carbon-free energy technology—additional use actually reduces social costs. The value of such resources is paradoxically maximized at a price of zero (or less). Because the private sector will not provide products for free, the public sector must be responsible for their protection and provision. On the other hand, when resources are rival, meaning that use by one person leaves less for others, leaving them as open-access resources (with no property rights) does not work well either. What is needed is a third way to propertize these resources without privatizing them. Several new (and old) common-property-rights systems have been proposed to achieve this goal, including various forms of common-property trusts.

The role of government also needs to be reinvented. In addition to the government's role in regulating and policing the private market economy, it has a significant role to play in expanding the commons sector, which can propertize and manage nonmarketed natural and social capital assets. It can also help develop new common-ownership models at various levels of scale that are not driven by growth principles and can play

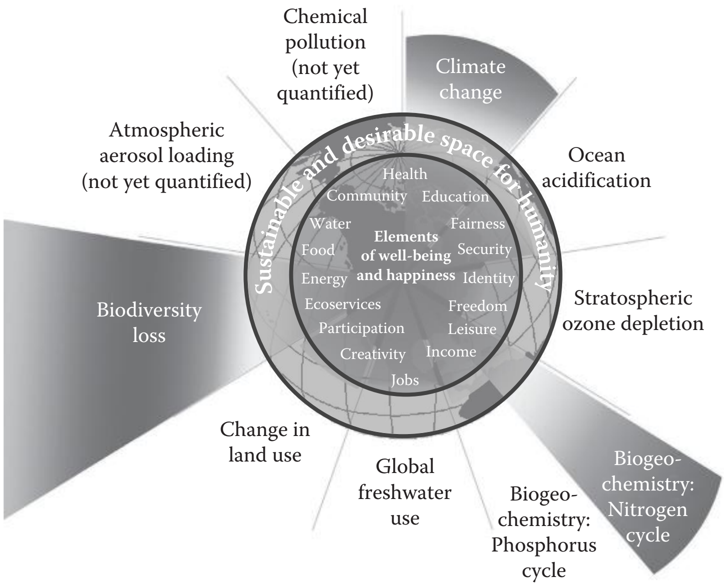

FIGURE 3.7
A sustainable and desirable place for humanity which combines planetary boundaries with fair and prosperous with social-economic system.

a planning and coordinating role to help manage a reduced-growth regime (Alperovitz 2011). Government also has a major role to play in facilitating societal development of a shared vision of what a sustainable and desirable future would look like. As Tom Prugh and colleagues (Prugh et al. 2000) have argued, a strong democracy, based on developing a shared vision, is an essential prerequisite to building a sustainable and desirable future.

One way to look at our goals for the new economy is shown in Figure 3.7. This figure combines planetary boundaries as the "environmental ceiling" with basic human needs as the "social foundation" (Williamson et al. 2010; Raworth 2012). This creates an environmentally sustainable, socially desirable, and just "doughnut" as the space within which humanity can thrive.

3.6 Valuation, Choice, and Uncertainty

> While there may be no "right" way to value a forest or a river, there is a wrong way, which is to give it no value at all.
>
> **Paul Hawken in the forward to Prugh et al. (1995)**

This section looks at the difficult and controversial issues of valuation, choice, and uncertainty. Conventional economic analysis usually assumes that individual human preferences are given and fixed, that the role of economics is to satisfy those preferences in the most efficient way possible, and that uncertainty can be handled in a fairly straightforward way by equating it to risk (uncertain events with known probabilities). As we will show, when one is concerned with sustainability, which is an inherently long-run problem, preferences cannot be considered to be fixed and given. Economics must then have a different and broader role, and we must acknowledge and deal with true uncertainty and indeterminacy, where probabilities are unknown and even the possibilities are often unknown.

3.6.1 Fixed Tastes and Preferences and Consumer Sovereignty

The conventional paradigm assumes tastes and preferences are fixed and given, and that the economic problem consists of optimally satisfying those preferences. Tastes and preferences usually do not change rapidly and, in the short run (i.e., one to four years), this assumption makes sense. But preferences do change over longer time frames and in fact there is an entire industry (advertising) devoted to changing them. Sustainability is an inherently long-run problem and in the long run it does not make sense to assume tastes and preferences are fixed. This is a very disturbing prospect for economists because it takes away the easy definition of what is "optimal." If tastes and preferences are fixed and given, then we can adopt a stance of "consumer sovereignty" and give the people what they want. We do not have to know or care why they want what they want, we just have to satisfy their preferences as efficiently as possible. But if preferences are expected to change over time and under the influence of education, advertising, changing cultural assumptions, and so on, we need a different criterion for what is "optimal." We have to figure out how preferences change, how they relate to this new criterion, and how they can or should be changed to satisfy the new criterion.

BOX 3.3 THE LIMITS OF "CONSUMER SOVEREIGNTY"

ROBERT COSTANZA

Issues of the limits of individual liberty have long been debated by moral philosophers. American democracy was founded on the idea of maximizing individual liberty and rights but within limits. Basically, the goal has been to allow people to do what they want as long as it does not interfere with the freedom or well-being of others.* As we have moved from an "empty world" to a "full world," more and more of the actions of individuals *do* interfere with others. We have also gradually expanded our view of who counts as an "other." Until fairly recently, women, blacks, and other minorities were not included among those having basic rights that could be trampled on by individual actions. More recently, we are beginning to acknowledge the rights of future members of our own species and of other species with whom we share the planet.

The fundamental question remains, however, as to *how* we should assess and control "interference" while allowing the maximum individual liberty, all within the constraints of no harm to others. In a full, interconnected world, almost anything we choose to do has positive and negative impacts on a whole host of other individuals, now and in the future. The simple act of buying a can of beans implies a whole range of negative environmental impacts on many "others" incurred during the production of the can, the growing of the beans, and the shipment of the beans to market. Should we be "free" to damage the well-being of others in this and countless other ways?

The conventional economic paradigm assumes "consumer sovereignty"—the idea that tastes and preferences are exogenous to the economic system and that the economic problem consists of optimally satisfying those "sovereign" preferences. But if preferences are expected to change over time and under the influence of education, advertising, changing cultural assumptions, and so forth, then this assumption is not adequate. Different criteria of optimality are needed. How preferences change, how they relate to the goal of sustainability and other social goals, and how they can or should be actively influenced to satisfy the new criteria need to be determined (Norton et al. 1998).

Over the years, society has developed several institutions to deal with the issue of the limits of consumer sovereignty in an increasingly full world. Laws constrain individuals from violating the rights of others and require punishment and/or compensation for transgressions. The market system is an institution for ensuring that an individual's freedom and property are not violated unless there is fair, mutually agreed on compensation. The problem is that many impacts occur outside the market system and/or

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* We relax this dictum a bit in the case of drug and alcohol abuse where individual liberty comes in conflict with the well-being of the same individual.

are not adequately covered by laws. These "externalities" (such as the environmental impacts of bean production and consumption) are pervasive in our now full world and leaving these costs out of the market and legal systems threatens everyone's liberty and freedom. It is no different than allowing customers to come into a food store and simply take what they want from the shelves without paying. We would certainly think that the excuse "making me pay would infringe on my personal liberty and freedom" is a ridiculous one in this case, and it is equally ridiculous when offered as justification for polluters not paying the currently extra-market costs of their activities.

REFERENCE

Norton, B., R. Costanza, and R. Bishop. 1998. The evolution of preferences: why "sovereign" preferences may not lead to sustainable policies and what to do about it. *Ecological Economics* 24: 193–211.

One alternative for this new criterion is sustainability itself, or more precisely sustainable scale, fair distribution, and efficient allocation. This criterion implies a two-tiered decision process (Page 1977; Norton 1986; Daly and Cobb 1989) of first coming to a social consensus on a sustainable scale and fair distribution and, second, of using both the market and other institutions, such as education and advertising, to implement these social decisions. This might be called "community sovereignty" as opposed to "consumer sovereignty." It makes most conventional economists very uncomfortable to stray from consumer sovereignty because it eliminates the tidy view of economics as simply optimally satisfying a fixed set of preferences, and it opens a Pandora's box of possibilities for manipulating preferences. If tastes and preferences can change, then who is going to decide how to change them? There is a real danger that a "totalitarian" government might be employed to manipulate preferences to conform to the desires of a select elite rather than to the society as a whole.

Two points need to be kept in mind: (1) preferences are being manipulated every day, and (2) we can just as easily apply open democratic principles (as opposed to hidden or totalitarian principles) to the problem in deciding how to manipulate preferences. So the question becomes: Do we want preferences to be manipulated unconsciously either by a dictatorial government or by big business acting through advertising? Or do we want to formulate them consciously based on social dialogue and consensus with a higher goal in mind? Ethics is the ordering and revising of our existing preferences in the light of a higher goal. Taking preferences as given would mean that the ethical problem has been solved once and for all. Either way, this is an issue that can no longer be avoided, and one that we believe can best be handled using open democratic principles and innovative thinking.

3.6.2 Valuation of Ecosystems and Preferences

The issue of valuation is inseparable from the choices and decisions we have to make about ecological systems. Some argue that valuation of ecosystems and their services is either impossible or unwise. For example, some argue that we cannot place a value on such "intangibles" as human life, environmental aesthetics, or long-term ecological benefits. But, in fact, we do so every day. When we set construction standards for highways, bridges, and similar projects, we value human life—acknowledged or not—because spending more money on construction would save lives. Another often made argument is that we should protect ecosystems for purely moral or aesthetic reasons; hence, we do not need valuations of ecosystems for this purpose. But there are equally compelling moral arguments that may be in direct conflict with the moral argument to protect ecosystems. For example, the moral argument that no one should go hungry. All we have done is to translate the valuation and decision problem into a new set of dimensions and a new language of discourse, one that in some senses makes the valuation and choice problem more difficult and less explicit.

So, although ecosystem valuation is certainly difficult, one choice we do not have is whether or not to do it. Rather, the decisions we make as a society about ecosystems *imply* valuations. We can choose to make these valuations explicit, or not; we can undertake them using the best available ecological science and understanding, or not; we can do them with an explicit acknowledgment of the huge uncertainties involved, or not; but as long as we are forced to make choices we are doing valuation. The valuations are simply the relative weights we give to the various aspects of the decision problem.

We believe that society can make better decisions about ecosystems if the valuation process is as explicit and participatory as possible. This means taking advantage of the best information available and making valuation uncertainties explicit. It also means developing new and better ways to make good decisions in the face of these uncertainties. Ultimately, it means being explicit about our goals as a society, in the short term and in the long term.

This leads back to the role of individual preferences in determining value. If individual preferences change (in response to education, advertising, peer pressure, etc.) then *value* cannot completely *originate* with preferences. We need to distinguish at least two kinds of value within this context:

(1) short-term or *current value* based on current individual preferences and (2) long-term or *sustainable value* based on the preferences needed to assure long-term sustainability (sustainable scale, fair distribution, and efficient allocation). Instead of being merely an expression of current individual preferences, sustainable value (at least in the mid to long term) becomes a system characteristic related to the item's evolutionary contribution to the survival of the linked ecological economic system.

Current value is the expression of individual preferences in the short term and locally, while sustainable value is the expression of community preferences in the long term and globally.

3.6.3 Uncertainty, Science, and Environmental Policy

One of the primary reasons for the problems with current methods of environmental management is the issue of scientific uncertainty—not just its existence but the radically different expectations and modes of operation that science and policy have developed to deal with it. If we are to solve this problem, we must understand and expose these differences about the nature of uncertainty and design better methods to incorporate it into the policy-making and management process.

To understand the scope of the problem, it is necessary to differentiate between *risk* (which is an event with a *known* probability, sometimes referred to as statistical uncertainty) and *true uncertainty* (which is an event with an *unknown* probability, sometimes referred to as indeterminacy). Every time you drive your car you run the *risk* of having an accident because the probability of car accidents is known with very high certainty. We know the risk involved in driving because, unfortunately, there have been many car accidents on which to base the probabilities. These probabilities are known with enough certainty that they are used by insurance companies to set rates that will assure those companies of a certain profit. There is little uncertainty about the risk of car accidents. If you live near the disposal site of some newly synthesized toxic chemical you may be in danger as well, but no one knows to what extent. No one knows even the *probability* of your getting cancer or some other disease from this exposure, so there is true uncertainty. Most important environmental problems suffer from true uncertainty, not merely risk.

One can think of a continuum of uncertainty, ranging from zero for certain information, to intermediate levels for information with statistical uncertainty, and to known probabilities (risk) to high levels for information with true uncertainty or indeterminacy. Risk assessment has become the central guiding principle at the U.S. Environmental Protection Agency (EPA) (SAB 1990) and other environmental management agencies, but true uncertainty has yet to be adequately incorporated into environmental protection strategy.

Science treats uncertainty as a given, a characteristic of all information that must be honestly acknowledged and communicated. Over the years, scientists have developed increasingly sophisticated methods to measure and communicate uncertainty arising from various causes. It is important to note that the progress of science has, in general, uncovered *more* uncertainty rather that leading to the absolute precision that the lay public often mistakenly associates with "scientific" results. The scientific method can only set boundaries on the limits of our knowledge. It can define the edges of the envelope of what is known, but often this envelope is very large and the shape of its interior can be a complete mystery. Science can tell us the range of uncertainty about global warming and toxic chemicals, and maybe *something* about the relative probabilities of different outcomes, but in most important cases it cannot tell us which of the possible outcomes will occur with any degree of accuracy or certainty.

BOX 3.4 PERVERSE SUBSIDIES

NORMAN MYERS

Many subsidies are "perverse" in that they are harmful to the economy and the environment. In Germany, for instance, subsidies for coal mining are so large that it would be economically efficient for the government to close down all the mines and send the workers home on full pay for the rest of their lives. The environment would benefit too—less coal pollution such as acid rain and global warming.

Subsidies for agriculture foster overloading of croplands, leading to erosion of topsoil, pollution from synthetic fertilizers and pesticides, and to release of greenhouse gases. Subsidies for fossil fuels aggravate pollution such as acid rain, urban smog, and global warming. Subsidies for road transportation promote some of the worst and most widespread forms of pollution. Subsidies for water encourage misuse and overuse of supplies that are increasingly scarce in many lands. Subsidies for ocean fisheries foster overharvesting of fish stocks. Forestry subsidies encourage overlogging and other forms of deforestation. Not only do these environmental ills entrain economic costs but the subsidies serve as direct drags on economies overall.

Of course, certain subsidies are worthwhile. They overcome deficiencies of the marketplace, and they support disadvantaged segments of society. Despite their distortionary effects in many instances, we sometimes need a bit of positive distortion if we are to get as much as we want of, for example, nonpolluting and renewable sources of energy (all the more when fossil fuels with their many problems are often subsidized several times more than alternative sources of energy). The same applies to support for materials recycling and agricultural set-asides.

Perverse subsidies in just the six sectors listed total at least $2 trillion per year. Plainly, perverse subsidies can exert a highly distortive impact on the global economy and can promote grand scale injury to environments and natural resources. Consider, for instance, road transportation.

In the United States, gasoline is cheaper than bottled water, thanks to myriad subsidies. In real terms, it is cheaper than at any time since Americans started to dig it out of the ground. What economists call the "full social cost" of gasoline—covering costs of whatever sort, including traffic congestion, road accidents, and environmental pollution—amounts to at least $7 per gallon. Gasoline subsidies create an energy policy by default, a policy that is the opposite of the government's priorities. They prolong the country's dependence on foreign supplies of oil, especially from the Persian Gulf. They discourage investments in cleaner technologies such as ultra-lean car engines. At the same time, traffic congestion in many major U.S. cities reduces one-third of vehicle travel to speeds averaging half of the free-flow rate; the annual cost of delays amounts to at least $100 billion per year. Then there are sizeable environmental costs. Some 100 million Americans live in cities where vehicle emissions push pollution levels above federal standards.

If Americans do not want to pay extra taxes for their gasoline, they might at least stop being effectively paid by their government and fellow citizens to burn the stuff. The covert costs of road transportation are well above $450 billion per year, which is equivalent to $1,500 per American.

The political climate today for reform of perverse subsidies is probably better than it has been for decades. Many governments are espousing the marketplace gospel with its reduced government intervention; and many governments are so hard up that they have special reasons to reduce subsidies. In fact, several governments have reduced some of their perverse subsidies: New Zealand, with an economy more dependent on agriculture than any other developed country, eliminated virtually all its agricultural subsidies in the mid-1980s when its government budget was finally overburdened to the breaking point. Mexico, South Africa, and Australia are moving toward full-cost pricing of water. But there are formidable obstacles. Special interest groups proliferate with their financial clout. There are dozens of lobbyists for each congressman in Washington; they spent more than $200 million a month on their campaigns in 2005 alone.

The best countermeasure is to highlight the costs of perverse subsidies to taxpayers and consumers. An average American pays taxes of at least $2,000 a year to fund perverse subsidies and pays almost another $2,000 through increased costs for consumer goods and through environmental degradation.

Based on Myers, N. and J. Kent. 2001. *Perverse Subsidies: Tax $s Undercutting Our Economies and Environments Alike*. Island Press, Washington, DC.

Our current approaches to environmental management and policy making, on the other hand, abhor uncertainty and gravitate to the edges of the scientific envelope. The reasons for this are clear. The goal of policy is making unambiguous, defensible decisions, often codified in the form of laws and regulations. Although legislative language is often open to interpretation, regulations are much easier to write and enforce if they are stated in clear, black and white, absolutely certain terms. For most of criminal law, this works reasonably well. Either Mr. Cain killed his brother or he did not; the only question is whether there is enough evidence to demonstrate guilt beyond a reasonable doubt (i.e., with essentially zero uncertainty). Because the burden of proof is on the prosecution, it does little good to conclude that there was an 80% chance that Mr. Cain killed his brother. But many scientific studies come to just these kinds of conclusions because that is the nature of the phenomenon. Science defines the envelope while the policy process gravitates to its edges—generally the edge that best advances the policymaker's political agenda. We need to deal with the whole envelope and all its implications if we are to rationally use science to make policy.

The problem is most severe in the environmental area. Building on the legal traditions of criminal law, policymakers and environmental regulators desire absolute, certain information when designing environmental regulations. But much of environmental policy is based upon scientific studies of the likely health, safety, and ecological consequences of human actions. Information gained from these studies is therefore only certain within their epistemological and methodological limits (Thompson 1986). Particularly with the shift in environmental concerns from visible, known pollution, to more subtle threats, regulators are confronted with decision making outside the limits of scientific certainty with increasing frequency (Weinberg 1985).

Problems arise when regulators ask scientists for answers to unanswerable questions. For example, the law may mandate that the regulatory agency come up with safety standards for all known toxins when little or no information is available on the impacts of these chemicals. When trying to enforce the regulations after they are drafted, the problem of true uncertainty about the impacts remains. It is not possible to determine with any certainty if the local chemical company contributed to the death of some of the people in the vicinity of their toxic waste dump. One cannot *prove* the smoking/lung cancer connection in any direct, causal way (i.e., in the courtroom sense), only as a statistical relationship. Global warming may or may not happen after all.

As they are currently set up, most environmental regulations, particularly in the United States, *demand certainty*, and when scientists are pressured to supply this nonexistent commodity there is not only frustration and poor communication but mixed messages in the media as well. Because of uncertainty, political and economic interest groups can often manipulate environmental issues. Uncertainty about global warming is perhaps the most visible current example of this effect.

The "precautionary principle" is one way the environmental regulatory community has dealt with the problem of true uncertainty. The principle states that rather than await certainty, regulators should act in anticipation of any potential environmental harm in order to prevent it. The precautionary principle is so frequently invoked in international environmental resolutions that it has come to be seen by some as a basic normative principle of international environmental law (Cameron and Abouchar 1991). But the principle offers no guidance as to what precautionary measures should be taken. It "implies the commitment of resources now to safeguard against the potentially adverse future outcomes of some decision" (Perrings 1991, 154), but it does not tell us how many resources or which adverse future outcomes are most important.

This aspect of the "size of the stakes" is a primary determinant of how uncertainty is dealt with in the political arena. The situation can be summarized as shown in Figure 3.8, with uncertainty plotted against decision stakes. It is only the area near the origin with low uncertainty and low stakes that is the domain of "normal applied science." Higher uncertainty or higher stakes result in a much more politicized environment. Moderate values of either correspond to "applied engineering" or "professional consultancy," which allows a good measure of judgment and opinion to deal with risk. On the other hand, current methods are not in place to deal with high values of either stakes or uncertainty, which require a new approach—what might be called "post-normal" or "second-order science" (Funtowicz and Ravetz 1991). This "new" science is really just the application of the essence of the scientific method to new territory. The scientific method does not, in its basic form, imply anything about the precision of the results achieved. It *does* imply a forum of open and free inquiry without preconceived answers or agendas aimed at determining the envelope of our knowledge and the magnitude of our ignorance.

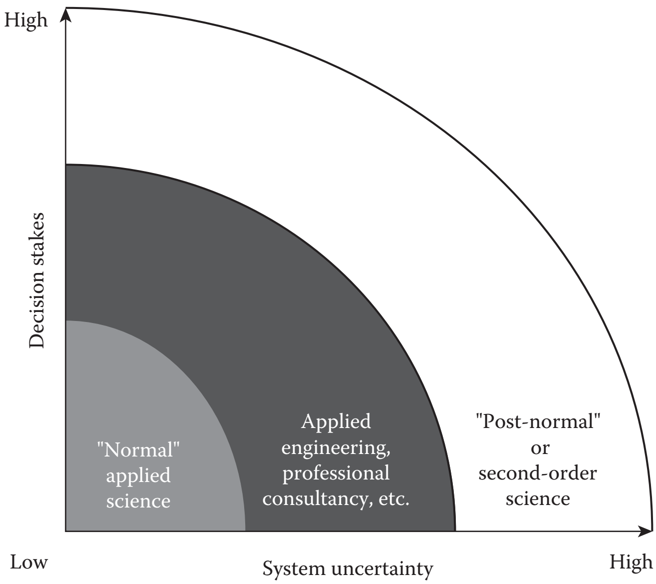

FIGURE 3.8
Three kinds of science. (From Funtowicz, S. O., and J. R. Ravetz, *Ecological economics: The science and management of sustainability*, Columbia University Press, New York, pp. 137–152, 1991.)

Implementing this view of science requires a new approach to environmental protection that acknowledges the existence of true uncertainty rather than denying it and that includes mechanisms to safeguard against its potentially harmful effects while at the same time encouraging development of lower impact technologies and the reduction of uncertainty about impacts. The precautionary principle sets the stage for this approach, but the real challenge is to develop scientific methods to determine the potential costs of uncertainty and to adjust incentives so that the appropriate parties *pay* this cost of uncertainty and have appropriate incentives to reduce its detrimental effects. Without this adjustment, the full costs of environmental damage will continue to be left out of the accounting (Peskin 1991), and the hidden subsidies from society to those who profit from environmental degradation will continue to provide strong incentives to degrade the environment beyond sustainable levels.

3.6.4 Technological Optimism versus Prudent Skepticism

Current economic policies are all based on the underlying assumption of continuing and unlimited material economic growth. This assumption allows problems of intergenerational, intragenerational, and interspecies equity and sustainability to be ignored (or at least postponed) because they are seen to be most easily solved by additional growth. Indeed, most conventional economists define "health" in an economy as a stable and high rate of growth. Energy, resource, and pollution limits to growth, according to these paradigms, will be eliminated as they arise by clever development and deployment of new technology. This line of thinking is often called "technological optimism."

An opposing line of thought (often called "technological skepticism") assumes that technology will *not* be able to circumvent fundamental energy and resource constraints and that eventually material economic growth will stop. It has usually been ecologists or other life scientists that take this point of view (notable exceptions among economists that were technological skeptics are J. S. Mill, Georgescu-Roegen, Boulding, and Daly), largely because they study natural systems that *invariably do* stop growing when they reach fundamental resource constraints. A healthy ecosystem is one that maintains a stable level. Unlimited growth eventually becomes cancerous, not healthy, under this view.

The technological optimists argue that human systems are fundamentally different from other natural systems because of human intelligence. History has shown that resource constraints can be circumvented by new ideas. Technological optimists claim that Malthus's dire predictions about population pressures have not come to pass and the "energy crisis" of the late 1970s is behind us.

The technological skeptics argue that many natural systems also have "intelligence" in that they can evolve new behaviors and organisms (including humans themselves). Humans are therefore a part of nature, not apart from it. Just because we have circumvented local and artificial resource constraints in the past does not mean we can circumvent the fundamental ones that we will eventually face. Malthus's predictions have not come to pass *yet* for the entire world, the pessimists would argue, but many parts of the world are in a Malthusian trap now, many have fallen historically, and other parts may well fall into it. Also those countries not in the Malthusian trap have avoided it precisely by heeding Malthus's advice to limit fertility.

This debate has gone on for many decades now. It was initially given an impulse by Barnett and Morse's (1963) *Scarcity and Growth,* the publication of *The Limits to Growth* by Meadows et al. (1972), and the Arab oil embargo in 1973. There have been thousands of studies over the last few decades on various aspects of our energy and resource future, and different points of view have waxed and waned. But the bottom line is that there is still an enormous amount of uncertainty about the impacts of energy and resource constraints. We are starting to hit *real* oil supply limits and CO_2 emission limits. Will fusion energy or solar energy or conservation or some as yet unthought-of energy source step in to save the day and keep economies growing? The technological optimists say yes;

the technological skeptics say no. Ultimately, no one knows. Both sides argue as if they were certain, but the most insidious form of ignorance is misplaced certainty.

Whatever turns out to be the case, a more ecological approach to economics and a more economic approach to ecology will be beneficial in order to maintain our life-support systems and the aesthetic qualities of the environment. But there are vast differences in the specific economic and environmental policies we should pursue today, depending on whether the technological optimists or pessimists are right.

We can cast this optimist/skeptic choice in a classic (and admittedly oversimplified) game theoretic format using the "payoff matrix" shown in Figure 3.9. Here the alternative policies that we can pursue today (technologically optimistic or skeptical) are listed on the left and the real states of the world are listed on the top. The intersections are labeled with the results of the combinations of policies and states of the world. For example, if we pursue the optimistic policy and the world really does turn out to conform to the optimistic assumptions, then the payoffs would be high. This high potential payoff is very tempting, and this strategy has paid off in the past. It is not surprising that so many would like to believe that the world conforms to the optimist's assumptions. If, however, we pursue the optimistic policy and the world turns out to conform more closely to the skeptical technological assumptions, then the result would be "disaster." The disaster would come because irreversible damage to ecosystems would have occurred and technological fixes would no longer be possible.

If we pursue the skeptical policy and the optimists are right, then the results are only "moderate." But if the pessimists are right and we have pursued the pessimistic policy, then the results are within the framework of game theory; this simplified game has a fairly basic "optimal" strategy. Given that we only get to play this game once, and we therefore cannot assign probabilities to the various outcomes, and that society as a whole should be risk averse in this situation, then we should choose the

Current policy	Real state of the world: Optimists right	Real state of the world: Skeptics right
Technological optimist policy	High	Disaster
Technological skeptic policy	Moderate	Sustainable

FIGURE 3.9
Payoff matrix for technological optimism versus skepticism.

policy that is the maximum of the minimum outcomes (i.e., the MaxiMin strategy in game theory jargon). In other words, we analyze each policy in turn, look for the worst thing (minimum) that could happen if we pursue that policy, and pick the policy with the largest (maximum) minimum. In the case stated here, we should pursue the skeptical policy because the worst possible result under that policy (sustainable) is a preferable outcome to the worst outcome under the optimist policy (disaster) (Costanza 2000b).

In other words, given our high level of uncertainty about this issue, and the enormous size of the stakes, it is irrational to bank on technology's ability to remove resource constraints. If we guess wrong then the result is disastrous; there will be irreversible destruction of our resource base and of our civilization itself. We should at least for the time being assume that technology will *not* be able to remove resource constraints. If it does, we can be pleasantly surprised. If it does not, we are still left with a sustainable system. Ecological economics assumes this prudently skeptical stance on technical progress.

3.6.5 Social Traps

No complex system can be managed effectively without clear goals and appropriate mechanisms for achieving them. In managing the Earth, we are faced with a nested hierarchy of goals that span a wide range of time and space scales. In any rational system of management, global ecological and economic health and sustainability should be "higher" goals than local, short-term national economic growth or private interests. Economic growth can only be supported as a policy goal in this context to the extent that it is consistent with long-term global sustainability.

Unfortunately, most of our current institutions and incentive structures deal only with relatively short-term, local goals and incentives (Clark 1973). This would not be a problem if the local and short-term goals and incentives simply added up to (or in other words were consistent with) appropriate behavior in the global long run, as many assume they do. Unfortunately, this goal and incentive consistency is frequently not the case. Individuals (or firms or countries) pursuing their own private self-interests in the absence of mechanisms to account for community and global interests frequently run afoul of these larger goals and can often drive themselves to their own demise.

These goal and incentive inconsistencies have been characterized and generalized in many ways, beginning with Hardin's (1968) classic paper on the tragedy of the commons (more accurately the tragedy of open-access resources) and continuing through more recent work on "social traps" (Platt 1973; Cross and Guyer 1980; Teger 1980; Costanza 1987; Costanza and Shrum 1988; Costanza and Perrings 1990;

Kubiszewski et al. 2010). Social traps occur when local or individual incentives that guide behavior are inconsistent with the overall goals of the system. Examples include cigarette and drug addiction, overuse of pesticides, economic boom and bust cycles, privatization of information, and a host of others. For example, overfishing in an open-access fishery is a social trap because by following the short-run economic road signs, fishermen are led to exploit the resource to the point of collapse.

Social traps are also amenable to experimental research to observe how individuals behave in trap-like situations and how to best avoid and escape from social traps (Edney and Harper 1978; Teger 1980; Brockner and Rubin 1985; Costanza and Shrum 1988; Rothstein 2005). The bottom line is that in cases where social traps exist, the system is not inherently sustainable, and special steps must be taken to harmonize goals and incentives over the hierarchy of time and space scales involved. In economic jargon, private costs and benefits must somehow be made to reflect social costs and benefits. Explicit steps must be taken to make the global and long-term goals incumbent on and consistent with the local and short-term goals and incentives.

This is in contrast to natural systems, which are forced to adopt a long-term perspective by the constraints of genetic evolution. This is not to say that individual species are immune to evolutionary traps set by adaptation to local conditions. But the system as a whole selects against these species in the long run. In natural systems, long-run "survival" generally equates to sustainability of the species as part of a larger ecosystem, and natural selection tends to find sustainable systems in the long run. Humans have broken the bonds of genetic evolution by the expanded use of learned behavior that our large brain allows and by extending our physical capabilities with tools. The price we pay for this rapid adaptation is a misleading temporary partial isolation from long-term constraints and a susceptibility to social traps.

Another general result of social trap research is that the relative effectiveness of alternative corrective steps is not easy to predict from simple "rational" models of human behavior prevalent in conventional economic thinking. The experimental facts indicate the need to develop more realistic models of human behavior under uncertainty that acknowledge the complexity of most real-world decisions and our species' limited information processing capabilities (Heiner 1983).

3.6.6 Escaping Social Traps

The elimination of social traps requires intervention—the modification of the reinforcement system. Indeed, it can be argued that the proper role of a democratic government is to eliminate social traps (no more and no less) while maintaining as much individual freedom as possible. Cross and Guyer (1980) list four broad methods by which traps can be avoided or escaped from. These are education (about the long-term, distributed impacts); insurance; superordinate authority (i.e., legal systems, government, religion); and converting the trap to a trade-off.

Education can be used to warn people of long-term impacts. Examples are the warning labels required on cigarette packages and the warnings of environmentalists about future hazardous waste or climate change problems. People can ignore warnings, however, particularly if the path seems otherwise enticing.

The main problem with education as a general method of avoiding and escaping traps is that it requires a significant time commitment on the part of individuals to learn the details of each situation. Our current society is so large and complex that we cannot expect even professionals, much less the general public, to know the details of all the extant traps. In addition, for education to be effective in avoiding traps involving many individuals, *all* the participants must be educated, and this is usually not possible.

Governments can, of course, forbid or regulate certain actions that have been deemed socially inappropriate (e.g., the smuggling of chlorofluorocarbons [CFCs] from developing countries into the United States). The problem with this direct, command-and-control approach is that it must be rigidly monitored and enforced, and the strong short-term incentive for individuals to try to ignore or avoid the regulations remains. A police force and legal system are very expensive to maintain, and increasing their chances of catching violators increases their costs exponentially (the costs of maintaining a larger, better-equipped force as well as the cost of the loss of individual privacy and freedom).

Religion and social customs can be seen as much less expensive ways to avoid certain social traps. If a moral code of action and a belief in an ultimate payment for transgressions can be deeply instilled in a person, the probability of that person falling into the "sins" (traps) covered by the code will be greatly reduced and with very little enforcement cost. On the other hand, using religion and social customs as means to avoid social traps is problematic because the moral code must be relatively static to allow beliefs learned early in life to remain in force later, and it requires a relatively homogeneous community of like-minded individuals to be truly effective. This system works well in culturally homogeneous societies that are changing very slowly. In modern, heterogeneous, rapidly changing societies, religion and social customs cannot handle all the newly evolving situations or the conflict between radically different cultures and belief systems.

Many trap theorists believe that the most effective method for avoiding and escaping social traps is to turn the trap into a trade-off. This method does not run counter to our normal tendency to follow the road signs; it merely corrects the signs' inaccuracies by adding compensatory positive or negative reinforcements. A simple example illustrates how effective this method can be. Playing slot machines is a social trap because the long-term costs and benefits are inconsistent with the short-term costs and benefits. People play the machines because they expect a large short-term jackpot, even though the machines are in fact programmed to pay off, say, $0.80 on the dollar in the long term. People may "win" hundreds of dollars playing the slots (in the short run), but if they play long enough they will certainly lose $0.20 for every dollar played. To change this trap to a trade-off, one could simply reprogram the machines so that every time a dollar was put in $0.80 would come out. This way the short-term reinforcements ($0.80 on the dollar) are made consistent with the long-term reinforcements ($0.80 on the dollar), and only the dedicated aficionados of spinning wheels with fruit painted on them would continue to play. Requiring the true odds to be posted would also be helpful but not as effective.

In the context of social traps, the most effective way to make global and long-term goals consistent with local, private, short-term goals is to somehow modify the local, private, short-term incentives. These incentives are any combination of the reinforcements that are important at the local level, including economic, social, and cultural incentives. We must design the social and economic instruments and institutions to bridge the gulf between the present and future, between the private and social, between the local and global, between the ecological and economic parts of the system.

3.6.7 The Dollar Auction Game

The "dollar auction game" (Shubik 1971) is a simple but enlightening model useful in showing the difference between local and global costs and benefits. This game is a social trap that was designed specifically to simulate the conflict escalation process. The dollar auction is just like a normal auction except that *both* the highest and the second-highest bidder have to pay the auctioneer their bid at the end of the game, but only the highest bidder gets the prize. You can try playing this game with a group or class. Simply offer a dollar bill for bid with the following rules: (1) both the highest bidder and the second-highest bidder pay; and (2) the minimum bid is $.05 over the current high bid (this just keeps the game moving).

This game usually results in some very unexpected behavior. Players in the dollar auction game frequently bid much more than $1 for a $1 prize—an irrational result that is the product of a series of "rational" decisions by the bidders. This happens because the structure of reinforcements in this game is a trap. Initially, it looks very appealing to bid $.05 on a $1 prize, but as the bidding escalates past $.50 it becomes clear that even though the winning bidder might make out, the auctioneer is now standing to make money on the auction (the two bids of more than $.50 minus the $1 prize). But the bidding usually does not stop at $.50, because the second-highest bidder (at say $.45) would lose his bid if he dropped out, and so he usually raises to at least $.55. It continues under this logic up to the $1 level, where it is clear that even the highest bidder will lose money by bidding more than $1 for a $1 prize. Even when the bidding reaches the $1 point, it usually continues because of the structure of the incentives. For example, if player A had bid $1 and player B had the second-highest bid at $.95, player B reasons that if he drops out he loses $.95; although if he raises to $1.05, he only loses $.05 (assuming he wins the $1 prize). So he usually raises, and this pattern of "rational" escalation (beyond the point where the overall outcome is rational) continues quite often to well beyond the $1 point. Individual and group behavior in the dollar auction game has been extensively studied by Teger (1980) who showed that almost all groups, from students to faculty to businessmen to clergy, are susceptible to being trapped in this game, and often bid as much as $5 or more for a $1 prize.

The dollar auction game can be converted to a trade-off by adding a "bidding tax" large enough to make dropping out rational in both the short run and the long run (Costanza and Shrum 1988). For example, if when player B was at $.95 he was told that it would now cost $2 to enter a bid of $1.05 (a $.95 bidding tax), he would reason that if he drops out he loses $.95 but if he raises he loses $1 even if he wins the prize! So the chances are increased that he would drop out and escape the trap. This method has proven to be effective in experiments using the dollar auction game (Costanza and Shrum 1988).

3.7 Trade and Community

During the 1980s, the international development, lending, and monetary agencies adopted the stance that development can best be achieved through opening up economies to international trade. During the 1990s, the North American Free Trade Agreement (NAFTA) and the Uruguay Round of the General Agreement on Tariffs and Trade were approved. These two agreements lowered tariffs and greatly facilitated the movement of financial capital between countries. The Uruguay Round established the World Trade Organization to monitor trade and adjudicate disputes. During this significant transformation in the international economic structure, economists took the position, based on the logic of exchange, that trade produced net benefits for both parties—hence freer trade was always better. Their position was consistent with 200 years of economic prescription. Environmentalists worried about national sovereignty with respect to environmental management, the likelihood that increased trade would lead to increased growth and environmental problems, and the difficulties of resolving environmental problems internationally. Labor unions in the industrialized nations were concerned that capital would move to the less developed nations because wages were lower and because environmental, health, and safety standards were lower. The economics profession had not considered how the expansion of trade relates to environmental management before the debate on international reorganization was well underway. Environmental economists took the position that trade can be good, but that international environmental institutions would be needed to standardize regulations to keep nations from competing for industrial capital through lowering their environmental standards. Based on the idea of free trade (trade liberalization) as the way forward, the Dominican Republic-Central America Free Trade Agreement (DR-CAFTA) was signed in 2004. The goal of the DR-CAFTA is a free trade zone among the countries of Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Dominican Republic, and the United States (Granados and Cornejo 2006).

Trade liberalization reduces trade barriers, such as import quotas, subsidies, and price controls (Stiglitz 2002; Gonzalez 2004). It is then assumed that trade liberalization leads to win-win solutions in which both the exporting and the importing countries increase their economic growth and achieve food security at the least cost (Muradian and Martinez-Alier 2001; Stiglitz 2002). However, numerous examples have shown that trade liberalization does not always lead to win-win situations because it creates dependency on food imports (Ghosh et al. 1996; Barkin 1998; Gonzalez 2004) as well as on fossil fuel, fertilizer, and pesticide inputs to agriculture (Ko et al. 1998; Altieri and Rojas 1999; Gonzalez 2004). Such dependency on import and export earnings can increase vulnerability of developing countries. Trade liberalization can also lead to increases in exports of other primary resources and resource-based products (Kessler and Van Dorp 1998; Paus 2004), contributing to the phenomena of the natural resource curse (Sachs and Warner 2001). For example, Pauly (2005) concludes that trade liberalization has created food deficits in 9 of the top 40 fish producing countries of the world.

From the broader perspective of ecological economics, trading more goods across more national boundaries, and freeing capital to move internationally, raises many more issues than were acknowledged by conventional economists (Daly 1993; Daly and Goodland 1994). The issue of community in particular was never formally addressed. For 200 years, economists have used the logic of exchange to promote individual choice and to disempower communities. Ecological economists, on the other hand, acknowledge the role of communities in forming individual preferences, affecting human well-being, and in facilitating environmental management. Each of these will be discussed in turn. First, we consider whether the logic of exchange supports the general prescription of free trade.

3.7.1 Free Trade?

The logic of exchange, Adam Smith's great discovery, has been used to promote free trade for two centuries. The logic is simply that *when two parties who are free to choose actually choose to enter into an exchange, it is because the exchange makes each party better off*. Based on this impeccable logic, economists have long intoned that governments should not restrict opportunities for people to make themselves better off through trade. Indeed, the political agenda of economics for 200 years to empower individuals and corporations and to restrain governments and other forms of collective action has been bolstered, if not driven, by the logic of exchange. The logic is faultless under the assumption of informed, utility-maximizing parties and no effects beyond the two parties. Economists assume that the burden of proof as to whether any particular case does not meet the assumptions and is detrimental to society should be assumed by those who question free trade.

The political agenda of free trade for individuals and corporations, unfettered by taxes or by other trade controls imposed through collective choice, however, does not logically follow from the logic of exchange. The problem, quite simply, is that the logic of exchange remains true regardless of how you define the parties entering into the exchange. It is true whether the parties are individuals, communities, bioregions, or nations. If it is true for nations, why should nations not be "free to choose" or be free to choose to affect the choices of individuals and corporations through taxes, quotas, or other controls? Economists have assumed that the parties should be individuals, in part because economics has followed the particular tradition in the social sciences that started with Hobbes and Locke assuming that societies are the sum of their individuals. But this is simply a convention in the dominant line of social science thought. Criteria beyond the logic of exchange are needed to determine which parties should be free to choose under different circumstances.

Although economists and the majority of politicians today presume that the logic of exchange provides a sound basis for preferring individual choice over collective choice, the fundamental problem of political economy remains one of deciding when individuals, groups, communities, or the state should be entrusted with decision-making authority. This has been the central dilemma of social organization and politics for millennia; we have only been fooling ourselves for the past two centuries.

Had the atomistic premise of natural philosophy not been so readily translated to "individualism" in the dominant line of Western social thought, we might today presume that communities, bioregions, nations, or even spatially overlapping cultural groups should be free to choose. The difference between individual and community interest, of course, is intimately tied to the systemic character of environmental systems. Nature cannot readily be divided up and assigned to individuals. For this reason, collective management or collective limitations on individual choice are frequently appropriate. But the fact that the logic of exchange is indeterminate with respect to how we define the parties also tells us that commons institutions do not have to be justified on the grounds that individual behavior imposes costs on others. People may simply prefer to work together in common and share the fruits of their efforts in common. We do not need the failure of the logic of exchange to justify common activity because the logic of exchange is equally applicable to groups.

3.7.2 Community and Individual Well-Being

Economics is founded on self-interest. But this self that interests us so much is in reality not an isolated atom but is constituted by its relations in community with others—the very identity of the self is social rather than atomistic. If the very self is constituted by relations of community, then self-interest can no longer be atomistically self-contained or defined independently of the community interest. Some knowledge is individualistically diffuse and ephemeral, and although it is a great virtue of the market that it can tap that knowledge, other knowledge is quite public, universal, and fairly permanent—the laws of thermodynamics, for example, or the knowledge that murder and theft are wrong. To insist that everything is reducible to atomistic selfish individuals acting to maximize their gain on the basis of diffuse, piecemeal knowledge locked in their separate sealed heads is to treat an abstraction as more real than the concrete experience from which it has been abstracted.

Distribution and scale involve relationships with the poor, future generations, and other species that are more social than individual in nature. *Homo economicus*, whether the self-contained atom of methodological individualism or the pure social automaton of collectivist ideology, is in either case a severe abstraction. Our concrete experience is that of "persons in community." We are individual persons, but our very individual identity is defined by the quality of our social relations. Our relations to each other are not just external, they are also internal; that is, the nature of the related entities (ourselves in this case) changes when relations among them change. We are related not only by the external nexus of individual willingness-to-pay for different things but also by relations of kinship, friendship, citizenship, and trusteeship for the poor, future generations and for other species, not to mention our physical dependence on the same ecological life-support system and our common heritage of language and culture. The attempt to abstract from all these relationships an atomistic *Homo economicus* whose identity is constituted only by individualistic willingness-to-pay is a severe distortion of our concrete experience as persons in community, another example of Whitehead's "fallacy of misplaced concreteness" (Whitehead 1925).

In ecological economics, we consider maintenance of the capacity of the Earth to support life as an objective, shared value that is constitutive of our identity as persons in community. We do not derive this fundamental value from subjective preferences of currently living individuals weighted by their incomes.

3.7.3 Community, Environmental Management, and Sustainability

Some things can be conveyed better, at least initially, with a parable—a story selected or designed to illustrate a point. Imagine a society of near-subsistence farmers with rights to land. Parents can improve the quality of the land by planting trees. Trees also provide other goods and services at various stages of their lives. The parents might choose to reduce their consumption in their youth to invest in trees in order to have more consumption in their older age. When one's objective is to redistribute rewards over time for oneself, we think of the activity as an investment. One could also invest in trees for oneself and accumulate them for transfer to one's children. Some of the returns from planting trees are enjoyed by the parents, though others go to their children. The extent to which current consumption is forgone and trees are planted to increase the parents' welfare or to meet the parents' "responsibility" to transfer assets to their children would be difficult to determine. Wealth, of course, does not simply accumulate linearly. Some parents choose to cut more wood for timber or firewood than what grew during the period they enjoyed the land, transferring less to their children than they had themselves received from their own parents. Natural disasters and war set the process back periodically just as a string of good years might make greedy parents look like misers. And the total amount that can be accumulated at any given time is limited by the cultural knowledge, technologies, and the nature of cooperation in the society.

Responsibility is within quotation marks to emphasize that this is a key piece of the story. The Iroquois of what is now the northeastern United States are said to have been conscious of seven generations when they made decisions affecting their future. Such a consciousness and whatever institutions maintained and implemented it are so different from modern consciousness and institutions that the very term "seven generations" symbolizes the unsustainability, environmentally and culturally, of modern life. A central argument of this book is that over centuries of believing that progress will take care of our progeny, modern peoples lost their sense of responsibility for their offspring and the institutions needed to assure appropriate transfers of assets. Let us consider the institutional aspects that complemented and maintained responsibility.

Protecting the well-being of future generations cannot be accomplished by individuals acting out of self-interest alone. It must be a common responsibility because one's great-great-grandchildren have seven sets of other great-great-grandparents in approximately one's own generation besides oneself and one's spouse. One never knows, however, who these other fourteen people are likely to be (Marglin 1963; Daly and Cobb 1989; Weiss 1989). Furthermore, even if one could enter into an agreement with the other great-great-grandparents, there are numerous relatives in between who must carry out the agreement over time. Thus, it is very difficult to assure the well-being of one's offspring beyond one's own immediate children unless the entire community throughout time is playing by a set of rules to achieve the desired outcome (Howarth 1992). Patrilineal, matrilineal, and other rules of inheritance, the awarding of dowries, responsibilities to train youth, and diverse other practices and obligations can be interpreted as intergenerational commons institutions that have facilitated the transfer of assets to the next generation. The social concerns, consciousness, and institutions that promote individual responsibility are coevolved elements that are critical to the conservation of resources and their transfer to the next generation.

An additional element needs to be introduced into the parable. Indeed, economists would be very concerned if human-produced capital were not integral to the episode. Parents might save in order to acquire human-produced capital—for example, more saws, or perhaps a bigger or better type of saw with which they could more easily harvest their trees. The role of saws as capital is different from trees. Our stylized parents know that saws provide a return by reducing natural tree capital but not vice versa. Note that the existence of two types of assets, trees and saws, considerably complicates the problem of collecting and processing information. It is the mix of trees and saws that is important. The next generation would not be very well off if it receives all trees and no saws and would be in dire straits indeed if it receives all saws and no trees. Assets need to be transferred from one generation to the next in the right proportions. Fortunately, in a small, relatively self-sufficient community, the proportion of trees and saws can be readily observed. Furthermore, members of the community can readily monitor the effects of their choices on their cumulative assets and can adjust the mix accordingly.

To extend the parable, imagine that our once nearly isolated and relatively self-sufficient community becomes connected to a larger community by the clearing of trails and the expansion of markets. Although nothing else changes directly, the improvement in travel and introduction of markets open up new opportunities that, by exercising them, affect the community in a myriad of indirect ways. Some people, for example, might specialize by selling their trees and investing in the production of saws while others might invest more heavily in trees. As the community increasingly connects to markets, such decisions would be made in response to price signals from factor, commodity, and financial markets. The community institutions that had maintained a balance between trees and saws and heretofore sustained the community over time would fall into disuse and no longer be maintained.

The dynamics from here could be perverse. There may be an expanding market for saws precisely because, as communities were drawn into the market economy, people were choosing to cut trees and were driving tree prices down, while the increased demand for saws would drive saw prices up, justifying greater investment in saws. If the market economy our community has joined has a way of assessing the overall mix of trees and saws within its area, informing everyone, and perhaps enforcing a proper mix, then disaster could be averted. Given the expanded area over which decisions are now interlinked, ultimately new intergenerational commons institutions will be needed to facilitate the appropriate transfer of assets over time. And yet the formation of commons institutions becomes more difficult the larger the community; now multiple smaller communities are combined into a larger community. One can imagine some efforts initially being made to establish commons institutions on a larger scale, but with the process of market expansion ongoing, such efforts are partially successful at best.

Eventually our community finds itself fully a part of modern society and a still globalizing economy. Though transfers of real assets in terms of land, housing, and factories from one generation to the next still constitute a significant portion of total transfers, parents are increasingly trying to meet their investment and intergenerational transfer objectives through financial claims to assets, through the education of their offspring and the cohorts they might marry, or through legislation at the state and national, and now even global, levels. In a complexly interconnected, globalizing economy with many types of interrelated assets such as we have today, comparable information on the mix of assets, let alone the complementarity of the mix, is much harder to assess.

Let us consider markets. Individual investors in financial markets only see interest rates, not the stocks of trees and saws, let alone the stocks of the myriad of natural and human-produced capital supporting modern economies. But let us address the global issue first, the complexity issue second. Economists will argue that the value of a corporation's assets would decline if it cut all of its trees, but corporations can and do move on to other forests. Economic models assume good information. But who is keeping track of the whole picture? Although most developed countries have fairly sophisticated monitoring institutions, many of those nations do not make their data available to the public. Environmental monitoring in less developed countries was improving rapidly at the end of the twentieth century, but our increasing awareness of the importance of biodiversity, among other things, has increased the demand for monitoring far faster than the supply. But even if all investors individually realize they are investing in saws that are deforesting on net, they may continue to do so if there is not an enforcement institution. They have no alternative but to hope that the returns from an investment dependent on a rapidly depleting resource can be reinvested again in some other sector to the benefit of their children even if they can see that all in the further future are losing on net. This is the nature of a common pool problem unmatched by commons institutions.

The problem, however, is not simply one of monitoring and enforcement but one of interpreting as well. With just trees and saws, contemplating the appropriate mix and deciding when there are too few of one or the other is relatively difficult. One must consider the age and species distribution of the trees as well as of the saws, the multiple uses of the trees, the likely future needs for tree services, and how these factors interact. Real economies, especially modern economies, depend on many more environmental resources, and their services and the interactions greatly compound interpretation. Note that economic theory requires that decision makers be informed, not simply have access to great mounds of raw data. This means that global models of the physical interdependencies of the economy are necessary to produce the information required by economically rational investors as we go from relatively self-sufficient communities, where resource monitoring and assessment can be done informally, to global economies, where sophisticated monitoring and assessment systems are necessary.

With respect to trying to achieve our asset transfer objectives through education or the state, the situation is equally bleak. We have given little thought to which types of education complement trees or saws, or which substitute for them, let alone tried to affect the mix of education with the objective of sustainability in mind. Nor have we begun to analyze how modern institutions such as "pay-as-you-go" social security affect asset accumulation and transfers, let alone design new intergenerational commons institutions to facilitate appropriate individual behavior in a global economy.

The parable, of course, is highly stylized and too simple, but the point remains that people historically were closer to the resources they used and in a better position to monitor the overall set of assets on which they depended. Global agencies currently trying to oversee the whole picture with respect to resources and economic processes are very weak, short on conceptual justification, and an anathema to current market ideology. Ironically, the logic of markets in fact justifies information institutions at a minimum. The parable is about the interplay among community, environmental management, asset transfers, and sustainability, and how they have been lost in the process of globalization.

3.7.4 Globalization, Transaction Costs, and Environmental Externalities

Economists have long argued that trade is good, more of it is even better, and governments should not intervene to constrain market transactions. Based on the logic of exchange, economists have provided strong justification for and generally favored the globalization of the world's economies through the expansion of the institution of the market.

At the same time, economists recognize that market exchanges entail transaction costs: the costs of perceiving a potential gain, contracting with other parties, and enforcing a contract. For individual goods traded in markets, transaction costs are relatively low and sufficiently overcome by the transactors to complete an exchange. To some extent in the markets for all goods, however, there are some benefits and costs associated with the exchange that are external to the transacting parties and that fall on external parties. Where transaction costs are sufficiently low for the external parties, they can become internal parties and influence the exchange. The problem of market failure exists when these transaction costs are prohibitively high and those external parties experiencing benefits or costs from the exchange remain external and do not affect the exchange (Norgaard and Liu 2007). Similarly, for commons institutions, it is the transaction costs of communicating and agreeing between individuals and enforcing agreements that ultimately determine whether common institutions arise and are sustained for the management of environmental resources and for the attainment of other collective goals.

Although it is well recognized that high transaction costs prevent the success of commons institutions and the internalization of externalities, why there are transaction costs and what makes them change are rarely discussed by economists. Economists systematically address the symptom of externalities but do not ask from whence externalities come. Ironically, the arguments for trade and the development of externalities are closely interrelated. Understanding transaction costs or the distances associated with trade identifies these connections.

The term "distance" helps us understand the interrelationships between trade and transactions costs (Giddens 1990). Distance can be physical, social, or both. The subsistence community at the beginning of our parable could easily observe the effects of their interactions with nature, easily interpret the nature of problems, and easily communicate with each other and agree on a collective action. Their number, cultural homogeneity, geographic scope, and the relative character of the technologies they had available to them kept everything "close" and transaction costs low. The geographic expansion of exchange increases physical distance. With greater distance, it is more difficult for people to see the consequences of their actions. Those who see the consequences are in one place, those who can do something about it are in another, and the distance between them makes communicating and agreeing on a collective solution difficult.

Specialization, which goes along with increased trade, increases social distancing by reducing shared experiences and ways of seeing the world. The parable started with a world of generalist farmers and ended with a world of academics distanced by their disciplines, bankers with amazing international camaraderie, communications specialists who care little about the substance of their message, doctors and dentists with specialties of their own, engineers who think physics can and should be used to override ecological and sociological problems, and so on through the alphabet. Specialization not only makes communication difficult, specialization makes it difficult to perceive problems that defy specialties (Norgaard 1992; Norgaard and Jin 2008). And as trade expands, existing national and cultural borders are crossed, further compounding the difficulties.

The likelihood that adequate intergenerational commons institutions evolve is a function of the size of the community. The difficulties of negotiating an agreement among individuals are a function, in part, of the number of connections among individuals. Two people have one connection, three people have three, four people have six, and five people have ten, thus increasing geometrically. To the extent that groups already exist and have appropriate communication hierarchies, then the costs of transacting individually can be lowered. But the appropriateness of a communication hierarchy depends on whether the groups' prior ordering of interests and knowledge to be communicated fits the new problem. In any case, the geographical expansion of trade increases the number of individuals in the area over which commons institutions are now needed, but, with a greater number of people, forming and maintaining commons are more difficult.

As trade expands, it creates new problems and challenges the communication systems of existing groups. Existing commons institutions become obsolete as the geographic scope of effects beyond the market that they managed expands beyond their existing boundaries. Thus, communities that have some autonomy, that are not constantly being challenged by strong external forces but rather are evolving largely through internal dynamics, are more likely to develop and sustain viable institutions to encourage individuals to transfer appropriate levels of assets. Such autonomy has not been a characteristic of the past few centuries of globalization. Thus, there is good reason to be concerned that the rise of trade and geographic expansion of economic activity has broken down the institutions of many separate communities that facilitated asset transfer. This globalization has also worsened the conditions for new institutions to arise because the expanding number of people who must come to terms geometrically increases the cost of coming to a new agreement.

In summary, the increased material consumption of current generations attributed to the gains from trade may well have been facilitated by the breakdown of commons, which facilitated the transfer of assets to future generations and the absence of their replacement on a larger scale. Although economists' promotion of exchange and specialization advances the markets for particular goods, it increases transaction costs and promotes the conditions for externalization of other goods through the failure of existing commons institutions and through a net increase in the externalization of environmental and other goods. Economics, by not using its own understanding of transaction costs more fully and acknowledging the problem of distancing, has unwittingly promoted two inextricably linked phenomena, both of which lead to more consumption in the present, but one of which results in less consumption in the future. There no doubt are gains from specialization and expansion of the market for the particular goods traded. At the same time, specialization and geographic expansion increase the transaction costs for effects associated with exchange but that are prevented from being included in determining the exchange by the very same increased transaction costs.

The negotiations to "free" trade in North America were prolonged by the difficulties of making new international agreements to cover the expanded context of environmental and social problems. To the extent that externality-resolving institutions have not expanded in scope and adjusted as fast as have trading patterns, the gains from trade are less than expected, perhaps even negative, because the economy is working less efficiently than presumed. Equally important, however, is the absence of discussions concerning intergenerational equity and institutions to facilitate transfers of assets to future generations. The term "environmental externality" is now very much a part of the vocabulary of international discourse, though the international institutions designed to deal with externalities are far too weak (Costanza et al. 1995). The concepts of intergenerational commons and the transfer of assets to future generations are not even a part of trade negotiations.

3.7.5 Policy Implications

A country's external policies should complement its internal policies; that is, policies adopted with respect to foreigners should not contradict or undercut policies adopted with respect to the country's own citizens.

Such contradictions would disrupt national community. We view international community as a federation—as a community of communities—not as one world cosmopolitan aggregation of individuals resulting from a "world without borders." National policies for national community are primary. The difficulty is that international free trade conflicts sharply with the basic national policies of: (a) getting prices right, (b) moving toward a more just distribution, (c) fostering community, (d) controlling the macroeconomy, and (e) keeping scale within ecological limits. Each conflict is discussed in turn.

a. *Getting prices right*: If one nation internalizes environmental and social costs to a high degree, following the dictates of adjustment, and then enters into free trade with a country that does not force its producers to internalize those costs, then the result will be that the firms in the second country will have lower prices and will drive the competing firms in the first country out of business. If the trading entities were nations rather than individual firms trading across national boundaries, then the cost-internalizing nation could limit its volume and composition of trade to an amount that did not ruin its domestic producers and thereby actually take advantage of the opportunity to acquire goods at prices that were below full costs. The country that sells at less than full-cost prices only hurts itself as long as other countries restrict their trade with that country to a volume that does not ruin their own producers. That, of course, would not be free trade. There is clearly a conflict between free trade and a national policy of internalization of external costs. External costs are now so important that the latter goal should take precedence. In this case, there is a clear argument for tariffs to protect, not an inefficient industry, but an efficient national policy of internalizing external costs into prices.

   Of course, if all trading nations agreed to common rules for defining, evaluating, and internalizing external costs, then this objection would disappear and the standard arguments for free trade could again be made in the new context. But how likely is such agreement? Even the small expert technical fraternity of national income accountants cannot agree on how to measure environmental costs in the system of national accounts, let alone on rules for internalizing these costs into prices at the firm level. Politicians are not likely to do better. Some economists will argue against uniform cost internalization on the grounds that different countries have different tastes for environmental services and amenities, and that these differences should be reflected in prices as legitimate reasons for profitable trade. Certainly agreement on uniform principles, and proper extent of departure from uniformity in their application, will not be easy. Nevertheless, suppose that this difficulty is overcome so that all countries internalize external costs, using the same rules applied in each case to the appropriate degree in the light of differing tastes and levels of income.

b. *Just distribution*: Wage levels vary enormously among countries and are largely determined by the supply of labor, which in turn depends on population size and growth rates. Overpopulated countries are naturally low-wage countries, and if population growth is rapid, they will remain low-wage countries. This is especially so because the demographic rate of increase of the lower class (labor) is frequently twice or more that of the upper class (capital). For most traded goods, labor is still the largest item of cost and consequently the major determinant of price. Cheap labor means low prices and a competitive advantage in trade. (The theoretical possibility that low wages reflect a taste for poverty and therefore a legitimate reason for cost differences is not taken seriously here.) But adjustment economists do not worry about that because economists have proved that free trade between high-wage and low-wage countries can be mutually advantageous thanks to comparative advantage—the ability to produce a good or service at a lower opportunity cost compared to others—to ensure the success of free trade (Muradian and Martinez-Alier 2001).

The doctrine of comparative advantage is quite correct given the assumptions on which it rests, but unfortunately one of those assumptions is that capital is immobile internationally. The theory is supposed to work as follows: when in international competition the relatively inefficient activities lose out and jobs are eliminated, at the same time the relatively efficient activities (those with the comparative advantage) expand, absorbing both the labor and capital that were disemployed in activities with a comparative disadvantage. Capital and labor are reallocated within the country, specializing according to that country's comparative advantage. However, when both capital and goods are mobile internationally, then capital will follow absolute advantage to the low-wage country rather than reallocate itself according to comparative advantage within its home country. It will follow the highest absolute profit, which is usually determined by the lowest absolute wage.

Of course, further inducements to absolute profits such as low social insurance charges or a low degree of internalization of environmental, social, health, and safety costs also attract capital, usually toward the very same low-wage countries. But we have assumed that all countries have internalized costs to the same degree in order to focus on the wage issue. Once capital is mobile, then the entire doctrine of comparative advantage and all its comforting demonstrations become irrelevant. The consequence of capital mobility would be similar to that of international labor mobility—a strong tendency to equalize wages throughout the world.

Given the existing overpopulation and high demographic growth of the Third World, it is clear that the equalization will be downward, as it has indeed been during the last decades in the United States. Of course, returns to capital will also be equalized by free trade and capital mobility, but the level at which equalization will occur will be higher than at present. U.S. capital will benefit from cheap labor abroad followed by cheap labor at home, at least until checked by a crisis of insufficient demand due to a lack of worker purchasing power resulting from low wages. But that can be forestalled by efficient reallocation to serve the new pattern of effective demand resulting from the greater concentration of income. More luxury goods will be produced and fewer basic wage goods. Efficiency is attained, but distributive equity is sacrificed.

The standard neoclassical adjustment view argues that wages will eventually be equalized worldwide at high levels, thanks to the enormous increase in production made possible by free trade. This increase in production presumably will trigger the automatic demographic transition to lower birth rates—a doctrine that might be considered a part of the adjustment package in so far as any attention at all is paid to population. Such a thought can only be entertained by those who ignore the issue of scale, as neoclassicists traditionally do. For all 7 billion people presently alive to consume resources and absorptive capacities at the same per capita rate as Americans or Europeans is ecologically impossible. It is much less possible to extend that level of consumption to future generations. Development as it currently is understood on the U.S. model is only possible for a minority of the world's population over a few generations—that is, it is neither just nor sustainable. The goal of sustainable development is, by changes in allocation, distribution, and scale, to move the world toward a state in which "development," whatever it concretely comes to mean, will be for all people in all generations. This is certainly not achievable by more finely tuned "adjustment" to the standard growth model, which is largely responsible for having created the present impasse in the first place.

Of course, if somehow all countries decided to control their populations and to adopt distributive and scale limiting measures such that wages could be equalized worldwide at an acceptably high level, then this problem would disappear and the standard arguments for free trade could again be evoked in the new context. Although the likelihood of that context seems infinitesimal, we might for purposes of a fortiori argument consider a major problem with free trade that would still remain.

c. *Fostering community*: Even with uniformly high wages made possible by universal population control and redistribution, and with uniform internalization of external costs, free trade and free capital mobility still increase the separation of ownership and control and the forced mobility of labor that are so inimical to community. Community economic life can be disrupted not only by fellow citizens who, though living in another part of your country, might at least share some tenuous bonds of community with you, but by someone on the other side of the world with whom you have no community of language, history, culture, law, and so on. These foreigners may be wonderful people; that is not the point. The point is that they are very far removed from the life of the community that is affected significantly by their decisions. Your life and your community can be disrupted by decisions and events over which you have no control, no vote, no voice.

Specialization and integration of a local community into the world economy do offer a quick fix to problems of local unemployment, and one must admit that carrying community self-sufficiency to extremes can certainly be impoverishing. But short supply lines and relatively local control over the livelihood of the community remain obvious prudential measures that require some restraint on free trade if they are to be effective. Libertarian economists look at *Homo economicus* as a self-contained individual who is infinitely mobile and equally at home anywhere. But real people live in communities and in communities of communities. Their very individual identity is constituted by their relations in community. To regard community as a disposable aggregate of individuals in temporary proximity only for as long as it serves the interests of mobile capital is bad enough when capital stays within the nation. But when capital moves internationally, it becomes much worse.

When the capitalist class in the United States in effect tells the laboring class, "sorry, you have to compete with the poor of the world for jobs and wages. The fact that we are fellow citizens of the same country creates no obligations on my part," then admittedly not much community remains, and it is not hard to understand why a U.S. worker would be indifferent to the nationality of his or her employer. Indeed, if local community is more respected by the foreign company than by the displaced American counterpart, then the interests of community could conceivably be furthered by foreign ownership in some specific cases. But this could not be counted as the rule, and serves only to show that the extent of pathological disregard for community in the United States has not yet been equaled by others. In any event, the further undercutting of local and national communities (that are real) in the name of a cosmopolitan world "community" that does not exist is a poor trade, even if we call it free trade. The true road to international community is that of a federation of communities and communities of communities—not the destruction of local and national communities in the service of a single cosmopolitan world of footloose money managers who constitute, not a community, but merely an interdependent, mutually vulnerable, unstable coalition of short-term interests.

d. *Controlling the macroeconomy*: Free trade and free capital mobility have interfered with macroeconomic stability by permitting huge international payments imbalances and capital transfers resulting in debts that are not repayable in many cases and excessive in others. Efforts to service these debts can lead to unsustainable rates of exploitation of exportable resources and to an eagerness to make new loans to get the foreign exchange with which to pay old loans, with a consequent disincentive to take a hard look at the real productivity of the project for which the new loan is being made. Efforts to pay back loans and still meet domestic obligations lead to government budget deficits and to monetary creation with resulting inflation. Inflation, plus the need to export to pay off loans, leads to currency devaluations, giving rise to foreign exchange speculation, capital flight, and hot money movements, disrupting the macroeconomic stability that adjustment was supposed to foster.

To summarize so far: free trade sins against allocative efficiency by making it hard for nations to internalize external costs; it sins against distributive justice by widening the disparity between labor and capital in high-wage countries; it sins against community by demanding more mobility and by further separating ownership and control; and it sins against macroeconomic stability. Finally, it also sins against the criterion of sustainable scale in a more subtle manner that will now be considered.

e. *Keeping scale manageable*: It has already been mentioned in passing that part of the free trade dogma of adjustment thinking is based on the assumption that the whole world and all future generations

> can consume resources at the levels current in today's high-wage countries without inducing ecological collapse. So, in this way, free trade sins against the criterion of sustainable scale. But, in its physical dimensions, the economy really is an open subsystem of a materially closed, nongrowing, and finite ecosystem with a limited throughput of solar energy. The proper scale of the economic subsystem relative to the finite total system really is a very important question. Free trade has obscured the scale limit in the following way.

Sustainable development means living within environmental constraints of absorptive and regenerative capacities. These constraints are global (e.g., climate change, ozone shield damage) and local (e.g., soil erosion, deforestation). Trade among nations or regions offers a way of loosening local constraints by importing environmental services (including waste absorption) from elsewhere. Within limits this can be quite reasonable and justifiable, but carried to extremes in the name of free trade it becomes destructive. It leads to a situation in which each country is trying to live beyond its own absorptive and regenerative capacities by importing these capacities from elsewhere. Of course environmental capacity-importing countries pay for the capacities they import, and all is well as long as other countries have made the complementary decision—namely, to keep their own scale well below their own national carrying capacity in order to be able to export some of their environmental services. In other words, the apparent escape from scale constraints enjoyed by some countries via trade depends on other countries' willingness and ability to adopt the very discipline of limiting scale that the importing country is seeking to avoid. What nations have actually made this complementary choice? All countries now aim to grow in scale, and it is merely the fact that some have not yet reached their limits that allows other nations to import carrying capacity. Free trade does not remove carrying capacity constraints; it just guarantees that nations will hit that constraint more or less simultaneously rather than sequentially. It converts differing local constraints into an aggregated global constraint. It converts a set of problems, some of which are manageable, into one big unmanageable problem. Evidence that this is not understood is provided by the countless occasions when someone who really should know better points to the Netherlands or Hong Kong as examples to be emulated and as evidence that all countries could become as densely populated as these two. How it would be possible for all countries to be net exporters of goods and net importers of carrying capacity is not explained.

Of course, the drive to grow beyond carrying capacity has other roots that are deeper than the free trade dogma. The point is that free trade makes it very hard to deal with these root causes at a national level, which is the only level at which effective social controls over the economy exist. Standard economists will argue that free trade is just a natural extension of price adjustment across international boundaries, and that "right prices" must reflect *global* scarcities and preferences. But if the unit of community is the nation, the unit in which there are institutions and traditions of collective action, responsibility, and mutual help, the unit in which government tries to carry out policy for the good of its citizens, then "right prices" should not reflect the preferences and scarcities of other nations. Right prices *should* differ among national communities. Such differences traditionally have provided the whole reason for international trade in goods—trade that can continue if balanced, that is, if not accompanied by the free mobility of capital (and labor) that homogenizes preferences and scarcities globally, while reducing national economic policy to ineffectiveness unless agreed upon by all freely trading nations.

It is admitted by neoclassical economists that externalities resulting from overpopulation can spill over to other nations and thus can provide a legitimate reason against free immigration, however uncongenial to liberal sentiments* (Baumol 1971). But externalities of overpopulation in the form of cheap labor can spill over into other countries through free migration of capital toward abundant labor, just as much as through free migration of labor toward abundant capital. The legitimate case for restrictions on labor immigration is therefore easily extended to restrictions on capital emigration for any country not wanting to suffer the consequences of another country's overpopulation (Culbertson 1971).

The nation-state certainly has many historical sins to atone for, but it is where community exists in the sense that it is the main unit in which policies are made for the common good. To say that national boundaries are just lines on the map, and that we should all be environmental Earth citizens is nice rhetoric but not very realistic. Given the urgency of action, and the reality of transnational corporate power eager to take over, we have no alternative but to work within the existing institution of the nation-state. Certainly population and per capita consumption will not be controlled at a global level. It will be done by nations. But the nations will have to cooperate and make binding international agreements.

For example, although all countries must worry about population and per capita consumption, it is evident that the South needs to focus more

* Economists tend to dismiss such wage effects as merely "pecuniary externalities" that deserve less attention than "technological externalities." The latter refers to costs or benefits shifted to third parties in a manner external to the price system; the former refers to third-party effects that operate through the price system. Because lowering the price of labor by free migration is a cost to the preexisting labor force and a benefit to employers and foreign laborers that is mediated by the wage rate, it is classed as a pecuniary externality and not given much consideration in economic theory (i.e., it is "merely a matter of distribution").

on population and the North more on per capita consumption. This fact will likely play a major role in all North/South treaties and discussions. Why should the South control its population if the resources saved thereby are merely gobbled up by Northern overconsumption? Why should the North control its overconsumption if the saved resources will merely allow a larger number of poor people to subsist at the same level of misery? Global problems are indeed global, but their solutions require national policies supported by international treaties. Nations have to be able to enact and enforce national policies agreed to in international treaties. If a nation's borders are porous to the flow of goods and services, capital, and labor then that country is in a poor position to carry out any national policy, including those it agreed to in international treaties.

4

Institutions, Instruments, and Policies

> While purity is an uncomplicated virtue for olive oil, sea air, and heroines of folk tales, it is not so for systems of collective choice.
>
> **Amartya Sen (1979, 200)**

In this chapter, we discuss some general and specific policy ideas that follow from the previously discussed principles, and we introduce instruments that may be useful in implementing these policies. We advocate a broad, democratic process to discuss and achieve consensus on these important issues. This is distinct from the polemic and divisive political process that seems to hold sway in many countries today. What is needed is deep discussion and consensus about long-term goals not constant quibbling over short-term details.

Democracy is not merely the process of voting. The two are far from the same thing. Voting, without broad-based discussion, information exchange, and, most importantly, agreement on shared goals and visions for the future, is merely the façade of democracy. We have a long way to go to actually achieve the kind of participatory, "living democracy" that Frances Moore Lappé and Paul DuBois and many others advocate (Button 1996; Dryzek 2000). It is within this context of living, participatory democracy that the policies and instruments we describe here need to be evaluated. They are not answers; they are inputs to the process of living democracy, which must involve all of society in a meaningful way. The starting point and the most critical task facing humanity today is the creation of a shared vision of a sustainable and desirable society, one that can provide permanent prosperity within the biophysical constraints of the real world in a way that is fair and equitable to all of humanity, to other species, and to future generations. Recent work with businesses and communities indicates that creating a shared vision is the most effective engine for change in the desired direction (Costanza 2000b). There are several visioning exercises that have created similar descriptions, including the Great Transition Initiative (http://www.gtinitiative.org) and the Future We Want (futurewewant.org). Ultimately and most importantly, this vision must be shared and further developed through participatory democratic processes (Box 4.1).

If humanity is to achieve a sustainable and desirable future, we must create a shared vision detailing what we as a society want to sustain and

BOX 4.1 THE NEED FOR A SHARED VISION OF A SUSTAINABLE AND DESIRABLE FUTURE

JOSH FARLEY AND ROBERT COSTANZA

Economics has frequently been defined as the science of allocation of scarce resources among alternative desirable ends. This implies a specific sequence that should be pursued in economic analysis. First and foremost, the economist must decide what ends are to be pursued. Many economists argue that decisions on ends should be left to political processes, suggesting that an essential precursor to economic analysis is in fact a democratic process that successfully articulates the desired ends. Only after determining the desired ends can the economist analyze what resources are necessary to achieve them and which of these resources are the scarcest. The final step is allocation via whatever institution or mechanism is most appropriate for the resources and ends in question. By concentrating almost solely on allocation via the market mechanism, conventional economics seems to invert this process. Presumably the neoclassical emphasis on allocation arises from an implicit, shared assumption that the desired end is ever-greater "utility," and utility is conferred solely by material consumption of excludable and rival market goods. The market therefore serves to reveal the desired ends through purchase decisions and to allocate the scarce resources necessary to achieve those ends. The underlying tautology is evident; by definition, markets can reveal preferences only for market goods. Ecological economics improves on this approach. Most ecological economists consider the scarcest resource to be low entropy matter–energy in general, emphasizing the goods and services provided by intact ecosystems. Many of these goods and services are not effectively allocated by unconstrained market forces; hence, markets often will neither reveal nor attain the desired ends. Ecological economists also recognize that ever-greater material consumption is undesirable and impossible on a finite planet. Further, pursuit of this unattainable goal deprives us of resources that could be used to attain other desirable ends. However, only a minority of ecological economists have focused directly on what the desirable ends are, and the complexity of the issue means that the relevant research is often somewhat abstract and academic. Yet the importance of determining a desirable end as the first step in economic analysis is becoming increasingly clear as we begin to experience the negative impacts of excessive economic growth. In the face of rapid human-induced environmental change and profound ecological and economic uncertainty, many people are worried about the well-being of their children and their children's children. In response to this concern, governments, institutions, and civil society have formed a broad, overlapping consensus around the goal of sustainable development. What is lacking is a clear unified vision of what sustainable development entails. In short, without a coherent, relatively detailed, shared vision of what a sustainable society would look like, economists (and other policy-oriented scientists) lack the clearly defined ends required to guide their efforts. Too often under these circumstances, economists fall back on the inherently unsustainable default vision of ever more rapid increases in material consumption. Democratic articulation of sustainable and desirable ends requires a shared vision detailing what we as a society want to sustain and incorporating the central shared values that express our hopes for the future. This vision must include a diversity of perspectives and be based on principles of fairness and respect (Farley and Costanza 2002).

Several groups are actively working toward creating this new, shared vision of a sustainable and desirable future for humanity. This work must continue and be given the central position it deserves.

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including the central shared values that express our hopes for the future. This vision must incorporate a diversity of perspectives and be based on principles of fairness, respect, and sustainability.

Here, we elaborate on the envisioning process and scenario planning. But a little bit of history first.

4.1 History of Environmental Institutions and Instruments

As we have noted, severe anthropogenic damage to many regions of the Earth began as soon as humans learned to apply entropy-increasing technology processes to agriculture and was sharply escalated by factory production in Europe during the Industrial Revolution. Massive loss of life from the spread of waterborne disease continued to be accepted as part of the human condition until advances in scientific knowledge concerning the role of microorganisms prompted public health research to develop sewage treatment systems. Vast urban expenditures on such systems eventually reduced the enormous loss of human capital from the uncontrolled discharge of sanitary waste into waterways. The application of appropriate science, appropriate technology, and community will was necessary to reduce the costly loss of human capital that had resulted from unprecedented population expansion, concentration of humans into unplanned urban areas, and uncontrolled appropriation of open-access resources.

In the United States, pollution of harbor waters, fear of human disease, and financial loss from contamination of oyster fisheries in the Chesapeake Bay finally forced the city of Baltimore to become the first major city in the nation to construct (during the period from 1909 to 1912) a municipal sewage treatment plant; Washington, DC, did not follow suit until the late 1930s (Capper et al. 1983). The Bethlehem Steel Company persuaded the state of Maryland to permit the company to run Baltimore City's sewage effluent through the company's plant as a coolant. This was arranged on terms very favorable for the company but to the considerable discomfort of the labor force in the plant (Reutter 1988).

Unfortunately, no such zeal was applied to the removal or treatment of toxic wastes from this steel plant or other factories polluting the Chesapeake Bay and the estuaries, rivers, lakes, and oceans of the Earth until late in the last half of the twentieth century. Appropriate policies and management instruments had been discussed by physical and social scientists, but the political will necessary to confront the economic power of the dominant industrial establishment was unequal to the task. Under the federal system in the United States, the central government left environmental management to the states. This was a system that virtually guaranteed environmental degradation because competition among states for economic growth was a convenient excuse for avoiding effective regulation. Nor, in the face of abdication of environmental responsibility by all levels of government, could victims of environmental damage count on redress in the court system. Although the awarding of damages for injury was a time-honored principle of common law, the burden of proof was on the plaintiff and it was formidable. Victims had to prove not only that they had suffered injury but that a specific party had caused the injury, to the exclusion of other sources of the injury.

This combination of institutionalized pollution permissiveness and lack of recourse from government or courts, combined with the global expansion of energy and material throughput into a finite environment following World War II, set the stage for a series of ecological catastrophes. These events not only energized the then small community of those concerned about the ecological health of the Earth, but they also increased the awareness of some leaders that ecological damage could reduce the profitability of economic systems, which had been their primary concern. Although academic scientists and even a small minority of economists were on record with their serious concerns about what they perceived as a collision course with ecological catastrophe, it took a best seller authored by a scientist, Carson's (1962) *Silent Spring*, to capture the public imagination. *Silent Spring* presented a dramatic message in a lyrical form that alerted the public to the long-run ecological consequences of the toxins-laden waters, urban smog, and accumulating litter, which were becoming all too evident to increasing numbers of citizens. Local but increasingly severe and frequent environmental catastrophes such as the Cuyahoga River catching fire in Cleveland in the late 1960s, the near death of Lake Erie, ubiquitous toxic spills, toxic dumps, fatal smog incidents in Pennsylvania, and smog in the Grand Canyon gradually convinced the majority of Americans that action was needed. Similar reactions followed in western Europe. Finally, a new and intensive inquiry into the state of the Earth and the policies and instruments needed for its protection could begin. The public awareness of the need for innovation in policy, however, moved far in advance of recognition of the need for innovation in instruments for carrying out these policies.

The U.S. legislative response to accelerating environmental damage was President Richard Nixon's National Environmental Protection Act of 1969. The goal was to halt the accelerating environmental degradation, and the policy instrument for implementing this objective was the traditional recourse to direct regulation. Reflecting the conventional wisdom of the time, the federal government legislated broad policy guidelines in general terms, leaving implementation primarily to the states. State compliance was sought through the pragmatic U.S. practice of offering generous federal grants for participation combined with potential federal intervention in cases where states failed to formulate effective plans (Box 4.2). This federal approach had served the nation well since the early federal period when it was introduced by President Thomas Jefferson in the era of "internal improvements" (Cumberland 1971).

Given the legislative history of the United States, as polluters were forced to recognize that some form of control was inevitable, they reluctantly accepted the familiar regulatory approach as that with which they were most familiar and which they could most easily manipulate to their own advantage. Legislators and bureaucrats recognized new opportunities for funding, power, and careers at the federal and state levels, which was the time-honored formula and quid pro quo for gaining acceptance of innovative programs.

Unfortunately, the new environmental regulations, though designed for acceptance by the major interest groups, lacked two dimensions

BOX 4.2 FROM A FAILED-GROWTH ECONOMY TO A STEADY-STATE ECONOMY

HERMAN DALY

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1. **Cap-Auction-Trade Systems for Basic Resources.** Caps limit biophysical scale by quotas on depletion or pollution, whichever is more limiting. Auctioning the quotas captures scarcity rents for equitable redistribution. Trade allows efficient allocation to highest uses. This policy has the advantage of transparency. There is a limit to the amount and rate of depletion and pollution that the economy can be allowed to impose on the ecosystem. Caps are quotas, limits to the throughput of basic resources, especially fossil fuels. The quota usually should be applied at the input end because depletion is more spatially concentrated than pollution and hence easier to monitor. Also, the higher price of basic resources will induce their more economical use at each upstream stage of production. It may be that the effective limit in use of a resource comes from the pollution it causes rather than from depletion—no matter, we indirectly limit pollution by restricting depletion of the resource that ultimately is converted into wastes. Limiting barrels, tons, and cubic feet of carbon fuels extracted per time period will limit tons of CO_2 emitted per time period. This scale limit serves the goal of biophysical sustainability. Ownership of the quotas is initially public—the government auctions them to individuals and firms. The revenues go to the Treasury and are used to replace regressive taxes, such as the payroll tax, and to reduce income tax on the lowest incomes. Once purchased at auction, the quotas can be freely bought and sold by third parties, just as can the resources whose rate of depletion they limit. The trading allows efficient allocation, the auction serves just distribution, and the cap serves the goal of sustainable scale. The same logic can be applied to limiting the off-take from fisheries and forests. With renewables, the quota should be set to approximate sustainable yield. For nonrenewables, sustainable rates of absorption of resulting pollution or the rate of development of renewable substitutes may provide a criterion.

2. **Ecological Tax Reform.** Shift the tax base from value-added (labor and capital) to "that to which value is added," namely the entropic throughput of resources extracted from nature (depletion) and returned to nature (pollution). This internalizes external costs and raises revenue more equitably. It prices the scarce, but previously un-priced, contribution of nature. Value-added is something we want to encourage, so stop taxing it. Depletion and pollution are things we want to discourage, so tax them. Ecological tax reform can be an alternative or a supplement to cap-auction-trade systems. Value-added is simultaneously created and distributed in the very process of production. Therefore, economists argue that there is no "pie" to be independently distributed according to ethical principles. As Kenneth Boulding put it, instead of a pie, there are only a lot of little "tarts" consisting of the value added by different people or different countries that are blindly aggregated by statisticians into an abstract "pie" that does not really exist as an undivided totality. To redistribute this imaginary pie, one should appeal to the generosity of those who baked larger tarts to share with those who baked smaller tarts, not to some invidious notion of equal participation in a fictitious common inheritance.
3. **Limit the Range of Inequality in Income Distribution.** Without aggregate growth, poverty reduction requires redistribution. Complete equality is unfair; unlimited inequality is unfair. So we need to seek fair limits to the range of inequality: a minimum income and a maximum income. The civil service, the military, and the university manage with a range of inequality that stays within a factor of 15 or 20. Corporate America has a range of 500 or more. Many industrial nations are below 25. Could we not limit the range to, say, 100, and see how it works? People who have reached the limit could either work for nothing at the margin if they enjoy their work or devote their extra time to hobbies or public service. The demand left unmet by those at the top will be filled by those who are below the maximum. A sense of community, necessary for democracy, is hard to maintain across the vast income differences in the United States. When rich and poor are separated by a factor of 500, they become almost different species. The main justification for such differences has been that they stimulate growth, which will one day make everyone rich. This may have had superficial plausibility in

an empty world, but in our full world, it is a fairy tale. I have advocated for a maximum income as well as a minimum income for a long time. The idea has been very unpopular, but thanks to the banksters and their bonuses, it is now becoming more popular.

4. **Free Up the Length of the Working Day, Week, and Year.** We need to allow greater options for part-time or personal work. Full-time external employment for all is hard to provide without growth. Other industrial countries have much longer vacations and maternity leaves than the United States. For the classical economists, the length of the working day was a key variable by which the worker (self-employed yeoman or artisan) balanced the marginal disutility of labor with the marginal utility of income and of leisure so as to maximize enjoyment of life. Under industrialism, the length of the working day became a parameter rather than a variable (and for Karl Marx was the key determinant of the rate of exploitation). We need to make it more of a variable, subject to choice by the worker. Milton Friedman wanted "Freedom to Choose"—OK, here is an important choice most of us are not allowed to make! And we should stop biasing the labor–leisure choice by using advertisements to stimulate more consumption and more labor to pay for it. Advertising should no longer be treated as a tax-deductible, ordinary expense of production.
5. **Re-Regulate International Commerce.** It is time for us to move away from free trade and free capital mobility and globalization. We should adopt compensating tariffs to protect efficient national policies of cost internalization from standards-lowering competition by foreign firms that are not required to count their full environmental and social costs. This "new protectionism" is very different from the "old protectionism" that was designed to protect a truly inefficient domestic firm from a more efficient foreign firm. We cannot integrate with the global economy and at the same time have higher wages, environmental standards, and social safety nets than the rest of the world. Trade and capital mobility must be balanced and fair, not deregulated or "free." Tariffs are also a good source of public revenue. This will run afoul of the World Trade Organization (WTO), so….
6. **Downgrade the International Monetary Fund/World Bank/WTO** to something like Keynes' original plan for a

multilateral, payments clearing union, charging penalty rates on surplus as well as deficit balances. Seek balance on current accounts, and thereby avoid large foreign debts and capital account transfers. For example, under Keynes's plan, the United States would pay a penalty charge to the clearing union for its large deficit with the rest of the world, and China would also pay a similar penalty for its surplus. Both sides of the imbalance would be pressured to balance their current accounts by financial penalties and, if need be, by exchange rate adjustments relative to the clearing account unit, called "the bancor" by Keynes. The bancor would serve as world reserve currency, a privilege that should not be enjoyed by any national currency. The bancor would be like gold under the gold standard, only you would not have to dig it out of the ground. The International Monetary Fund (IMF) preaches free trade based on comparative advantage and has done so for a long time. More recently, the IMF, World Bank (WB), and WTO have started preaching the gospel of globalization, which, in addition to free trade, means free capital mobility internationally. The classical comparative advantage argument, however, explicitly assumes international capital *immobility*! When confronted with this contradiction, the IMF waves its hands, suggests that you might be a xenophobe, and changes the subject. The IMF, WB, and WTO contradict themselves in service of the interests of transnational corporations. International capital mobility, coupled with free trade, allows corporations to escape from national regulation in the public interest, playing one nation against another. Because there is no global government, they are, in effect, uncontrolled. The nearest thing we have to a global government, IMF/World Bank/WTO, has shown no interest in regulating transnational capital for the common good.

7. **Move Away from Fractional Reserve Banking toward a System of 100% Reserve Requirements.** This would put control of the money supply and seigniorage in the hands of government rather than private banks, which would no longer be able to create money out of nothing and lend it at interest. All quasi-bank financial institutions should be brought under this rule, regulated as commercial banks subject to 100% reserve requirements. Banks would earn their profit by financial intermediation only, lending savers' money for them (charging a loan rate higher than the rate

paid to savings account depositors) and charging for checking, safekeeping, and other services. With 100% reserves, every dollar loaned to a borrower would be a dollar previously saved by a depositor, reestablishing the classical balance between abstinence and investment. The government can pay its expenses by issuing more noninterest-bearing fiat money to make up for the eliminated bank created, interest-bearing money. However, it can only do this up to a strict limit imposed by inflation. If the government issues more money than the public wants to hold, the public will trade it for goods, driving the price level up. As soon as the price index begins to rise, the government must print less and tax more. Thus, a policy of maintaining a constant price index would govern the internal value of the dollar. The external value of the dollar could be left to freely fluctuating exchange rates (or preferably to the rate against the bancor in Keynes's clearing union).

8. **Stop Treating the Scarce as If It Were Nonscarce, but Also Stop Treating the Nonscarce as If It Were Scarce.** We should enclose the remaining commons of rival natural capital (e.g., atmosphere, electromagnetic spectrum, public lands) in public trusts and price them by a cap-auction-trade system, or by taxes, while *freeing from private enclosure and prices* the nonrival commonwealth of knowledge and information. Knowledge, unlike throughput, is not divided in the sharing but multiplied. Once knowledge exists, the opportunity cost of sharing it is zero, and its allocative price should be zero. International development aid should more and more take the form of freely and actively shared knowledge, along with small grants, and less and less the form of large, interest bearing loans. Sharing knowledge costs little, does not create unrepayable debts, and increases the productivity of the truly rival and scarce factors of production. Existing knowledge is the most important input to the production of new knowledge and keeping it artificially scarce and expensive is perverse. Patent monopolies (also known as "intellectual property rights") should be given for fewer "inventions" and for fewer years. Costs of production of new knowledge should, more and more, be publicly financed and then the knowledge freely shared.
9. **Stabilize Population.** We should be working toward a balance in which births plus in-migrants equals deaths plus out-migrants. This is controversial and difficult, but, as a start,

contraception should be made available for voluntary use everywhere. And although each nation can debate whether it should accept many or few immigrants, and who should get priority, such a debate is rendered moot if immigration laws are not enforced. We should support voluntary family planning and enforcement of reasonable immigration laws, democratically enacted. A lot of the pro-natalist and open-borders rhetoric claims to be motivated by generosity, but it is "generosity" at the expense of the U.S. working class—a cheap labor policy. Progressives have been slow to understand this. The environmental movement began with a focus on population but has frequently given in to political correctness.

10. **Reform National Accounts.** Gross domestic product (GDP) should be separated into a cost account and a benefits account. We could then compare them at the margin and stop throughput growth when marginal costs equal marginal benefits. In addition to this objective approach, we should recognize the importance of the subjective studies that show that, beyond a threshold, further GDP growth does not increase self-evaluated happiness. Beyond a level already reached in many countries, GDP growth delivers no more happiness but continues to generate depletion and pollution. At a minimum, we must not just assume that GDP growth is "economic growth," but we must prove it. And we can start by trying to refute the mountain of contrary evidence.

that were essential for adequately confronting the accelerating pollution problems: sound scientific grounding and economic efficiency. Predictably, environmental protection lagged behind the expanding throughput of pollutants into air and water, and onto the land.

The major objection to the inefficiency of the regulatory approach came initially from the economics profession in which a small minority had broken with the traditional preoccupation with promoting economic growth to focus on evaluating and ameliorating the unanticipated detrimental side effects of growth, especially pollution. The existence of these spillover phenomena, now termed *externalities*, had been recognized in the economics literature since their identification by Pigou (1920) but were regarded as more of an academic anomaly than a real world problem. Ayres and Kneese (1969) confronted the economics profession with the proposition that pollution externalities, far from being an anomaly, were actually pervasive in industrial economies with their massive throughputs. Furthermore, regulatory approaches were not proving equal to the task of coping with the vast throughput of mass and energy with which industrial economies were converting low-entropy inputs into high-entropy pollutants. More efficient instruments of pollution control were needed.

The scientific basis for this phenomenon had actually been worked out in impressive detail by another economist, Georgescu-Roegen (1971), who, as noted earlier, argued eloquently for the need to reformulate economic thinking and models for consistency with the fundamental physical laws of thermodynamics and entropy, hitherto almost totally neglected by the profession. Casting the environmental problem in terms of externalities, a concept familiar to economists, focused attention directly on policy instruments because Pigou had demonstrated that an offsetting tax on detrimental externalities, such as pollution, could restore economic efficiency and increase welfare in otherwise competitive economies. Thus, a large literature emerged in support of replacing inefficient regulations with economically efficient taxes on pollution. Initially, this notion failed to gain wide support outside of the economics profession, but because of its compelling potential efficiency gains, it became imbedded in U.S. and other management programs, as will be explored in this chapter. As society was forced in Western nations to expand the amount of real resources allocated to protecting their populations and resources, the need for greater economic efficiency in the use of these scarce resources became more urgent. However, strict application of the efficiency principle appeared to neglect distributional issues and to threaten the now vested interests of polluters and regulators alike, delaying and limiting its acceptance in the political arena. And, as we have previously noted, the issue of sustainable scale had not yet been recognized and incorporated.

As the United States and other nations began curbing some of the grosser environmental insults from point source emissions of pollutants, ecologists and resource managers could begin to address more subtle but more ominous phenomena, such as sharp declines in species diversity, natural habitats, and in ecosystem health. Ecologists and others began to point out that the human economy was a subsystem of the Earth's total ecology and could not long function sustainably or even efficiently without a healthy life-support system (Costanza 1991). This brings us to ecological economics' efforts to reintegrate social and natural science around the three goals of sustainable scale, fair distribution, and efficient allocation (Daly 1992; Daly and Farley 2004) (Box 4.3).

Despite this growing awareness of threats to the global ecology, the intensity of the Cold War simultaneously accelerated the generation of nuclear wastes, along with other long-lived toxic wastes, and diminished the will to contain or to control them. The greater openness in the East

BOX 4.3 ASAP POLICY BRIEFING: FAIR DISTRIBUTION WITHIN NATIONS

Summary: The global economy, which is driving humankind beyond the limits of the planetary boundaries, is itself driven by the theoretical construct and practice of global finance. A perpetually growing economy is at some point in conflict with a finite biosphere and will impose profound implications for how we live our lives, and without a doubt for finance, as well. Just as we are in ecological overshoot, we are even more in financial overshoot. Finance in general and specifically the flow of real investment capital is one of the critical leverage points to shift to a regenerative economy that serves humanity and stewards the integrity of Earth's ecosystems.

Visit http://www.asap4all.com for in-depth analysis and debate on fair distribution.

and the West since the end of this 40-year arms race is beginning to reveal the appalling extent of the chemical, nuclear, and biological wastes produced, stored, and discarded deliberately and accidentally. Without drastic and costly remedial action, vast areas of the Earth will remain contaminated and unfit for habitation for long periods. The seriousness of this problem and its complexity demonstrated the need for a new generation of policies and instruments that would be based upon science, which is sufficiently sophisticated to deal with the complexity of the problem, economically efficient enough to accomplish the goals with the funds available, and socially equitable enough to win the consensual, democratic support required nationally and internationally. Ecological economics offers just such a transdisciplinary approach for approaching these formidable challenges (Box 4.4).

Various conclusions can be drawn from this brief overview of the evolution of thinking about environmental policy instruments. The management structure developed by a society for protection of its environment tends to reflect the distribution of economic and political power of interest groups within that society. However, without the inclusion of broader scientific perspectives such as ecology, thermodynamics, uncertainty, and sustainability, and without broader social concepts such as fairness, equity, happiness, and ethical values, the most well-intentioned efforts at environmental protection will be overwhelmed by the continued exponential growth of production, consumption, technology, and population. The magnitude of remedial work to be accomplished means that the instruments used must be economically efficient. But they must at the same time be fair and lead to an ecologically sustainable scale of activity. The following sections investigate these issues in more detail.

BOX 4.4 THE URGENT NEED FOR A NEW DEVELOPMENT PARADIGM IN A RAPIDLY URBANIZING WORLD

DEBRA ROBERTS

The success of the New Development Paradigm (NDP) will depend to a large extent on what is done in urban areas. This is the century of the city; urban areas are currently home to more than half the world's population and are the location of the majority of global assets, infrastructure, and economic activities (UN Habitat 2012). They are also the location of a large proportion of the population and economic activities most at risk from global environmental change and are the key drivers of global consumption and production. As such, they are accountable for a high proportion of global greenhouse gas (GHG) emissions and waste production and their ecological footprints affect the whole planet—despite the fact that they occupy only between 0.2% and 2.4% of the global land surface (Seto et al. 2011). Current projections of global population growth over the next several decades indicate that the majority of growth will occur in urban areas—particularly, the urban areas of the global south (UNDESA 2011). It is anticipated that urban populations will double from 3.6 to 6.3 billion by 2050 (UNDESA 2011) necessitating a related increase in capital formation, economic activity, and infrastructure development and will produce related increases in GHG emissions and the loss of life sustaining biodiversity and ecosystem services (Seto et al. 2012). Many of the existing and new urban centers—especially on continents such as Africa—will be small (less than 500,000 people), informal developments with limited governance and local government capacity—although new figures suggest this may change with an increasing urban concentration in large cities of a million or more (UNDESA 2011).

The increasing concentration of populations, assets, and economic activities in urban areas, irrespective of income level, makes urban areas a critical the focal point for NDP implementation. If people are to live well in the future, they will have to live well in urban areas. The way urban areas are planned, developed, and managed will have a major impact on the accessibility and sufficiency of the services and resources (mobility, health, food security, leisure opportunities, security, etc.) that are central in creating well-being and happiness. Without the implementation of the NDP in urban areas' economic and development processes, poverty reduction and ecological sustainability will be threatened globally. With approximately more than a billion people living in informal settlements in urban areas

(UN Habitat 2003), the largest existing and emerging concentrations of vulnerable urban populations, assets, infrastructure, and ecosystem services are in cities and towns in low- and middle-income countries. Dealing with the informality in the urban areas of the global South poses significant challenges to the implementation of the NDP and suggests the need for a conceptualization of the NDP in a manner that engages this informality in a positive way rather than identifying it as a problem to be solved.

Many of the measures needed for the implementation of the NDP will fall within the responsibilities of local governments because most risks and vulnerabilities associated with the current paradigm are rooted in local contexts and because much of the risk to ecological, social, and cultural systems is within their responsibilities. Local government (as the conduit of significant resources and a major developer of infrastructure) is therefore a central stakeholder in helping to contextualize and implement the NDP locally through strengthening of local ecological and built infrastructure and services, ensuring better integrated urban spatial planning, supporting community action, and ensuring synergy with the private sector actors around issues of sustainability and resilience. It is important to note, however, that the universal provision of basic infrastructure and services will be insufficient to enable the transition to well-being and happiness, and other factors such as preservation of local culture, ensuring the integrity of local communities, and spiritual fulfillment are also important needs in urban areas. The importance of harmonization and synergy of poverty reduction, livelihood development, food security, universal access to adequate housing and basic services, and disaster risk reduction, with climate adaptation and mitigation and the protection of ecosystem services is critical to the local implementation of the NDP. Thus, implementing the NDP requires local urban institutions that facilitate coordination and that have the capacity to bring people together and to assist communities and institutions in responding collectively to mainstreaming well-being measures. Operationalization of the NDP will also need a redirection of current priorities, investment, and capacity building plans including those that strengthen the investment capacity of urban, city, and metropolitan governments because many currently are unable to extend a full range of services and the institutional support necessary for effective well-being in these settlements

Multiple changes across legal and regulatory frameworks, jurisdictions, policies, and intergovernmental flows are also necessary to mainstream the NDP in urban areas. Other challenges to overcome include: reducing the lack of clarity of multilevel governance mandates; addressing the tension between local and higher level and sometimes international agency-driven priorities; overcoming the political disjuncture between short-cycle electoral, growth, and competitiveness concerns and competition of local short-term priorities with long-term NDP horizons; overcoming the lack of human and financial resources; and compartmentalization and fragmentation of urban government. Because effective implementation of the NDP needs local responses and includes major roles for local governments and civil society (especially those representing those most at risk), consideration needs to be given to mechanisms by which international support for the NDP can work at scale while supporting local processes. This localization of action is critical if we are to secure a better future for our best creation: the city.

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4.2 The Need to Develop a Shared Vision of a Sustainable Society

4.2.1 Envisioning

A broad, overlapping consensus is forming around the goal of sustainability, including its ecological, social, and economic aspects as described here. But movement toward this goal is being impeded not only by lack of knowledge, or lack of "political will," but also by a lack of a *coherent,* *relatively detailed, shared vision of what a sustainable society would actually look like*. Developing this shared vision is an essential prerequisite to generating any movement toward it. The default vision of continued, unlimited growth in material consumption is inherently unsustainable, but we cannot break away from this vision until a credible and desirable alternative is available. The process of collaboratively developing this shared vision can also help to mediate many short-term conflicts that will otherwise remain irresolvable. There has been a lot of success using envisioning and "future searches" in organizations and communities around the world (Weisbord 1992; Weisbord and Janoff 1995). This experience has shown that it is possible to get disparate (even adversarial) groups to collaborate on envisioning a desirable future, given the right forum. The process has been successful in hundreds of cases at the level of individual firms and communities up to the size of large cities. The challenge is to scale it up to whole states, nations, and the world.

The concept of resilience is also important/essential for developing a shared vision. The resilience of a system refers to its ability to maintain its structure and pattern of behavior in the presence of stress (Holling 1973). A healthy system is one that possesses adequate resilience to survive various small-scale perturbations. The concept of system resilience has two main components: (1) the length of time it takes for a system to recover from stress (Pimm 1984) and (2) the magnitude of stress from which the system can recover, or the system's specific thresholds for absorbing various stresses (Holling 1973).

Meadows (1996, 2010) discusses why the processes of envisioning and goal-setting are so important (at all levels of problem solving); why envisioning and goal-setting are so underdeveloped in our society; and how we can begin to train people in the skill of envisioning and begin to construct shared visions of a sustainable society. She tells the personal story of her own discovery of that skill and her attempts to use the process of shared envisioning in problem solving. From this experience, several general principles emerged, including:

1. In order to envision effectively, it is necessary to focus on what one really wants, not what one will settle for. For example, the lists here show the kinds of things people really want, compared to the kinds of things they often settle for.

Really Want	**Settle for**
Self-esteem	Fancy car
Serenity	Drugs
Health	Medicine
Human happiness	Gross domestic product (GDP)
Permanent prosperity	Unsustainable growth

2. A vision should be judged by the clarity of its values, not the clarity of its implementation path. Holding to the vision and being flexible about the path is often the only way to find the path.
3. Responsible vision must acknowledge, but not get crushed by, the physical constraints of the real world.
4. It is critical for visions to be shared because only shared visions can be responsible.
5. Vision has to be flexible and evolving.

Probably the most challenging task facing humanity today is the creation of a shared vision of a sustainable and desirable society, one that can provide permanent prosperity within the biophysical constraints of the real world in a way that is fair and equitable to all of humanity, to other species, and to future generations. This vision does not now exist, although the seeds are there. We all have our own private visions of the world we really want; we need to overcome our fears and skepticism and begin to share these visions and build on them, until we have built a vision of the world we want. There has been some movement forward in realizing the importance of envisioning a shared world. The most recent United Nations Conference on Sustainable Development (Rio+20 in 2012) was entitled "The Future We Want." Although, unfortunately not much has been done to create or implement this shared vision, the conversation has certainly begun to build momentum.

In the previous chapters, we have sketched out the general characteristics of this world—it is ecologically sustainable, fair, efficient, and secure—but we need to fill in the details in order to make it tangible enough to motivate people across the spectrum to work toward achieving it. The time to start is now.

Nagpal and Foltz (1995) began this task by commissioning a range of individual visions of a sustainable world from around the world. They laid out the following challenge for each of their "envisionaries":

> Individuals were asked not to try to predict what lies ahead, but rather to imagine a *positive* future for their respective region, defined in any way they chose—village, group of villages, nation, group of nations, or continent. We asked only that people remain within the bounds of plausibility, and set no other restrictive guidelines.

The results were revealing. Although these independent visions were difficult to generalize, they shared at least one important point. The "default" Western vision of continued material growth was not what people envisioned as part of their "positive future." They envisioned a future with "enough" material consumption, but where the focus has shifted to maintaining high quality communities and environments, education, culturally rewarding full employment, and peace.

Other initiatives have also attempted to create a shared vision at different scales. One is the *Solutions* magazine/journal (http://www.thesolutionsjournal.org), which publishes one article in each issue that provides the author's vision of the future. A summary to these visions has recently been assembled in book form (Costanza and Kubiszewski 2014).

4.2.2 Scenario Planning

"Scenario" is a term with multiple meanings. Scenario exercises vary in their objectives and hence their characteristics (Biggs et al. 2007), and we acknowledge that each of the many variants has an important place in decision-making processes. In this case, we define scenario analysis or scenario planning as a structured process of exploring and evaluating the future. Scenarios consider how alternative futures, typically structured around the identification of a focal issue (O'Brien 2000), may unfold from combinations of the most influential and uncertain drivers and their interactions with more certain driving forces.

Scenario planning differs from forecasting, projections, and predictions, in that it explores plausible rather than probable futures (Peterson et al. 2003). Scenarios are most useful for dealing with uncertainty when there is insufficient information about the probabilities that different events will occur. Scenario planning is based on four assumptions (DTI 2003):

1. The future is unlike the past and is significantly shaped by human choice and action.
2. The future cannot be foreseen, but exploring possible futures can inform present decisions.
3. There are many possible futures; scenarios therefore map within a "possibility space."
4. Scenario development involves rational analysis and creative thinking.

Scenarios are best suited to exploring situations of high uncertainty and low controllability (Peterson et al. 2003), for example, climate change and global governance. In these situations, scenarios can help to illuminate the consequences of these uncontrollable forces and to formulate robust responses locally. A frequently cited example is the use of scenarios by Royal Dutch Shell (Wack 1985; Kahane 1992). Shell began developing scenarios in the 1970s and engaged in a process to imagine a future that, at the time, no one thought would happen. When turbulence hit the world oil market in the late 1970s, Shell, though unable to directly intervene in the market, navigated the shocks much better than its competitors who did not use scenarios for strategic planning.

Although aspects of the future worlds depicted by scenarios may come to eventuate in time, these worlds are best treated as caricatures of reality from which we can learn. Often, they illustrate alternative "stable states" or "basins of attraction" that can be either desirable or undesirable worlds to live in. The ultimate role of scenarios is to help understand how society can either exit an undesirable world or make it more desirable (Gallopin 2002).

Scenarios have been developed for a range of applications from global to local scales, including corporate strategy (Wack 1985), political negotiations (Kahane 1992, 2004), and community-based natural resource management (Wollenberg et al. 2000; Evans et al. 2006; Bohensky et al. 2011). Several examples relevant to this exercise are described as follows.

4.2.2.1 The Great Transition Initiative

An ongoing effort with its beginnings in the 1990s (Gallopin et al. 1997) (http://gtinitiative.org), the scenarios have changed name and number over time, but the current set involves four major scenarios: *Fortress World*, *Market Forces*, *Policy Reform*, and *Great Transition (Raskin et al. 2002).*

The *Fortress World* scenario is a variant of a broader class of *Barbarization* scenarios, in the hierarchy of the Global Scenario Group (Gallopín et al. 1997). *Barbarization* scenarios envision the grim possibility that the social, economic, and moral underpinnings of civilization deteriorate as emerging problems overwhelm the coping capacity of markets and policy reforms.

The *Market Forces* scenario is a story of a market-driven world in the twenty-first century in which demographic, economic, environmental, and technological trends unfold without major surprises relative to unfolding trends. Continuity, globalization, and convergence are key characteristics of world development—institutions gradually adjust without major ruptures, international economic integration proceeds apace, and the socioeconomic patterns of poor regions converge slowly toward the development model of the rich regions.

The *Policy Reform* scenario envisions the emergence of strong political will for taking harmonized and rapid action to ensure a successful transition to a more equitable and environmentally resilient future. It explores the requirements for simultaneously achieving social and environmental sustainability goals under high economic growth conditions similar to those of *Market Forces*.

The *Great Transition* scenario explores visionary solutions to the sustainability challenge, including new socioeconomic arrangements and fundamental changes in values. This scenario depicts a transition to a society that preserves natural systems, provides high levels of welfare through material sufficiency and equitable distribution, and enjoys a strong sense of local solidarity.

An interactive Web site allows users to visualize and explore the scenarios (http://www.tellus.org/results/results_World.html). The descriptions of these scenarios in the published books and Web sites are the most extensive of the scenario studies mentioned here and probably the most extensive of any existing scenario exercises. The status and trends of more than 40 variables are plotted for each scenario, including several variables related to ecosystem services (i.e., CO_2 emissions, water use, forested area) and an overall "Quality of Development Index" that is similar in structure to the Genuine Progress Indicator (GPI) and other indices of societal well-being.

4.2.2.2 Four Futures for New Zealand: Work in Progress (Taylor and Allen 2007)

Researchers in New Zealand and an advisory group created four scenarios along the two axes of resources (depleted or plenty) and identity (individual or cohesion). The two plentiful resource scenarios were titled: (A) *Fruits for a Few*, where a focus on individual identity leads to tight resource control, with benefits held in the private sector and costs spread on the wider public and (B) *Independent Aotearoa*, where a focus on social cohesion leads to a dynamic cohesive society, seeing itself as a global citizen. Although outward looking, it remains critical and is confident enough to be distinctly different as a South Pacific nation. The two depleted resource scenarios are: (C) *New Frontiers*, where the focus on individualistic values, defined by visible financial status, rather than by family and cultural traditions leads to a fragmented society where the losers feel there is unfairness while the winners enjoy their freedoms as consumers and (D) *Living on No. 8 Wire*, where a focus on social cohesion leads government to intervene to manage trade-offs between economic gain and environmental degradation, to increase trade barriers and to promote equitable redistribution.

Like the Millennium Ecosystem Assessment and Great Transition Initiative (GTI) scenarios, the New Zealand (NZ) scenarios were described in great detail, including their impacts on ecosystem services and on quality of life. This exercise included a survey of attitudes toward the scenarios. A group of participants was asked in a game playing exercise about which scenario they thought NZ was presently in, which scenario it was headed toward, and which scenario they would most like to see realized. The results were quite dramatic. Most participants thought NZ was currently in the *Fruits for a Few* scenario and that it was headed toward the *New Frontiers* scenario, but that they overwhelmingly preferred the *Independent Aotearoa* scenario, where quality of life was enhanced by social cohesion and resource management.

Much more work is necessary to implement living democracy and within that to create a truly shared vision of a desirable and sustainable future. This ongoing work needs to engage all members of society in a substantive dialogue about the future they desire and the policies and instruments necessary to bring it about. In the following sections, we discuss the history of some current Western institutions and policy instruments that have been used to address environmental issues, and we offer some new ideas to expand this range. They are not "solutions" to the problems of environmental management or sustainability but rather inputs to the broad democratic discussion of options and futures. They need to be used in various combinations and modified to fit different cultural contexts. They also can serve as the starting point for development of new policies and instruments, which are better adapted to unique circumstances.

4.2.3 Overcoming Roadblocks

The history of human-dominated socioecological systems is one of the successive climbs to regional prominence followed by crises that were either successfully addressed, leading to sustainability, or not, leading to decline. Historical research demonstrates that crises leading to a society's decline do not result from a single, easily identifiable cause with easily identifiable solutions (Tainter 1988; Flannery 1994; Diamond 2005; Costanza et al. 2007). They usually result from the human-dominated ecosystem moving to a brittle, nonresilient state due to internal changes or external forcings (Weiss and Bradley 2001; Diamond 2005; Tainter 2006).

For example, the Earth's climate has gone through natural and often abrupt variations, creating new conditions, persistent for decades and centuries, which were unfamiliar to the inhabitants of the time (Weiss and Bradley 2001). Dramatic effects and societal decline, however, occur only when socioecological systems have become brittle and are unable to adapt due to other causes, including deforestation and habitat destruction; soil degradation (erosion, salinization, and soil fertility losses); water management problems; overhunting; overfishing; effects of invasive alien species; human population growth; and increased per capita impact of people. Some ancient civilizations that were not able to adapt to climate change, leading to their demise, include:

- The Akkadian empire of Mesopotamia, where a shift to more arid conditions contributed to an abrupt collapse about 6,180 years ago (Cullen et al. 2000).
- Parts of low latitude northeastern Africa and southwestern Asia, where severe drought caused major disruption about 4,300 years ago (Drysdale et al. 2006).

- The Tiwanaku civilization of the central Andes, where a prolonged period of drought led to collapse of the agricultural base about 1,000 years ago (Weiss and Bradley 2001).

Environmental problems also contributed to the decline of the Polynesians of Pitcairn Island, Easter Islanders, Mayans, Greenland Norse, Anasazi, Tang of Ancient China, and the Roman Empire.

Today, we face a set of interconnected crises that threaten the sustainability of our increasingly brittle global socioecological system. These include climate change (Weiss and Bradley 2001; Bernstein et al. 2007), the imminent peak and decline in key nonrenewable energy resources (Zittel et al. 2006, 2007; Zuchetto 2006; Wells et al. 2007; Zittel and Schindler 2007), and a loss of biological diversity that may reduce the resilience of our global ecosystem and its ability to provide for human needs (Vitousek et al. 1997; Western 2001; Wilson 2002). Although most societies that declined in the past were replaced by new ones (Tainter 1988; Diamond 2005), those societies were relatively isolated, lacking the interdependency of our current global community and the interconnectedness of the crises we face today. The possibility that our global society may suffer decline makes this a “no-analog” period in human history where massive social or environmental failure in one region can threaten the entire system (Costanza et al. 2007).

Effectively adapting to potential collapse requires a thorough realignment of the way we view and interact with our surroundings—what has been called a socioecological “regime shift” (Gunderson and Holling 2002). A socioecological regime is a culture embedded in, and co-evolving with, its ecological context. “Regime” suggests a complete, interacting set of cultural and environmental factors that operate as a whole. When the ecological context changes so that the existing regime is no longer adaptive, societies must either identify and surmount the roadblocks confronting a regime shift or else become unsustainable and decline.

One way to assess this transition is through an analytical framework that identifies the conceptual (i.e., related to worldviews), institutional, and technological roadblocks to societal sustainability and that explores how their redesign can avoid a global societal decline. Worldviews, institutions, and technologies correspond to Meadows’s (2010, pp. 41–49) “leverage points” “places within a complex system … where a small shift in one thing can produce big changes in everything.”

4.2.3.1 The Components of Culture

A culture can be viewed as an interdependent set of worldviews, institutions, and technologies (WITs). Worldviews are broadly defined as our perceptions of how the world works and what is possible, encompassing the relationship between society and the rest of nature, as well as what is desirable (the goals we pursue). Our worldview is unstated, deeply felt, and unquestioned. These unconscious assumptions about how the world works provide the boundary conditions within which institutions and technologies are designed to function.

Institutions are broadly defined as a culture's norms and rules (Ostrom 2005), and they include the key structures that are universal among all cultures: kinship, economy, religion, polity, governance, and education (Turner 2003). These structures constrain individuals' behavior, define a recognizable culture (Gunderson and Holling 2002), and serve as problem solving entities that allow societies to adapt to their environments (Tainter 2000, 2003). The institution of money, for example, emerged to solve the problem of unacceptably high transaction costs and limited liquidity in barter economies with a well-developed division of labor (Turner 2003). Technologies are broadly defined as the applied information we use to create human artifacts (in the aforementioned example, a printing press for money), as well as the institutional instruments used to help us meet our goals (in our current monetary system, a decision to lower interest rates).

4.2.3.2 Change as an Evolutionary Process

Cultural change is an evolutionary process (Turner 2003; Boyd and Richerson 2005) acting on WITs. The evolution of cultures follows rules analogous to those governing the evolution of organisms, but they vary in their units of selection (cultural variants vs. genetic variants) and the method of transmission of successful variants to the next generation (learning vs. genes) (Tainter 2000). Individuals within populations display a variety of traits that relate to their social lifestyles, such as strategies for procuring food and interacting with others. Multiple variants of each trait are possible and can be either conceptually driven (lifestyle choices based on personal preference), institutionally prescribed (belonging to a religion that forbids eating red meat), or constrained by current technology (the advent of petroleum-based travel changing the diets of Alaskan indigenous communities).

For any individual worldview, institution, or technology, there are many variants that a society may adopt, and each variant has its costs and benefits relative to local conditions and selection pressures. The frequencies with which each of these behavioral variants are seen in a population change over time in response to different selection pressures. Selection pressures include changing resource availabilities, environmental conditions, shifts in behavior of other key species or members of the population, and the frequencies of other linked trait variants. Variants that more favorably interact with the socioecological context generally increase in their frequency within the population, while those that are less favorable generally decrease in frequency. In this context, the frequencies of all cultural variants within a population make up the population's culture, and this emergent culture defines the population.

Though the evolutionary process of cultural change acts on WITs differently, worldviews, institutions, and technologies are mutually interdependent and mutually reinforcing. Although institutions are perhaps the chief traits upon which cultural selection acts, a specific worldview or set of worldviews will drive the institutions and technologies we develop by providing boundary conditions (Ostrom 2005). For example, if our goal is to improve quality of life, we will develop institutions and technologies that promote that goal, whereas if our goal is endless economic growth, we will develop a different set of institutions and technologies. Conversely, our worldviews are reinforced by the rules our institutions set for us. For example, institutions such as education and the media play a critical role in shaping our worldview and our set of goals. Technologies, in turn, also have a powerful impact on institutions and worldviews. For example, technologies that allowed us to shift from dependence on the fixed flow of solar power to the stock of fossil fuels that we can extract and use as fast as we like has reinforced the worldview that economic growth can continue forever. A regime shift is not merely technological or programmatic in nature. It will do no good to set up new institutions to monitor pollution if we continue to develop technologies that create pollution, or if we continue to believe that ecosystems can be increasingly degraded without any repercussions. One cannot execute a regime shift without changing worldviews, institutions, and technologies together, as an integrated system.

The desired outcome of selection on our worldviews, institutions, and technologies is to create a society that is adapted to its surroundings and situations (Turner 2003) and provides for the well-being of its populations. However, it is possible for formerly adaptive worldviews, institutions, and technologies to become maladaptive. Institutions and technologies can have significant impacts on their environments, which may also undergo exogenous changes, and so cultural evolution must re-adapt to changed surroundings in an ongoing coevolutionary process (Gowdy 1994; Norgaard 1994), resulting in new socioecological regimes. Maladaptation occurs when WITs or variants of WITs become "locked-in." Economic, technical, or political inertia, sunk costs, and other forces can prevent alternative WITs or WIT variants from being implemented (Yoffee 1979; Costanza 1987; Carrillo-Hermosilla 2006). The result of a society locked in to a maladaptive WIT is, potentially, a societal decline such as those observed in many historical settings, as mentioned earlier.

These instances of large-scale, permanent societal decline have dramatic consequences, potentially involving voluntary or involuntary reductions in societal complexity, substantial reductions in population, and political disintegration or the reduction of controlled territory (Tainter 1988; Diamond 2005; Tainter 2006). Such radical negative socioecological regime shifts are often referred to as collapses (Tainter 1988; Diamond 2005; Costanza et al. 2007; O'Sullivan 2008). In some cases, such as the recent example of the fall of the Soviet Union, regime shifts may only introduce temporary negative impacts, while in other more severe instances the resulting decline is permanent and leaves an open niche for another society to emerge and occupy (Tainter 1988; Diamond 2005). Whether societal declines are permanent or temporary, their occurrence is the result of cultural selection acting within a cultural and environmental context (Turner 2003).

To escape a situation of lock-in with multiple, reinforcing maladapted cultural variants, societies can foresee potential decline and design other cultural variants, thereby allowing a positive regime shift or one with merely temporary setbacks, thus changing the course of the future. One question inevitably emerges regarding the transition to an alternative socioecological regime: Will it occur in a controlled, deliberate way that people will find socially acceptable, or will it occur in an uncontrolled way that people perceive as harsh, difficult, and severe? Put more bluntly, can the transition occur without societal collapse?

Crises are typically defined as a decisive moment or turning point. From an evolutionary standpoint, a period of cultural crisis is one where selection pressures are acting on worldview, institutions, and technologies strongly enough that changes in WIT variants are required to alleviate the pressure. Given that cultural evolution will necessarily take place through the process of selection, passing through periods of crisis is a necessary part of the process. If we are to transition to a more sustainable society, we therefore cannot evade crisis. Indeed, when selection pressures become powerful enough to reshape society, it will appear to the adherents to the dominant WIT that their world is in a state of crisis. Such crises are best viewed as an opportunity to redesign a socioecological regime to better adapt to the changing conditions.

Whether the transition can progress with or without decline or collapse is a separate issue. The key point is that cultural transitions involve the rise or fall of metrics that measure specific social elements, such as economic expenditures (i.e., gross national product) or social complexity. Some of these metrics may well decline after a long period of increase. Declines in some metrics, such as per capita energy consumption, net energy, or social complexity, may be long-term and permanent, although declines in other metrics may be temporary and rebound once societies adapt to their new realities. The rise and fall of most of these metrics is not necessarily good or bad for a society, so long as the society is able to adapt its WITs to the changing conditions so that individuals within the society are able to meet their needs throughout the transition.

Although the promise of crisis as a part of cultural transition may seem pessimistic, the transitional process itself need not be difficult. As human beings, we have an awareness of our WITs that other social animals lack, and thus we have the potential to study the different variants of these WITs, make educated guesses as to which variants may serve us better as circumstances change, and to adopt policies that will allow us to transition to these more adaptive institutional variants before the process of cultural selection forces us to. This amounts to, in effect, designing our way through the process of cultural evolution (Bánáthy 1998; Alvord et al. 2004). Although we will not avoid every pitfall, taking a proactive approach toward the needed institutional adaptations can reduce the negative impacts and perceptions of crises endemic to cultural transitions and thus make it rewarding (even though it may require transitions). Perhaps the best analogy is with breaking an addiction. A crisis is often required to allow the addict to see and acknowledge their addiction, and the transition to a post-addiction state can be quite traumatic. But with proper knowledge of the process, care, and foresight, the transition can be relatively smooth and highly rewarding.

4.3 Successes, Failures, and Remedies

For purposes of achieving the environmental and other social values identified here, society has created an array of interlocking institutions. For satisfying material needs and wants, competitive markets have evolved as efficient though not perfect institutions. For addressing market failures, pursuing equity goals, and other community purposes, governmental institutions have evolved, though few would defend them as totally satisfactory. Therefore, in order to address the intervention failures of government, citizens have banded together to form voluntary nongovernmental organizations (NGOs). However, it should come as no surprise that even these NGOs have their failures and shortcomings, as will be examined here shortly. These formal institutions, markets, governments, and voluntary organizations, though potent forces, should not cause us to overlook the most fundamental source of power in an open society, namely, the actions and values of individuals.

Individual actions and values are the ultimate determinants of environmental quality and of the possibility for sustainability. Individual decisions about what to purchase, consume, wear, and drive, about where and how to live, what jobs to seek, how many children to have, will decide the future. Each of these consumption decisions determines what resources, renewable or irreplaceable, must be used in its production, and what pollutants will be emitted when they become waste, as all produced goods inevitably must become sooner or later. It is individual and family choices about family size, lifestyle, residential style, career paths, and voting choice that will determine the viability of the environment, the life span of our natural resources, the diversity of the biosphere, and the possibility of global sustainability. Obviously, the amount of freedom and latitude we have in making these choices varies widely and is a function of affluence and education. Therefore, it follows that the responsibility for wise choice (and example) falls most heavily on the rich, the privileged, the educated, the famous, and the powerful. Choosing sustainability is thus ultimately a matter of moral, ethical choice and thus a result of individuals' fundamental values. Although these human values are basically independent of the biophysical constraints that limit their realization, we nevertheless believe that they are affected in part by knowledge. Knowledge about ecology, about economics, and about their interrelationships will help modify some of the values that lead to excessive consumerism, to the search for satisfaction in materialism, and to the search for social salvation through quantitative growth of economic throughput.

4.3.1 The Policy Role of Nongovernmental Organizations

Although governments are now (since the 1970s) staffed at many levels with agencies nominally charged with environmental protection, it is difficult, upon close examination of the performance of these agencies, for those working for effective environmental management to avoid disillusionment. Indeed, it would be naive to have any other expectation than that these agencies will faithfully reflect the distribution of political and economic power of the society in which they are embedded. Therefore, environmental agencies have not only been limited in their ability to achieve environmental improvement, they have at times obstructed it and even dismantled environmental programs. James Watt as secretary of the U.S. Department of the Interior and Ann Gorsuch Burford as administrator of the Environmental Protection Agency (EPA) served from 1981 to 1983 and are examples of officials who were appointed to turn back the clock on environmental protection, and who succeeded in creating damage that will be difficult to repair. The 1996 "contract with America," despite good intentions, envisions even greater environmental retrogression.

It is one of the strengths of a pluralistic society that alternative institutions emerge in order to protect vital interests. One response to governmental intervention failures in managing the environment is the emergence of NGOs. Work by Buchanan and others (1987) in the public choice field helps explain this phenomenon of intervention failures. Although there are many able, idealistic public servants who are dedicated to the public interest, with Watt and Burford being extreme examples of those serving special interests, few would argue that government alone, relying upon current practices, can be depended upon for environmental protection. However, some steps should be taken in order to make existing institutions more effective in carrying out their legal responsibilities for protecting and managing environmental resources. One, for example, would be to establish awards that provide additional financial and professional incentives to resource managers who perform outstandingly efficient and innovative work in environmental protection.

Another option could be for citizens to provide more support for conservation groups that have proven themselves to support environmental protection where public agencies have failed and for these groups to coordinate their programs.

4.3.2 Adaptive Ecological Economic Assessment and Management

It is undeniable that technological innovation has generated significant advances in human welfare. However, in retrospect, not all technologies have resulted in positive net improvements in human welfare. Nor have advanced technologies been managed responsibly. The most obvious cases of technologies without which humanity would be better off are the military technologies of mass destruction, such as nuclear and biochemical weapons, which society is struggling to ban. Additionally, it is possible to cite some nonmilitary technologies, such as nuclear energy, agricultural chemicals, and even the internal combustion engine, which have had large unintended negative environmental consequences. Certainly the final judgment of history has yet to be rendered on these technologies, but at the minimum, all but the most doctrinaire libertarians would concede that there is room for better management of these technologies. However, once these technologies are introduced, it is difficult to squeeze the genie back into the bottle. A reasonable inference to be drawn from experience is that lessons might be gained from history that can guide and manage the introduction of massive technological systems that potentially have far-reaching consequences for humanity.

Granted that the law of unintended consequences makes it impossible to anticipate all of the technology's impacts for better or for worse, this does not mean that it is totally impossible or undesirable to devise minimal guidelines in advance of introduction for assessing and managing technologies, especially those having global implications. Although technological laissez faire may have been appropriate in a relatively empty world, now that humans have the capability of rendering the Earth uninhabitable, we no longer can afford to let survival depend upon the benevolence and wisdom of naive technological enthusiasts.

The shaping of policies and instruments for technology assessment is a difficult task requiring transdisciplinary research of a high order, but some minimal guidelines can be offered (Cumberland 1990a).

- Exceptional caution should be exercised before the introduction of high-entropy producing systems, such as fossil fuels and nuclear energy.
- Low-entropy producing systems, such as solar energy, are less irreversible and less damaging than high-entropy systems.
- Technologies that depend upon a high ratio of human intelligence and information to material and energy throughput have a higher probability of advancing human welfare than do high-entropy technologies.

Examples of low-entropy technologies depending upon high input ratios of intelligence and information to mass and energy notably include the telescope, the microscope, reading glasses, the compass, the sextant, the chronometer, and other navigational instruments that literally opened up new worlds to humanity. It remains to be seen whether the much higher entropy exploration of space will bring comparable benefits to humanity. Other examples of benevolent technologies are transistors and silicon chips, which have made possible the computer, yet that save energy.

Obviously any technology, even that characterized by lowest entropy, can be applied to antisocial purposes of crime and warfare, so no guarantees of benevolence can be realistically expected, and the distinction must be made between the potential environmental impact of the technology and the purposes to which it is applied. What technology essentially does is to extend the power of humans to accomplish constructive or destructive ends. Thus, the mastery of technology requires its assessment before adoption and the responsible social control of its application as well as a realistic understanding of human motivation.

Several guidelines for the management of technology can be drawn from regrettable lessons of history. We should have now learned that before adopting new systems, it would be desirable to examine the full life cycle of the technology. This elementary precaution could save us from such disasters as making major commitments to nuclear energy before understanding the problems of storing radioactive wastes, safeguarding them from terrorists, and decommissioning contaminated plants.

Another guideline for the management of technologies is to require, *before the acceptance and adoption of new systems*, the implementation of mass balance and energy balance accounting systems so that a comprehensive tracking of wastes is assured.

4.3.3 Redirecting Technology toward Sustainable Solutions

Conventional economists have long assumed that technological progress would overcome any resource constraints and allow endless economic growth (Simon 1981b). A far less challenging, but still formidable, goal for technological progress would be to help stave off the looming crises already caused by endless growth described earlier. To do this, we would need to make rapid progress on alternative energy technologies and develop alternative approaches to agriculture. Given the urgency of the problem, we must assess various types of institutions and disseminate these technologies as quickly as possible.

Today, much research and development is performed by corporations driven by economic incentives. But there are a number of serious problems inherent to market-driven research. First, it can be difficult and expensive to make information excludable (i.e., to prevent people from benefiting from information unless they pay). The private sector is unlikely to produce nonexcludable information because other firms could simply copy it at low cost, giving them a competitive edge over the firm that actually invested in it. Patents can make information relatively excludable, but then anyone who uses that information in subsequent inventions must pay for the right to do so. Unfortunately, technologies that generate public goods (such as climate stability) or that meet the needs of the poor (such as affordable food) produce no revenue to pay patent royalties. Such royalties are, therefore, an added deterrent to generating these technologies. For example, some scientists developed golden rice, a genetically modified strain that produces vitamin A and improves quality of life for the malnourished poor. However, after developing this technology, the scientists discovered that they had potentially infringed on 70 separate patents, which have proved a serious obstacle to distributing the rice to poor farmers (Kowalski 2002).

The solution to the conflict between food production and ecosystem services would appear to be agro-ecology—projects that increase the provision of ecosystem services from agricultural land and also increase food production and farmer income from ecological restoration (De Schutter 2010). However, the private sector generally fails to invest in agro-ecology (Vanlogueren and Baret 2009), favoring instead technologies that increase market production at the expense of ecosystems.

Alternative energy supplies are also critical. However, the energy sector is among the least innovative of all industries, investing only about 6% as much in research and development as the manufacturing sector (Avato and Coony 2008). Private sector investment in energy technology (research development and employment) has in fact fallen steadily since the 1980s and accounts for only 0.03% of sales revenue in the United States (Coy 2012).

Cooperative, public sector investment efforts, in contrast, would address these problems. The public sector by definition is interested in the provision of public goods. Research financed by the public sector can be made freely available for all to use, eliminating the costs of protecting intellectual property rights. A metastudy of returns to research and development (R&D) typically conducted by the public sector found average annual rates of return of 80% (Alston et al. 2000).

Markets are simply ill-suited for producing information at lowest possible cost. The most important input into new technologies is existing knowledge; information is like grass that grows faster the more it is grazed. When patents raise the price of accessing this knowledge, it raises the price of developing new information.

Furthermore, markets reduce the value of information once it has been developed. If a firm develops a clean, decentralized, inexpensive, and safe alternative to fossil fuels, it would be able to sell the technology at a very high cost, potentially too high for firms in developing countries to afford. These firms would then continue to burn coal and other fossil fuels, leading to continued global climate change. Paradoxically, the value of information is maximized at a price of zero, but at this price there is zero incentive for markets to provide the technology. The solution is not to create private property rights that reduce the value of information but rather the cooperative, public provision of green technologies that are freely available for all to use.

Because many of the most serious threats to global ecosystems were caused by the excessive consumption of the wealthiest nations, those same nations should provide the bulk of the funding required for R&D in the green technologies that solve those problems. Ideally, all nations would contribute to such an effort to the best of their abilities. Many economists are worried that some nations would free-ride on investments by others. However, free-riding on certain technologies would help protect the environment and would also provide benefits to those countries that made the initial investments.

4.3.4 Habitat Protection, Intergenerational Transfers, and Equity

Many options exist for habitat protection, including purchase, easements, and gifts, each having a role (Cumberland 1991). Protection should begin as soon as possible, before adverse uses and property rights are established. This section explores priorities for acquisition and relates habitat protection to equity across regions, groups, and generations.

The central point of this section is that in selecting the stock of environmental resources to be passed along to future generations, emphasis should be given to such resources as large-scale living ecosystems containing species diversity, complex interrelationships between species, and, above all, the capability of supporting evolutionary processes over sufficiently long enough time frames that species can evolve and adapt to both man-made and natural changes in climate and other environmental conditions. Obvious candidates include rain forests, estuaries, wetlands, lakes, river basins, grasslands, polar regions, and coral reefs. However, the ultimate selection of the highest priorities for protection of sustainable ecosystems should be made by transdisciplinary teams including not only ecologists but other representatives of life sciences, Earth sciences, physical sciences, and social sciences preferably with insights also from the arts and humanities.

After the identification of the scientific principles and priorities for selecting sustainable ecosystems for intergenerational transfer, the challenge of designing the most effective policy measures for acquiring and protecting these ecosystems will remain.

A major challenge will be gaining acceptance for large-scale current sacrifices that will produce uncertain benefits in an uncertain future. Another complicating factor is the need for consensus on goals for global cooperation in implementation. The fact that serious intragenerational inequalities exist in the distribution of current income and wealth will make it difficult to achieve consensus on the need for intergenerational transfers and will complicate the problem of apportioning sacrifices. A related problem is that, in an uncertain future, the continuity of a commitment to pass on ecological resources cannot be guaranteed for future generations that are not parties to the agreement. Therefore, intermediate generations may be tempted to consume all or part of an inheritance that was intended for the more distant future. There is the danger of a prisoners' dilemma in which uncertainty about the action of intermediate generations could reduce the welfare of more distant future generations. However, as successful experience is gained in protecting intergenerational transfers, uncertainties could be reduced and welfare gains increased.

Well-known public goods problems could pose additional difficulties in making intergenerational transfers, to the extent that future benefits will be shared by all regardless of which group made the sacrifice to provide them. In the case of global public goods such as the atmosphere and oceans, those groups making current sacrifices to protect the resources could not reap the entire benefits. This free-rider problem could reduce incentives to sacrifice unless measures could be designed to spread the burden widely.

Therefore, in choosing policy instruments for acquiring and protecting sustainable ecosystems, new alternatives must be created utilizing what limited insights are available from the fields of public choice and policy science. It is unlikely that acceptable policies can be derived from any one discipline such as economics, with its primary focus on efficiency, or ecology with its limited institutional content, or from any other single discipline. Therefore, it seems self-evident that policy instruments for intergenerational transfers must be drawn from a transdisciplinary approach.

Given the fact that making bequests requires sacrifices and therefore involves scarcity problems, economic efficiency concepts can be helpful in achieving the maximum amount of resource protection for a given amount of resources available, or they can assist in achieving specified resource endowments at minimum total cost. The field of economics can also offer some limited insights into problems of distribution and equity. An especially important concept is that of Pareto improvement, which suggests that policies are most likely to gain acceptance if they can be designed so that there are no losers, or alternatively so that the gains from the policy are great enough to compensate the losers *and that compensation actually occurs.*

The criteria for ecological bequests must be based upon good science that should emphasize protecting species diversity and minimizing entropy increase. Finally, in order to gain acceptance, policies for making intergenerational transfers must be realistically based upon acceptance by the major interest groups involved. Society has already begun the process of making intergenerational environmental transfers in the form of wilderness areas, wildlife sanctuaries, protected parts of the polar regions, and similar set-asides. These programs have been initiated not only by local, state, national, and international governmental organizations but also by NGOs such as the Nature Conservancy. Significantly, many families and individuals have demonstrated the value they place upon intergenerational environmental transfers through their willingness to bear the opportunity cost of holding land and resources in their natural state. Another example is the case of Hungary's parliament that in 2007, created an environmental ombudsman–steward. The main goal of the ombudsman is to ensure environmental sustainability for current and also future generations. In protecting living ecosystems, these public and private initiatives offer guideposts for the much greater future efforts that will be necessary for achieving sustainable global environments.

In cases where governments already own very large tracts, such as in the western United States, the task of acquisition and set-aside can be relatively easily accomplished. Setting aside tracts currently held by governments has the advantage of not requiring additional expenditure, but it must be recognized that there is an opportunity cost equal to the value of the highest alternative use to which the asset could be put. The least-cost way of protecting valuable ecosystems is through simple appropriation, but this approach may fail the equity test. In cases where high-priority ecosystems are in private hands, a wide array of policy instruments for acquisition is available. The most straightforward method is through purchase, which has the equity advantage of fully compensating current owners but has the budgetary disadvantage of being very costly. The funds available for acquiring ecosystems can be stretched through the purchase of easements strong enough to protect the desired ecological feature but sufficiently permissive to grant current owners lifetime estates or limited use in return for long-run protection.

In the cases where funds are raised by the government for acquisition, the cost to current generations is made explicit through the taxing and budgeting process and in democratic societies can be achieved only through consensus. Transfers of funds from the general public to the current owners of the ecologies are made explicit under this procedure. An important economic consideration is what the taxpayers must give up in order to make the transfer possible, and what the recipients of the funds do with the proceeds. Thus, when government purchases of ecological assets occur, redistribution occurs not only among generations, but within current generations.

4.4 Policy Instruments: Some Background

An important element in the evolution of ecological economics has been a serious concern not only with the goals, policies, and programs needed for environmental sustainability but also with the design of improved and innovative policy instruments needed for the successful accomplishment of these goals. Thus far, we have emphasized the basic principles of ecological economics and derived from them an agenda of programs that seem to us to be essential in changing our course from the current policy of looting the planet to that of protecting species diversity and of building a sustainable human society on Earth with concern for equity among groups, regions, and generations.

However, one critical factor that is often given short shrift in discussions of environmental protection is analysis of the *policy instruments* that are fundamental to the achievement of program objectives. For example, Gore's *Earth in the Balance* (1992) provides a visionary set of programs that, if implemented, could advance us significantly toward the goal of a sustainable society. However, he gives much less attention to the policy instruments needed for achieving the admirable goals he enumerates. This is not intended as criticism but as an observation that even some of the most serious and dedicated environmentalists, among whom Gore has certainly been in the forefront, are more comfortable in dealing with the large issues of goals and purposes than with the technical aspects of instruments for achieving them. We, on the other hand, believe that a serious approach to environmental management must include analysis of the management instruments to be used as an integral part of the program to be implemented.

One reason for the typical neglect of policy instruments is the widespread dependence, especially in the United States, on a regulatory approach to environmental management. Beginning with the National Environmental Protection Act of 1969, establishing the EPA, the primary approach to environmental protection has continued to be the promulgation of regulations intended to achieve the desired objectives. This approach has achieved a great deal and unquestionably has left the United States in a much better position than we would have been in without it. However, few would agree that the results have been entirely satisfactory, and questions must be raised:

- Might some other approaches have given better results?
- Are present approaches inadequate for dealing with the growing problems of the future?
- Can improved policy instruments be designed to provide better results, or lower costs, or both?

Many who have studied these problems have concluded that all of these questions can be answered in the affirmative.

Although pollution is only one of the many causes of environmental damage, it is the one that best illustrates the evolution of policy instruments and from which insights can be drawn for addressing related environmental issues. For controlling pollution, policymakers have devised a wide menu of instruments, ranging all the way from moral exhortation to imprisonment. Some of the most important include regulating emissions, taxing emissions, taxing products the use of which pollutes, requiring permits to pollute, paying polluters to abate, labeling products as to contents, educating consumers, and imposing deposit-refund systems on polluting products. One useful way of classifying this wide range of options is to divide them into two general categories: conventionally defined as either regulatory or the incentive-based (IB) use of economic measures.

The regulatory approach is sometimes referred to, especially by those who disapprove of it, as the command-and-control or CAC approach. However, the CAC terminology is more appropriately applied to central planning for an entire economy, such as that of the former Soviet Union, rather than as a description of a subset of environmental policy instruments, which are entirely consistent as a correction to market failures in a predominantly market economy.

Rather than casting the evaluation of policy instruments in terms of regulatory *versus* incentive systems, a more constructive approach is to investigate the conditions under which incentives yield better results as compared with conditions under which regulations make more sense. Cropper and Oates (1992), among others, have provided much needed insight into this issue.

Incentive systems are potentially more appropriate for the control of some pollutants rather than others. For example, regulation will continue to be the preferred instrument in the case of severe threats to human health, such as radionuclides and severely toxic carcinogens, where the optimal level of emission approaches zero. The prevalence of scientific uncertainty about all but the most simple damage functions is a powerful argument for explicitly recognizing the limitations on knowledge and for acknowledging them in formulating pollution control policies. Therefore, environmental policies such as the precautionary principle and instruments such as assurance bonding, which are discussed further on, have been developed in order to preserve the advantages of economic incentives in the face of incomplete scientific knowledge about the effects of pollutants and about the interactions among them (Box 4.5).

In the face of uncertainty, appropriate public policy is to prevent emissions (which is usually much cheaper than cleaning them up) and thus to limit exposure initially. This can be achieved by ending the assumption of safety for emissions unless damage has been proven and by shifting the burden of proof to emitters by requiring the demonstration of safety by the emitter before use, rather than the more costly procedure of requiring regulators to prove damage. Economic incentives can be effective instruments for this purpose, particularly when used in conjunction with regulations.

Policy instruments based upon economic incentives can be powerfully efficient methods for achieving allocation objectives, but it is important to avoid the error in logic into which the economics literature often lapses of assuming that markets, just because they can be such powerful guides in achieving allocative goals, are equally valid for determining the other two critical goals: sustainable scale and equitable distribution. We need to put in place separate instruments for achieving the prior goals of sustainable scale and equitable distribution before applying efficient methods of reaching them.

4.4.1 Regulatory Systems

Environmental management in the United States, as noted earlier, is based upon a federal regulatory system under which Congress has enacted national guidelines for regulations, with implementation left largely to

BOX 4.5 SCIENTIFIC UNCERTAINTY AND PUBLIC POLICY

NORMAN MYERS

Many environmental problems are difficult to evaluate because they are beset with scientific uncertainty. Obvious examples include mass extinction of species (how many species are we losing per year, how many shall we lose within the next 50 years?), the ultimate impacts of pollutants (notably endocrine disrupters), and the biggest problem that is probably subject to the most scientific uncertainty, climate change. In all these areas, scientific uncertainty bedevils the question of costs. We are generally aware of the costs of action, but we know far less about the costs of inaction. Hence inaction rules the day.

The key question is: What is "legitimate scientific caution" in the face of uncertainty—especially when uncertainty can cut both ways? Some observers may consider that in the absence of conclusive evidence and assessment, it is better to stick with low estimates of environmental impacts on the grounds that they are more "responsible." But there is an asymmetry of evaluation at work. A low estimate, ostensibly "safe" because it takes a conservative view of such limited evidence as is to hand in documented detail, may fail to reflect the real situation just as much as does an "unduly" high estimate that is more of a best judgment affair based on all available evidence with varying degrees of demonstrable validity. A minimalist calculation with apparently greater precision may in fact amount to spurious accuracy. In a situation of uncertainty where not all factors can be quantified to conventional satisfaction, let us not become preoccupied with what can be precisely counted if that is to the detriment of what ultimately counts.

This applies especially to issues with policy implications of exceptional scope, as in the case of climate change. Suppose a policymaker hears scientists stating they cannot legitimately offer final guidance about a problem because they have not yet completed their research with conventionally conclusive analysis in all respects. Or suppose the scientists simply refrain from going public about the problem because they feel, in accord with certain traditional canons of science, they cannot validly say anything much before they can say all. In these circumstances, the policymaker may well assume there is little to worry about for the time being—absence of evidence about a problem implies evidence of absence of a problem. By consequence, the policymaker may decide to do nothing—and to do nothing in a world of unprecedentedly rapid change can be to do a great deal. In these circumstances, undue caution from scientists can become undue recklessness in terms of the policy fallout; their silence can send a resounding message, however, unintentional. As in other situations beset with uncertainty, it will be better for us to find we have been roughly right than precisely wrong.

the states. This approach evolved from growing recognition in the second half of the twentieth century that serious environmental damage could not be prevented by relying exclusively upon state and local governments, whose competition for economic development was an impediment to effective local environmental management. Federal efforts to implement environmental management have been characterized as the regulatory system to distinguish them from alternative approaches such as the use of economic incentives or incentive-based (IB) systems. In the United States, the regulatory approach predominates. For stationary sources of air pollution each state is required to develop a state implementation plan (SIP) to ensure that emissions of particulate matter, sulfur oxides, and nitrogen oxides are in compliance with national air quality standards. In all of these cases, enforcement is left primarily to the states. In theory, failure to meet local air quality standards is penalized by termination of federal subsidies for major highway and other programs. However, continued failure to achieve local air quality goals in many major metropolitan areas with strong political and economic power has resulted in repeated postponement of deadlines for meeting air quality goals. The Clean Air Act of 1990 was intended to provide an improved approach to these problems.

U.S. water pollution control also relies upon a state–federal division of responsibilities with emphasis upon emissions and ambient quality. Ambient quality is defined not in terms of quantitative standards but in terms of more qualitative objectives, such as fitness for supporting swimming and fishing.

The regulatory approach has had only limited success in achieving the desired levels of environmental protection in the U.S. market economy and the system has failed disastrously in the centrally directed economies of the former USSR (Feshbach and Friendly 1992) and in eastern Europe. In general, the regulatory system can work well where there are clear environmental goals with overwhelming political consensus, similar costs of abatement across all actors, relative certainty about what is being emitted, and easy and effective enforcement. These conditions hold in all too few cases, and we have already identified and controlled many of them (i.e., large industrial point sources and sewage treatment plants).

Making further progress with only the regulatory system will be much more difficult.

The limits of the regulatory approach in achieving acceptable levels of environmental protection and the high cost of these traditional policies have led economists and others to propose less costly, more effective incentive-based management instruments, such as pollution charges, marketable emission permits, and performance and assurance bonds. The lack of widespread acceptance to date of alternatives to regulation suggests that current practices are viewed as possessing superior political and historical acceptability or at least of not being as unacceptable as the proposed innovations. Among the nominal advantages of regulation are:

1. Simplicity, familiarity, and acceptance.
2. Historical U.S. reliance upon legislative regulation in order to deal with perceived problems.
3. Acceptance by major emitters and interest groups.
4. Long-term incorporation into the legal system.

However, despite these advantages, the regulatory approach has failed to meet rising expectations for environmental quality and contains numerous inherent disadvantages, especially in the case of diffuse, chronic, non-point-source pollution. These disadvantages include:

1. Effective regulation requires a level of technical and proprietary information, which is seldom available to regulators.
2. Successful enforcement of regulation requires high monitoring and enforcement costs.
3. The costly bureaucracies associated with regulation result in high expenditure per unit of pollution reduction.
4. Environmental regulations are easily evaded or avoided.
5. The lack of strong incentives to reduce pollution below the mandated level reduces motivation for technological advance and for preventing pollution before it is generated.
6. Polluters are permitted to ignore the costs their actions impose upon society *at the time decisions are made*.

In addition, the regulatory system, having its roots in the legal system, is based on a presumption of no damage on the part of polluters until they can be proven to have violated the regulations or to have caused demonstrable damages. Given the high degree of uncertainty about the fate and effects of pollutants, this presumption can lead to significant difficulties, especially in those cases where this uncertainty is high.

Despite these limitations associated with regulatory systems, especially with respect to problems such as pollution where incentives are significant, regulatory systems still have a major role to play in addressing the basic environmental problems of concern here: population, technology, habitat, and species diversity. Our point is that the efficiency of regulatory systems can be substantially enhanced by incorporating economic incentives within them.

4.4.2 Incentive-Based Systems: Alternatives to Regulatory Control

The urgent need for alternative approaches to environmental management that are less costly and more efficient than traditional approaches has long been recognized (Baumol and Oates 1975). The major, but not only, alternatives suggested to the regulatory approach have been based on some form of economic incentives (Baumol and Oates 1975; Anderson et al. 1990).

The accumulating evidence suggests that the present regulatory approach to environmental management in the United States and throughout much of the Earth, though leaving us better off than we would have been without any management system, does not inspire confidence in its adequacy for addressing the twin challenges of explosive global population growth coupled with growing expectations of exponential increases in per capita consumption by the growing billions of passengers on spaceship Earth. We therefore emphasize that problems of achieving sustainable scale and distributional equity are basic to the human condition. Once these goals have been addressed, it becomes important to devise efficient instruments for accomplishing them. Unfortunately, it is inefficiency that characterizes most of the regulatory environmental control instruments now in place, though they have gained grudging acceptance. These shortcomings of the current regulatory approach are evident in the limited results from the excessive levels of bureaucracy and expenditures involved, compounded by the inadequate scientific basis for current programs. Reform efforts must therefore aim at improving the efficiency of environmental protection programs and the scientific basis upon which they rest. We turn first to the role of economic efficiency, and to its limitations.

4.4.2.1 The Role of Economic Efficiency

From the perspective of economic efficiency, the regulatory approach appears to be both cumbersome and costly. Indeed, now that most of the nations on Earth have rejected command and control methods in favor of competitive markets for guiding economic policy, it seems anachronistic to rely so heavily upon regulatory techniques for organizing environmental policy rather than attempting to reap in the policy arena some of the efficiency advantages that economic incentives have demonstrated in the organization of markets.

Proposals for economic incentive-based (IB) instruments for environmental management encompass a wide range of alternatives, including:

- Taxes on pollution emissions (Pigouvian taxes or charges).
- Product charges (levied on products whose use causes environmental damage, such as chlorofluorocarbons [CFCs], carbon fuels, agricultural chemicals, and fertilizers).
- Subsidies for pollution abatement (similar to taxes in concept but not in distributional consequences), especially for agriculture and sewage treatment.
- Marketable permits for pollution emissions.
- Creation of property rights for open access and other environmental resources.
- Creation of economic incentives for acting in the common interest.

Several themes run through the literature that advocate more extensive use of these IB instruments as alternatives or supplements to current regulatory policies. The most important is the achievement of economic efficiency through correction of market failures such as:

- Externalities, especially pollution.
- Open-access resources.
- Inadequate provision of public goods (because of nonexcludability and nondepletability).
- Poorly defined property rights.
- Uncertainty and incomplete information.
- Myopic time discounting.

Incentive-based instruments are designed to correct or offset these market failures as shown in the following.

4.4.2.2 Pollution Fees and Subsidies

The classic incentive-based alternative to regulation of pollution is a tax, fee, or charge per unit of pollution emitted, known as a Pigouvian tax after Pigou (1920). However, the intellectual foundation for the incentive approach is Adam Smith's concept of the invisible hand operating in free, competitive markets. In this model, which emphasizes economic efficiency, rational utilitarian consumers attempting to maximize utility, and competitive producers attempting to maximize profits, will automatically generate optimal allocation of scarce resources. Thus, free competitive markets are assumed to permit the pursuit of self-interest by producers and consumers to result in socially desirable outcomes, *except* where the (rigorous) conditions for competitive markets are not achieved and any of a number of well-defined market failures (listed earlier) are present.

The significance of this approach for environmental management is that if markets existed, or could be created, for ecosystem goods and services, consumers could purchase the types and quantities of environmental quality and sustainability they desired relative to their means and their competing wants, just as they do now for marketed goods and services. Obviously, for the true believer the market approach is a compelling one because if it could be made to work, it would effectively dispose of the environmental problem, which would then be reduced to a level of seriousness no greater than, say, of selecting one's household detergent. For readers interested in economic theory and graphics, a simple diagram typically found in texts on environmental economics (a version of which is presented and discussed in Figure 4.1) is provided.

4.4.2.3 Popular Critiques of the Incentives for Efficiency Approach

Given the strong theoretical case in favor of IB pollution controls (Cropper and Oates 1992), it is appropriate to inquire into the reasons for their low level of acceptance in the United States. Some objections to IB pollution controls are based upon popular misconceptions, myths, and imagery, and interest group pressures. Other objections to IB policies are more firmly based upon legitimate concerns, and merit thorough analysis. They include concerns about data requirements, spatial differentiation, gaps in scientific knowledge, and inadequate transdisciplinary research. These are valid objections, but they may also be raised with respect to regulatory instruments or any other environmental control instruments.

As we have discussed, a criticism to which economic efficiency policy instruments are vulnerable is that of inadequate sensitivity to issues of sustainability, equity, welfare, and fairness. Indeed, much of the economics literature explicitly accepts the dichotomy and trade-off between equity and efficiency, recognizing that although efficiency is the proper concern of economics, it generally speaks with less credibility about

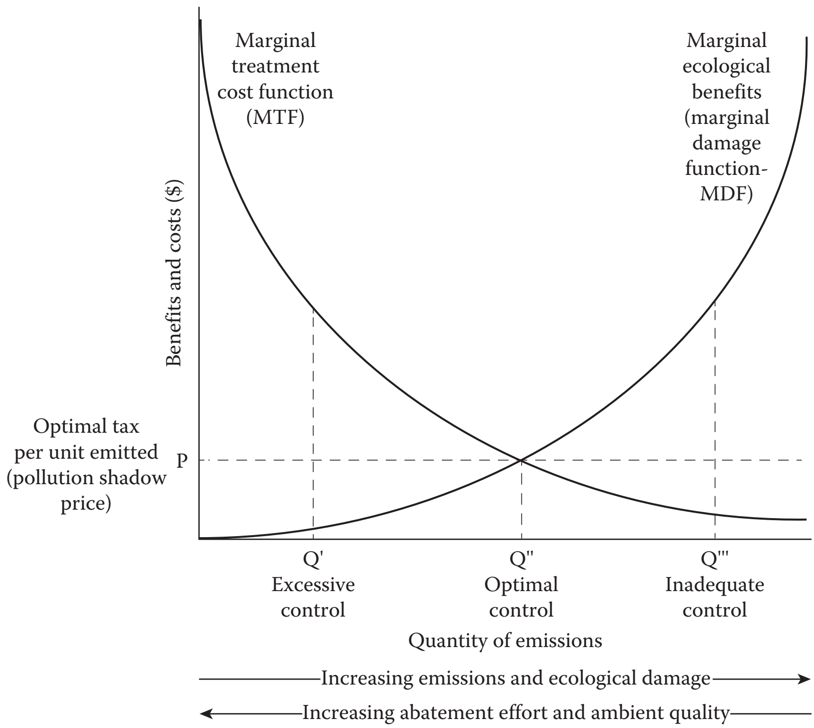

FIGURE 4.1
Optimal pollution control and environmental quality.

equity and has until recently ignored sustainability. We have noted, however, one principle dealing with equity that appears throughout the economics literature and that is relevant to policy analysis. This is the concept of Pareto fairness. This concept is drawn from the more general notion of Pareto optimality worked out by the Italian sociologist Vilfredo Pareto (1927), dealing with the necessary conditions for efficient general equilibrium solutions (Randall 1987). However, inherent in the more general case of Pareto optimality is the concept of Pareto fairness, which in its simplest form requires that changes in policies or other arrangements should not be undertaken unless they make some people (or even one person) better off without making any party worse off. Although this theorem has extensive and significant implications for the analysis of human welfare (Randall 1987), we only note here that policy changes are more likely to be acceptable and successful if they can be designed to make no one worse off.

This Pareto fairness principle is one reason for proposing that marketable pollution permits be given without charge to existing polluters, even though there may be objections to this course on efficiency and ethical grounds. The same principle can be used to justify compensating property owners at public expense for potential losses resulting from zoning changes, and for other "takings." Compensation, though costly to the public, may be a valid price to pay in other cases where the general welfare is improved by a policy change. These are all examples of the equity versus efficiency conflict emphasized earlier.

In terms of popular misconceptions, real and imaginary, opponents of incentive-based systems have persuaded large elements of the public that emission charges constitute a "license to pollute" and that this is somehow reprehensible. Actually both pollution charges and the current system of regulations represent "licenses to pollute," or property rights to pollute, but these rights now are *free* to the polluter in the case of the regulatory system and there are no dynamic incentives for polluters to reduce pollution below the currently permitted levels. The IB system would require payment for each unit of emission and thus would generate the appropriate continuous dynamic economic incentives to reduce pollution further, develop new pollution control technologies, and to generate public revenue that could be used for mitigation of the remaining pollution or for other public purposes.

In terms of interest group pressures, emitters object to emission charges because they would have to pay for the privilege of expropriating common property resources (the assimilative capacity of air and water), which they now enjoy without charge. Initially, the switch from free emissions to charges would amount to a transfer of income and wealth from emitters to the general public. The political and economic obstacles to such an innovation are obvious. In the long run, however, because the IB system leads to an improvement of economic efficiency, both the emitters and public would benefit. It is this initial short-run hurdle that must be overcome if IB systems are ever to be implemented.

One way of addressing this interest group problem, as noted earlier, would be to give, rather than sell, emission permits to present emitters. This has the ethical disadvantage of "grandfathering in" present polluters who would stand to benefit in direct proportion to the damage they are currently imposing upon the environment, but it also has the advantage of creating property rights that could generate incentives to reduce pollution in that unused permits could be sold, adding efficiency to the system thereafter (Cumberland 1990a).

In addition to the political and interest group objections to incentive-based pollution control methods, there are also substantive scientific problems of knowledge and uncertainty, especially in terms of optimizing approaches. Derivation of optimal pollution charges (Figure 4.1) requires knowledge of the marginal treatment cost function and the marginal damage functions. Conceptually, marginal treatment cost functions should be computable from engineering and other data (Cumberland and Kahn 1982). Computing marginal environmental damage functions is more difficult and involves at least three steps even in the simplest case of damage to a single species from a single pollutant at one point:

1. Estimating the reduction in ambient concentrations associated with reductions in emission levels.
2. Estimating biological damage functions associated with levels of ambient concentrations.
3. Assigning economic values to the relevant levels of biological damage.

Early assumptions by economists about the existence of damage functions for individual pollutants derivable by scientists from dose–response relationships and relevant for efficiency-based policy, appear to have been overly optimistic now that ecological economists are actually learning to develop transdisciplinary working relationships with physical scientists. Clearly, the more realistic case of multiple emission sites, multiple species, plus positive and negative synergism between multiple pollutants involves formidable problems of research, analysis, and uncertainty (Cumberland 1990a). The formal information requirements for deriving optimal water quality standards and optimal emission charges for ecologies as complex as estuaries are so demanding that they may never be fully met.

Epidemiological research on human exposure to toxic chemicals has revealed some of the limits of science in determining safe standards, given problems of gender, age, concentration, genetic heritage, synergism, and other variables. However, this situation need not preclude efforts to establish standards based upon best current scientific judgment. This is particularly essential in the case of multiple pollutants, as in an estuary, where interrelationships among toxic substances are most likely to be synergistic and nonlinear. In such cases, damage functions could be estimated on the basis of best current judgment for the total mix of pollutants, and average emission charges could be applied to the discharge of every pollutant. The use of economic incentives could provide a least-cost (i.e., cost-effective) route to achieving environmental goals however they are set and thus is not dependent upon achieving an improbable level of scientific certainty (i.e., optimization).

4.4.2.4 Advantages and Disadvantages of Incentive-Based Systems of Regulation

In a realistic, dynamic situation, the use of IB pollution charges has several potential efficiency advantages over regulation. The most important advantage is that there are differences in the costs of pollution control among firms and the regulatory approach gives inadequate incentives to abate for lower-cost firms. With an IB system, more modern firms with lower-cost pollution control technologies will undertake more abatement rather than pay the charges, while firms with higher pollution control costs will prefer to pay the charges rather than abate. Society will then obtain more pollution control at lower total costs than if all firms, including those with higher abatement costs, are required to impose the same level of control, as is typical under a regulatory approach.

Comparable cost savings and efficiency increases might be achievable in water pollution control as well. Under the effluent charges system, more of the total cleanup is performed by low-cost firms than is the case under regulation. The potential cost savings are greatest when there are significant differences in treatment costs among polluters. Incentives are greater for continual improvements in pollution abatement technology under a pollution charge system than under a regulatory system under which all firms abate equally or under which abatement technology is specified.

Under an alternative IB system based upon transferable pollution (TP) permits, firms have economic incentives to find cost-saving abatement technology because of the property rights they then have in their unused abatement permits, which can be sold to firms having higher cost abatement technologies. These cost-reduction incentives have the merit of shifting the marginal treatment cost curve downward and to the left (Figure 4.1), further increasing the optimal level of environmental quality. If competitive markets could be created for transferable pollution permits, their price per unit of emission would approximate the same shadow price as that for pollution charges (P in Figure 4.1).

Incentive-based pollution control policies have many other potential advantages over regulatory approaches:

1. They have the ethical advantage of consistency with the Organisation for Economic Co-operation and Development (OECD) "polluter pays" principle.
2. They raise public revenues.
3. They pass the cost of pollution control along to the consumer of pollution-intensive products, providing the public with the proper signals for modifying consumer behavior and imposing the costs of environmental damage upon those who cause it and those who benefit from it.
4. They provide polluters with economic incentives to prevent pollution, thus saving society the much greater cost of attempting to clean up the pollution after it occurs.
5. Marketable permits do not require that regulators have the level of technical proprietary information required for efficient regulation.

6. They can provide incentives for shifting the burden of monitoring from the government to the polluter.
7. They offer profitable opportunities for industry to undertake development projects for improvements in pollution abatement technology.
8. They can shift the incidence of tax burdens away from socially desirable objectives (incomes and jobs) toward reducing socially undesirable phenomena (pollution).

On the other side of the balance sheet, a number of substantive problems limit the applicability of the market approach to environmental management. Among the most serious are that market theory does not directly address the issues of:

1. Sustainable scale.
2. Income distribution, or equity, and therefore of unequal access to environmental protection among individuals, nations, regions, and generations.
3. Limitations of scientific information and of knowledge by individuals may impair their ability to make wise choices.
4. Additionally, the market failures that would need correction in order to make markets work for environmental quality are numerous and pervasive. They include externalities, excessive time discounting, common property resources, open-access resources, public goods, and noncompetitive markets.

Recognition in recent decades of the pervasiveness of market failures has resulted in much effort by economists to develop a wide range of compensatory methods for offsetting market failures. The conventional economic wisdom has been that, although market failures are serious impediments to economic efficiency, most markets are sufficiently robust that with the judicious application of corrective measures such as taxes on pollution, the overwhelming efficiency advantages of market economies can be retained and are well worth saving.

The major problem with the strictly efficiency-based economic approach to environmental management is that even if all market failures could be corrected or offset by compensating countermeasures such as pollution taxes, the resulting outcomes, though economically efficient, would not necessarily be universally perceived as an improved state of affairs. Society does not exist for or by economic efficiency alone. Though economic efficiency is important, and should be an element in any successful management approach, society will also insist upon the protection of other crucial, deep-seated values such as fairness, equity, scientific validity, democratic pluralism, and political acceptability. Therefore, one lesson that can be drawn from environmental management practices to date and from efforts to reform them is that unidimensional approaches, whether regulatory, efficiency-based, or science-dominated, have a low probability of success as compared to more broadly based, multiobjective, eclectic, transdisciplinary approaches. It is for this reason that ecological economists have developed a range of policy instruments that meet all of the aforementioned criteria of equity, efficiency, scientific validity, and political acceptability. Examples of policy instruments designed to meet these multiple public policy criteria are given in the following sections.

4.4.3 Three Policies to Achieve Sustainability

In this section, three fairly broad, interdependent proposals are described and discussed. Taken together, they would go a long way toward achieving sustainability. The market incentive-based instruments suggested to implement the policies are intended to do the job with relatively high efficiency and effectiveness. They are not the only possible mechanisms to achieve these goals, but there is considerable evidence that they could work rather well in certain cultural and legal circumstances. By focusing on specific policies and instruments, we can also address the essential changes that need to be made in the system and can begin to build a broad enough consensus to implement these changes.

Various aspects of the proposals have appeared in various other forms elsewhere (cf. Pearce and Turner 1989; Daly 1990b; Costanza 1991; Perrings 1991; Costanza and Cornwell 1992; Costanza and Daly 1992; Cropper and Oates 1992; Young 1992; Bishop 1993). This section represents an attempt to synthesize and generalize them as the basis for developing an "overlapping consensus" (Rawls 1987). A consensus that is affirmed by opposing theoretical, religious, philosophical, and moral doctrines is most likely to be fair and just and is also most likely to be resilient and to survive over time.

In summary, the policies are:

1. A broad natural capital depletion (NCD) tax to assure that resource inputs from the environment to the economy stay within planetary boundaries and are sustainable, while giving strong incentives to develop new technologies and processes to minimize impacts (Costanza and Daly 1992).
2. Application of the precautionary polluter pays principle (4P) to assure that the full costs of outputs from the economy to the environment are charged to the polluter in a way that adequately deals with the huge uncertainty about the impacts of pollution, including climate change, and encourages technological innovation (Costanza and Cornwell 1992).

3. A system of ecological tariffs (ETs) as one way (short of global agreements that are difficult to negotiate and enforce) to allow countries to implement the first two proposals without putting themselves at an undue disadvantage (at least on the import side) relative to countries that have not yet implemented them.

4.4.3.1 Natural Capital Depletion Tax

One way to implement the sustainability constraint of no net depletion of natural capital is to hold throughput (consumption of total natural capital) constant at present levels (or lower truly sustainable levels) by taxing natural capital consumption, especially energy, very heavily. Nobel Laureate Robert Solow has emphasized the importance of replacing depleted natural capital by an amount of human-made capital sufficient to maintain the aggregate social capital intact in order to ensure sustainability and intergenerational equity (Solow 1993). Not everyone would share Solow's optimism about the extent to which other forms of capital can be substituted for natural capital, but to the extent that this is feasible, a national capital depletion (NCD) tax would be an efficient instrument for achieving it. Society could raise most public revenue from such an NCD tax and could compensate by reducing the income tax, especially on the lower end of the income distribution—perhaps even financing a negative income tax at the very low end. Technological optimists who believe that efficiency can increase by a factor of ten should welcome this policy, which raises natural resource prices considerably and would powerfully encourage just those technological advances in which they have so much faith. Skeptics who lack that technological faith will nevertheless be happy to see the throughput limited because that is their main imperative in order to conserve resources for the future. The skeptics are protected against their worst fears; the optimists are encouraged to pursue their fondest dreams. If the skeptics are proved wrong and the enormous increase in efficiency actually happens, then they will be even happier (unless they are total misanthropists). They got what they wanted, but it just cost less than they expected and were willing to pay. The optimists, for their part, can hardly object to a policy that not only allows but offers strong incentives for the very technical progress on which their optimism is based. If they are proved wrong, at least they should be glad that the rate of environmental destruction has been slowed.

Implementation of this policy does not hinge upon the *precise* measurement of natural capital, but the valuation issue remains relevant in the sense that the policy recommendation is based on the perception that we are at or beyond the optimal scale. The evidence for this perception consists of the greenhouse effect, ozone layer depletion, acid rain, and the general decline in many dimensions of the quality of life. It would be helpful to have better quantitative measures of these perceived costs, just as it would be helpful to carry along an altimeter when we jump out of an airplane. But we would all prefer a parachute to an altimeter if we could take only one thing. The consequences of an unrestrained free fall are clear enough without a precise measure of our speed and acceleration. But we would need at least a ballpark estimate of the value of natural capital depletion in order to determine the magnitude of the suggested NCD tax. This, we think, is possible, especially if uncertainty about the value of natural capital is incorporated in the tax itself, using, for example, the refundable assurance bonding system discussed here.

The political feasibility of this policy is an important and difficult question. It certainly represents a major shift in the way we view our relationship to natural capital and would have major social, economic, and political implications. But these implications are just the ones we need to expose and face squarely if we hope to achieve sustainability. Because of its logic, its conceptual simplicity, and its built-in market incentive structure leading to sustainability, the proposed NCD tax may be the most politically feasible of the possible alternatives to achieving sustainability.

We have not tried to work out all the details of how the NCD tax would be administered. In general, it could be administered like any other tax, but it would most likely require international agreements or at least national ecological tariffs (as discussed shortly) to prevent some countries from flooding markets with untaxed natural capital or with products made with untaxed natural capital (see further on). By shifting most of the tax burden to the NCD tax and away from income taxes, the NCD tax could actually simplify the administration of the taxation system while providing the appropriate economic incentives to achieve sustainability (Box 4.6).

4.4.3.2 The Precautionary Polluter Pays Principle

One of the primary reasons for the problems with current methods of environmental management is the issue of scientific uncertainty. The issue is not just its existence, but the radically different expectations and modes of operation that science and policy have developed to deal with it. If we are to solve this problem, we must understand and expose these differences about the nature of uncertainty and design better methods to incorporate it into the policy-making and management process.

Problems arise when regulators ask scientists for answers to unanswerable questions. For example, the law may mandate that the regulatory agency come up with safety standards for all known toxins when little or no information is available on the impacts of these chemicals. When trying to enforce the regulations after they are drafted, the problem of true uncertainty about the impacts remains. It is not possible to determine

BOX 4.6 ENVIRONMENTAL TAXATION IN EUROPE AND THE UNITED STATES

During the past decade, European countries have continued to increase and refine their use of environmental tax instruments. Although taxes on motor fuels and motor vehicles generate about 90% of the revenue from environmentally related taxes in the European Union, European countries have designed taxes that target a broader array of tax bases, including plastic bags, landfill waste, aggregates, batteries, pesticides, fertilizer, sulfur dioxide, and greenhouse gas emissions not related to energy. In addition, their experience with taxes that have been in force for a number of years has allowed them to fine-tune the measures to increase their effectiveness—for example, by increasing tax rates and eliminating exemptions. The longer track record is starting to generate ex post facto evaluations that show numerous instances where the taxes have reduced pollution and the consumption of natural resources.

New taxes generate new revenues, giving governments the choice about how to use the new funding. A significant number of new environmental taxes in Europe—often CO_2/energy taxes—have adopted a revenue-neutral tax approach, often referred to as environmental tax reform, green tax shifting, or the double dividend. Instead of sending the revenues to the general fund or dedicating them to the environmental problem, the government simultaneously enacts a similar degree of fiscal relief from other existing tax burdens that may dampen economic activity, such as income and social security taxes on labor. Austria, Denmark, Finland, Germany, the Netherlands, Sweden, and the United Kingdom have formally adopted environmental tax reforms.*

The United States has followed a different path. The Clinton administration's proposed broad-based energy tax on the Btu content of fuels failed to pass Congress in 1993, and motor fuel taxes remain substantially below the European levels. In the United States, revenues from federal environmentally related taxes constituted 3.5% of total tax revenues in 2003, compared to an average of 7%

* *See* European Environment Agency, Market-based Instruments for Environmental Policy in Europe 41–49 (2006); European Environment Agency, Using the Market for Cost-effective Environmental Policy 7, 24–33 (2006); National Environmental Research Institute, The Use of Economic Instruments in Nordic and Baltic Environmental Policy 2001–2005, at 9–12, 225–26 (2006).

for the OECD countries and highs of 10% in Denmark and 16% in Turkey.*

In recent years, federal environmental tax policies in the United States have tended to focus on creating tax credits and tax deductions for targeted activities that have an environmentally positive effect, rather than sending negative price signals for environmentally damaging activities. The Energy Policy Act of 2005, the first major piece of energy legislation since the early 1990s, relied heavily on tax incentives to execute federal policy. It created short-term benefits for energy conservation investments, such as an income tax deduction for energy efficient lighting, heating and cooling systems installed in commercial buildings and an income tax credit for alternative-fuel vehicles linked to fuel economy. In the electricity-generating sector, it created incentives for alternatives to traditional coal-burning plants, including a tax credit for utilities that produce electricity from coal using technology that will lower emissions and an extension of tax credit for electricity produced from wind power for wind farms.

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* OECD database on instruments used for Environmental Policy and Natural Resources Management, http://www.oecd.org (Oct. 2006).

with any certainty whether the local chemical company contributed to the death of some of the people in the vicinity of their toxic waste dump. One cannot prove the smoking/lung cancer connection in any direct, causal way (i.e., in the courtroom sense), only as a statistical relationship.

As they are currently set up, most environmental regulations, particularly in the United States, *demand certainty*, and when scientists are pressured to supply this nonexistent commodity, there is not only frustration and poor communication but mixed messages in the media as well. Because of uncertainty, environmental issues can often be manipulated by political and economic interest groups. Uncertainty about climate change is perhaps the most visible current example of this effect.

The "precautionary principle" is one way the environmental regulatory community has begun to deal with the problem of true uncertainty. The principle states that rather than await certainty, regulators should act in anticipation of any potential environmental harm in order to prevent it. The precautionary principle is so frequently invoked in international environmental resolutions that it has come to be seen by some as a basic normative principle of international environmental law (Cameron and Abouchar 1991).

Implementing this view of science requires a new approach to environmental protection that acknowledges the existence of true uncertainty rather than denying it, and includes mechanisms to safeguard against its potentially harmful effects, while at the same time encouraging development of lower impact technologies and the reduction of uncertainty about impacts. The precautionary principle sets the stage for this approach, but the real challenge is to develop scientific methods to determine the potential costs of uncertainty and to adjust incentives so that the appropriate parties *pay* this cost of uncertainty and have appropriate incentives to reduce its detrimental effects. Without this adjustment, the full costs of environmental damage will continue to be left out of the accounting (Peskin 1991), and the hidden subsidies from society to those who profit from environmental degradation will continue to provide strong incentives to degrade the environment beyond sustainable levels (Cameron and Abouchar 1991).

Over the past decades, there has been extensive discussion about the efficiency that can theoretically be achieved in environmental management through the use of market mechanisms (Brady and Cunningham 1981; Cropper and Oates 1992). These mechanisms are designed to alter the pricing structure of the present market system to incorporate the total, long-term social and ecological costs of an economic agent's activities. Suggested incentive-based mechanisms, in addition to pollution taxes, and tradable pollution discharge permits discussed earlier, include financial responsibility requirements and deposit–refund systems. Dealing with the pervasive uncertainty inherent in environmental problems in a precautionary way is possible using some new versions of these incentive-based alternatives.

One incentive-based instrument to manage the environment for precaution under uncertainty is a *flexible environmental assurance bonding system* (Costanza and Perrings 1990). This variation of the deposit–refund system is designed to incorporate *both* known and uncertain environmental costs into the incentive system and to induce positive environmental technological innovation. It works in this way: in addition to charging an economic agent directly for known environmental damages, an assurance bond equal to the current best estimate of the largest potential future environmental damages would be levied and kept in an interest-bearing escrow account for a predetermined length of time. In keeping with the precautionary principle, this system requires the commitment of resources *now* to offset the potentially catastrophic future effects of current activity. Portions of the bond (plus interest) would be returned *if and when* the agent could demonstrate that the suspected worst-case damages had not occurred or would be less than originally assessed. If damages did occur, portions of the bond would be used to rehabilitate or repair the environment and possibly to compensate injured parties. Funds tied up in bonds could continue to be used for other economic activities. The only cost would be the difference (plus or minus) between the interest on the bond and the return that could be earned by the firm had they invested in other activities. On average one would expect this difference to be minimal. In addition, the “forced savings” that the bond would require could actually improve overall economic performance in economies such as that of the United States, which chronically undersaves.

By requiring the users of environmental resources to post a bond adequate to cover uncertain future environmental damages (with the possibility for refunds), the burden of proof (and the cost of the uncertainty) is shifted from the public to the resource user. At the same time, agents are not charged in any final way for uncertain future damages and can recover portions of their bond (with interest) in proportion to how much better their performance is than the worst case.

Deposit–refund systems, in general, are not a new concept. They have been successfully applied to a range of consumer, conservation, and environmental policy objectives (Bohm 1981). The most well-known examples are the systems for beverage containers and used lubricating oils that have both proven to be quite effective and efficient. Another precedent for environmental assurance bonds are the producer-paid performance bonds often required for federal, state, or local government construction work. For example, the Miller Act (40 U.S.C. 270), a 1935 federal statute, requires contractors performing construction contracts for the federal government to secure performance bonds. Performance bonds provide a contractual guarantee that the principal (the entity that is doing the work or providing the service) will perform in a designated way. Bonds are frequently required for construction work done in the private sector as well.

Performance bonds are frequently posted in the form of corporate surety bonds, which are licensed under various insurance laws and, under their charter, have legal authority to act as financial guarantee for others. The unrecoverable cost of this service is usually 1%–5% of the bond amount. However, under the Miller Act (FAR 28.203-1 and 28.203-2), any contract above a designated amount ($25,000 in the case of construction) can be backed by other types of securities, such as U.S. bonds or notes, in lieu of a bond guaranteed by a surety company. In this case, the contractor provides duly executed power of attorney and an agreement authorizing collection on the bond or notes if they default on the contract (PRC Environmental Management 1986). If the contractor performs all the obligations specified in the contract, the securities are returned to the contractor and the usual cost of the surety is avoided.

Environmental assurance bonds would work in a similar manner (by providing a contractual guarantee that the principal would perform in an environmentally benign manner) but would be levied for the current best estimate of the *largest* probable potential future environmental damages. Funds in the bond would be invested and would produce interest that could be returned to the principal. An "environmentally benign" investment strategy would probably be most appropriate for a bond such as this.

These bonds could be administered by the regulatory authority that currently manages the operation or procedure (e.g. in the United States the EPA could be the primary authority). But a case can be made that it is better to set up a completely independent agency to administer the bonds. The detailed design of the institutions to administer the bond is worthy of considerable additional thought and analysis and will depend on the details of the particular situation (see further on).

The bond would be held until the uncertainty or some part of it was removed. This would provide a strong incentive for the principals to reduce the uncertainty about their environmental impacts as quickly as possible, either by funding independent research or by changing their processes to ones that are less damaging. A quasi-judicial body would be necessary to resolve disputes about when and how much refund on the bonds should be awarded. This body would utilize the latest independent scientific information on the worst-case ecological damages that could result from a firm's activities but with the burden of proof falling on the economic agent that stands to gain from the activity, not on the public. Protocol for worst-case analysis already exists within the EPA. In 1977, the U.S. Council on Environmental Quality required worst-case analysis for implementing the National Environmental Protection Act of 1969 (NEPA). This required the regulatory agency to consider the worst environmental consequences of an action when scientific uncertainty was involved (Fogleman 1987).

One potential argument against the bond is that it would select for relatively large firms that could afford to handle the financial responsibility of activities that are potentially hazardous to the environment. This is true, but it is exactly the desired effect because firms that *cannot* handle the financial responsibility should *not* be passing the cost of potential environmental damage on to the public. In the construction industry, small "fly-by-night" firms are prevented (through the use of performance bonds) from cutting corners and endangering the public in order to underbid responsible firms.

This is not to say that small businesses would be eliminated—far from it. They could either band together to form associations to handle the financial responsibility for environmentally risky activities or, preferably, they could change to more environmentally benign activities that did not require large assurance bonds. This encouragement of the development of new environmentally benign technologies is one of the main attractions of the bonding system, and small, start-up firms would certainly lead the way.

The individual elements of the 4P system have broad theoretical support and have been implemented before in various forms. The precautionary principle is gaining wide acceptance in many areas where true uncertainty is important. Incentive-based environmental regulation schemes are also gaining acceptance as more efficient ways to achieve environmental goals. For example, the U.S. Clean Air Act reauthorization contains a tradable permit system for controlling air pollution. Both the precautionary and the polluter pays principles are also incorporated in Agenda 21, the final resolutions of the 1992 United Nations Conference on Environment and Development (AGENDA 21 1992). By linking these two important principles, we can begin to effectively deal with uncertainty in an economically efficient and ecologically sustainable way.

In a sense, we are already moving in the direction of the 4P system. As strict liability for environmental damages becomes more the norm, farsighted firms have already started to protect themselves against possible future lawsuits and damage claims by putting aside funds for this purpose. The 4P system is, in effect, a *requirement* that all firms be farsighted. It is an improvement on strict liability because it:

1. Explicitly moves the costs to the present, where they will have the maximum impact on decision making. (Costanza and Shrum, 1988).
2. Provides "edge-focused, second-order scientific" assessments of the potential impacts from a comprehensive ecological economic perspective in order to ensure that the size of the bond is large enough to cover the worst-case damages.
3. Ensures that appropriate use of the funds is made in case of a partial or complete default.

Because of its logic, fairness, efficiency, ability to implement the precautionary and polluter pays principles in a practical way, and use of legal and financial mechanisms with long and successful precedents, the 4P system promises to be both practical and politically feasible. We think it can do much to help head off the current environmental crisis before it is too late.

4.4.3.3 Ecological Tariffs: Making Trade Sustainable

If all countries in the world were to adopt and enforce the 4P system and NCD taxes, there would be no problem (at least from an ecological point of view) in allowing "free" trade. Given recent commitments of the global community to the idea of sustainable development (AGENDA 21 1992), it does not seem totally out of the question that a global agreement along these lines could someday be worked out. But in the meantime, there are alternative instruments that could allow individual countries or trading blocks to apply the 4P system and NCD taxes in their local economies without forcing producers overseas to do so. It is within at least the spirit of the General Agreement on Tariffs and Trade (GATT) guidelines to allow countervailing duties to be assessed to impose the same ecological costs on internally produced and imported products. The key is fairness. A country cannot impose duties on imports that it does not also impose on domestically produced products. But if a country chose to adopt the 4P and NCD tax systems domestically, it could also adopt a system of ecologically based tariffs that would impose equivalent costs on imports. This is a different use for tariffs than the usual one. In the past, tariffs have been used to protect domestic industries from foreign competition. The proposed (and more defensible) use of tariffs (in conjunction with the 4P and NCD taxes) is to protect the domestic (and global) environment from private polluters and nonsustainable resource users, regardless of their country of origin or operation. The mechanisms for imposing tariffs are well established. All that we are changing is the motive and the result. The proposed ecological tariffs would result in patterns of trade that do not endanger sustainability.

4.4.4 Toward Ecological Tax Reform

Taken together, the three policy instruments suggested earlier (NCD taxes, the 4P, and ETs) would go a long way toward assuring ecological sustainability, while at the same time taking advantage of market incentives to achieve this result at high efficiency. They represent components of what is coming to be called "ecological tax reform."

There is a growing consensus among a broad range of stakeholder groups in the United States, and even more so in Europe, concerning the need to reform tax systems to tax "bads" rather than "goods." Taxes have significant incentive effects that need to be considered and utilized more effectively. The most comprehensive proposed implementation of this idea is coming to be known under the general heading of "ecological tax reform" (Costanza and Daly 1992; Passell 1992; Repetto et al. 1992; von Weizsäcker and Jesinghaus 1992; Hawken 1993). Earlier discussions of similar schemes were given by Page (1977), who considered a national severance tax, and Daly (1977), who discussed a depletion quota auction.

The basic idea is to limit the throughput flow of resources to an ecologically sustainable level and composition, thus serving the goal of a sustainable scale of the economy relative to the ecosystem, a goal that was neglected until recently. The more traditional goal of efficient allocation of resources is also served by this instrument because it raises the tax on bads and lowers the tax on goods—it internalizes externalities in a blunt general way, without getting stuck in the informational tar baby of calculating Pigouvian taxes and fretting over "second best" problems. The third goal of distributive equity is helped as well as hindered. Because the throughput tax is basically a capturing for public purposes of the scarcity rent to natural capital as economic and demographic growth increases its value, it has some of the equity appeal of Henry George's rent tax. However, like all consumption taxes, it is regressive. This could be counteracted by retaining a zero tax bracket for very low incomes and a progressive income tax structure for the rest of the population. Of the three major goals of economic policy (sustainable scale, efficient allocation, and just distribution), ecological tax reform serves the first two quite well and the third partially, requiring some supplement from a progressive income tax structure.

The idea is to gradually shift much of the tax burden away from "goods" such as income and labor and toward "bads" such as ecological damages and consumption of nonrenewable resources. Such a shift would have far-reaching implications and should simultaneously encourage employment and ecological sustainability.

There are three basic problems that need to be addressed:

1. *The research problem*. What would be the quantitative effects of various forms of ecological tax reform on the three policy goals discussed above? Would it significantly induce efficient resource-saving technologies? Would that raise or lower employment? What taxes would most effectively limit scale? How close can we come to the efficient and equitable ideal of taxing mainly rent? What are the implications for international trade of raising revenue by ecological taxes rather than income taxes?
2. *The communication problem*. How do we adequately develop and communicate with the relevant stakeholder groups the options for ecological tax reform and their implications?
3. *The political problem*. How could such an idea be implemented in the current political climate?

We believe that these three problems are best addressed in an integrated and coordinated manner, as described earlier.

The time for action is running short—especially to prevent climate disruption, but the political will to implement significant changes seems to be finally at hand. The tax reforms suggested embody the mix of environmental protection and economic development potential necessary to make them politically feasible. The next steps are to further elaborate and test the instruments and to build a broad, overlapping consensus to allow their ultimate implementation. It is not too late to protect our natural capital and to achieve sustainability.

4.4.5 A Transdisciplinary Pollution Control Policy Instrument

As pointed out earlier, when economists deal with common environmental issues but analyze these issues with the use of models that are both differing and partial, they may arrive at conflicting policy prescriptions. Earlier we emphasized the complexity of these issues and the need to find common ground. In moving on from policy prescriptions to policy instruments for implementing policies, it is therefore not surprising to find economists in disagreement (e.g., pollution taxes vs. tradable permits) not only among themselves, but—more to the point—in disagreement with ecologists (nature sanctuaries vs. ecotourism), who in turn are opposed by regulators who prefer a bureaucratic command-and-control structure. If sustainable development is to be achieved, the need to find common ground is compelling. This section suggests how the search for common ground might contribute to the design of a policy instrument for pollution control.

The proposed transdisciplinary framework, which supplements economic insights through a team approach by explicitly including concepts from ecology and the physical sciences as well as concerns for equity, distribution, and political feasibility, is illustrated in Figure 4.2 (Cumberland 1994).

This model is proposed as an alternative to the purely economic model, which is predicated upon marginal damage and treatment cost functions whose intersection yields a single uniquely efficient level of pollution tax, treatment, and environmental quality. In contrast, the proposed approach recognizes three separate ranges of environmental quality or levels of ecological health, each with its appropriate policy measure. The model allows for a range, band, or zone of low levels of emissions within which damage is too low to measure or too low to reduce the productivity of the system. Until emissions and concentrations of pollutants reached a level at which damage could be detected, emitters would be permitted to release waste within legal limits without charge as under the present practice in the United States. This is termed the property right zone. For equity reasons, emitters are not taxed for emission levels below which (1) no damage occurs, (2) no accumulation results, and (3) ecological productivity is not impaired. Here emissions fall well within the assimilative capacity of the environment. Within this range or band of emissions, the marginal cost of monitoring and administration would probably exceed marginal ecological damage and thus not justify the expense of administration costs.

The next level of policy concern is that at which ecological criteria indicate that pollution emissions and concentrations have measurably damaged the environment and threatened the productivity of the system. Within this emission range, a pollution charge, calibrated

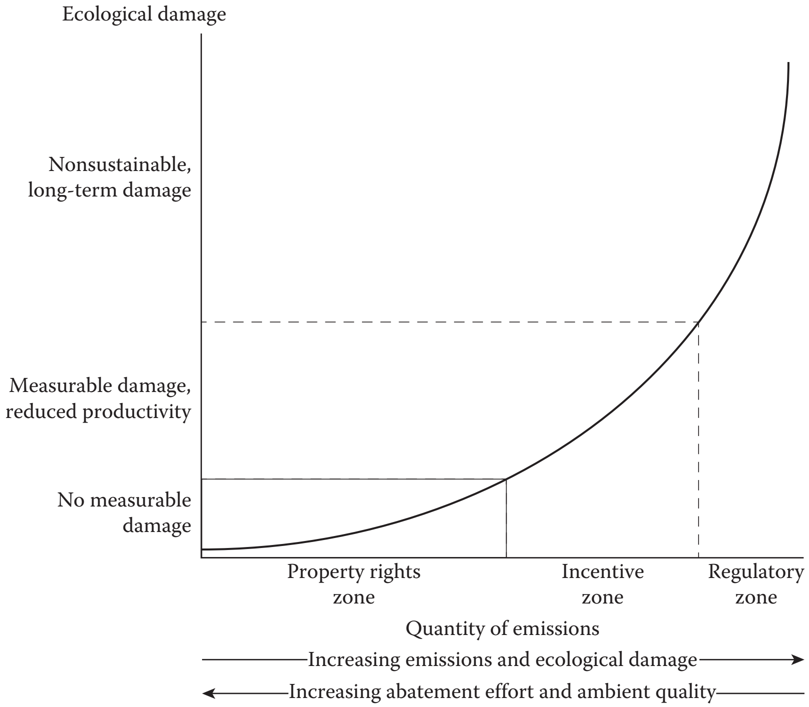

FIGURE 4.2
An ecological economic approach to pollution control. (From Cumberland, J. H., *Toward sustainable development: Concepts, methods and policy*, Island Press, Washington, DC, 1994.)

like the optimal tax in Figure 4.1, and set at a level sufficient to prevent transgressing into the cumulative damage zone, is imposed upon each additional unit of pollution emitted. This is termed the incentive range because the pollution tax is used as an economically efficient measure for confronting emitters with financial incentives to reduce pollution to efficient levels, as in Figure 4.1. Despite an understandable reluctance by regulators to place exclusive reliance on financial incentives, establishing an incentive range or band could serve the important goal of achieving the highest level of environmental safety per unit of social cost. The establishment of an incentive zone also creates a discrete threshold within which emitters are given the incentives to limit their emissions to nondamaging, assimilable levels. The central importance of the incentive zone here and of IB policies in general is that they apply the powerful forces of competition to the reduction of pollution through economic rewards to those who act in the public interest. Thus, they shift entrepreneurial talents away from regulatory evasion toward efficient, less entropic technical improvement. Within these first two management bands, the proposed instrument is similar to a Pigouvian tax.

However, even the ability and willingness to pay pollution taxes should not permit the privilege of purchasing rights to unconstrained emissions beyond ecologically acceptable limits. A third level of policy concern is therefore reached when pollution emissions and concentrations threaten to rise to the point that ecological criteria indicate irreversible, nonsustainable damage to the system. This is the regulatory zone because at this threshold, the option of pollute-and-pay would be superseded by regulatory prohibition of any further increases in emissions. Although an efficient pollution tax would have been designed to preclude taxed emissions from reaching an unsustainable level, back-up regulatory authority would serve as a safeguard against miscalculation and uncertainty.

There is an efficiency disadvantage in the proposed approach. Strict efficiency requires that each unit of emission be taxed at the same rate. However, in this proposal, those emitting within a no-damage range could continue to emit at initial levels even after new emissions pushed the total into the taxable incentive range. This equity–efficiency trade-off in the incentive zone is introduced in order to provide a measure of protection to existing firms against the possible impact of future entrants having greater market power. Also, the absolute cutoff of further emissions once the regulatory range has been reached would preclude the entry of new, more efficient firms.

Both the equity and efficiency goals, however, could be served by a variant of this tripartite approach, using tradable permits instead of charges. Provided that markets could be established for them, permits would be issued without charge in the property right range of no measurable damage. After the threshold of measurable damage was crossed, additional permits would be offered for sale on the open market, but their number would be limited to a level set by ecological criteria to prevent irreversible damage and transgression into the regulatory range. Therefore, additional emission permits would not be available at any price once the regulatory range had been reached. Economic efficiency would automatically result from the equilibrium price of permits set by bidders in the market.

Thus, limitations on sales of marketable permits to ecologically safe levels combine the best features of regulation and economic incentives. The option of selling emission permits in competitive markets would automatically allow new and technologically efficient producers to emerge and to phase out those more pollution intensive producers but only if the latter found this to be an attractive option. Resale of permits would also automatically adjust markets for inflation, unlike Pigouvian emission charges, which would require administrative action for efficient response to price level changes. In fact, transferable permits for emissions in all ranges would have efficiency advantages over limiting charges to the incentive range by permitting new, efficient emitters to purchase permits and by requiring all emitters to pay the same price per unit of emission rather than merely cutting off all new emissions beyond the efficiency limit.

4.4.5.1 Cap and Trade

Identifying and imposing strict resource and emission caps is vital for a sustainable economy. The contraction and convergence model developed for climate-related emissions should be applied more generally. Declining caps on throughput should be established for all nonrenewable resources. Sustainable yields should be identified for renewable resources. Limits should be established for per capita emissions and wastes. Effective mechanisms for imposing caps on these material flows should be set in place. Once established, these limits need to be built into the macroeconomic frameworks.

Ownership of the quotas is initially public; the government auctions them to individuals and firms. The revenues go to the Treasury and could be used to replace regressive taxes, such as the payroll tax, and to reduce income tax on the lowest incomes, or else to increase investments in public goods or energy efficiency measures that benefit the poor. Once purchased at auction, the quotas can be freely bought and sold by third parties, just as can the resources whose rate of depletion they limit. The trading allows efficient allocation, the auction serves just distribution, and the cap serves the goal of sustainable scale. However, free trading threatens speculative investments and other forms of gaming the market to capture rent. More frequent auctions of permits that could not subsequently be traded could avoid this risk. The same logic can be applied to limiting the off-take from fisheries and forests. With renewables, the quota should be set to approximate sustainable yield. For nonrenewables, sustainable rates of absorption of resulting pollution or the rate of development of renewable substitutes may provide a criterion (Daly 2010). It is worth noting that in a survey conducted in Vermont, only 5.8% of respondents favored distributed revenue equally among households; 64.2% favored investing it in natural resources, 14.2% favored investing it public goods such as education and healthcare, and the remainder favored some mix of dividends and public investments (Kirk 2010).

The idea of a carbon tax and other pollution taxes as a replacement for payroll taxes has gotten political support. It has been recognized that it makes more sense to tax what we burn instead of what we earn (Barnes and McKibben 2010). A very popular method, the Alaskan Permanent Fund, pays a dividend to the citizens of Alaska from the fossil fuel revenue the state collects (Barnes and McKibben 2010). This model is known as "cap and dividend," "where some fraction of the revenues of an auction on emissions allowance is returned to citizens on an equal per capita basis"

(Kunkel and Kammen 2011). However, in the case of fossil fuel use, where prices are determined at the global level, and not influenced by extraction rates in any single state, this leads to citizen pressure to "drill, baby, drill," increasing outputs and revenue. In the case of cap and auctions on emissions, local caps would determine prices. Given the highly inelastic demand for fossil fuels (and hence for the waste absorption capacity for CO_2), the tighter the cap, the greater the total revenue, since every 1% restriction in quantity would lead to a greater than 1% increase in price.

Cap and dividend is considered by some to be a fair and transparent model because it is based on the amount of carbon-based energy a person consumes. The more a person consumes, the more he/she would have to pay. It would also have a progressive distributional effect; poor people usually consume less energy than the middle class and the rich (Kunkel and Kammen 2011). For cap and dividend to work, there would have to be a cap on fossil fuel supplies. It is much easier and more cost-effective to have an economy-wide cap on suppliers than emitters. Companies that sell fossil fuel would have to buy permits equal to the carbon content of the fuels they sell. Then, once a year there would be an auditing to make sure the companies have enough permits; if they do not, they would have to pay a high penalty. The number of permits would be reduced every year, decreasing the amount of carbon that enters the economy. As the carbon cap declined, prices would increase and private capital would shift to cleaner alternative technologies and cleaner production and consumption.

Another important element of this model is the dividend, which would be paid equally to every American once a month. As carbon prices increase, so would the dividend, and this in turn would increase the livelihoods of the poor (Barnes and McKibben 2010; Kunkel and Kammen 2011).

However, from a global perspective, a cap and dividend regime in the United States or another wealthy country may be unfair. Both Europe's existing cap and any of the proposed caps in the United States far exceed a fair share of global absorption capacity and completely fail to account for past contributions to the carbon stock. As discussed previously, reducing flows to ecologically sustainable levels in the short run would likely cause economic collapse, with the worst impacts likely to be borne by the poor. Perhaps the most sustainable, fair, and efficient approach would be for rich countries to invest revenue in making existing infrastructure more energy efficient and in new, open-source technologies for alternative energy and energy efficiency. This would be more sustainable because it would accelerate the rate at which we develop new technologies and reduce emissions. It would be more fair because it would put the burden of developing new technologies on the wealthy countries, and because the poor would likely benefit most from more energy efficient housing and infrastructure. And it would be more efficient because information is nonrival and should therefore be open access to all, which requires public sector investment, as explained earlier. Currently, the United States energy sector invests only 0.03% of sales in R&D, which is clearly inadequate given the importance of developing low carbon energy (Coy 2010).

A variation on the cap-auction-trade mechanism is the commons asset trust, for example, the Earth Atmospheric Trust described earlier (Barnes et al. 2008). In this mechanism, as in the cap-auction-trade, caps are established around a resource. However, in this case a trust manages the sale of permits and the revenue from the auction. It can adjust the availability of permits, depending on need, though ultimately resource use cannot exceed planetary boundaries. The trust would provide equal dividends to the citizens (in a national system) or to countries for distribution to their populations (in an international system), or else invest revenues in public goods. The benefit of providing dividends directly to the population is that it provides some mitigation to the inevitable price increases passed down to consumers (Barnes and McKibben 2010). However, households and businesses frequently fail to adopt energy efficiency measures with high rates of return (Nauclér et al. 2009). This may be especially true for poor households that lack the resources, knowledge, and initiative required to undertake such investments. Recycling revenue into energy efficiency investments with high rates of return would effectively increase total benefits and could therefore benefit poor households even more than dividends.

An alternative and intermediate option is also available by returning some fraction of the annual revenues as dividends to the population but using the remainder for other purposes related to preserving and enhancing the common assets, such as atmosphere and climate. This would allow for rewarding people that have a lower carbon footprint as well as for providing funds for related projects such as researching and developing renewable energy, deploying renewable energy technologies in developing countries, paying for ecosystem services like carbon sequestration, and so forth (Costanza and Farley 2010).

National environmental policies nearly all result in internalizing previously uncounted ecological and social costs. This naturally increases prices relative to those in countries that do not internalize these costs, putting domestic firms at a competitive disadvantage in international trade if the country's international policy is free trade. In this case, national and international policies are inconsistent. An international policy consistent with national cost internalization would require moving away from free trade by imposing cost-equalizing tariffs on imports produced under conditions that do not internalize these costs. This is protection, to be sure—but it is protection of an efficient national policy of cost internalization not protection of an inefficient national firm. Without such protection, or international agreement on cost-internalizing measures, there would be a competitive, cost-externalizing race to the bottom. Globalization (free trade coupled with free capital mobility) seeks to substitute the transnational corporation for the nation as the controlling economic power. Existing traditional community at the national level is sacrificed to the abstraction of a very tenuous "global community."

4.4.5.2 Implementation and Operational Considerations

Clearly, practical problems would have to be faced in implementing these proposals, depending upon local and other conditions. In deriving the damage and treatment cost functions, difficult decisions would have to be made concerning multiple pollutants, multiple species affected, and multiple spatial jurisdictions, depending upon the availability of data and knowledge. For example, Tietenberg has discussed techniques for dealing with multiple sources and multiple receptors of pollution damage (1988). Fine tuning would require different tax levels appropriate spatially and temporally for different pollutants, again depending upon the state of data and knowledge. Given the limitations of scientific knowledge and the extent of uncertainty, a pragmatic approach could require simply proceeding on the basis of scientific consensus concerning the best current information. Given problems of assessing the differential impacts and synergisms among different pollutants, simple estimates of relative toxicity could serve as the basis for setting pollution charges or permit fees subject to the accumulation of additional data. Monitoring and enforcement would be essential. Nevertheless, it must be emphasized that these imperatives are just as compelling for all environmental management systems, including those now in place.

Some of the features of this proposal would be precluded in places where pollutants were already causing measurable damage, which is unfortunately already the case in much of the world. In such instances, the property right zone would be forfeited and pollution taxes would become relevant on all emissions. Rates on these taxes could then be increased to keep damages within the incentive range and prevent spillover into the nonsustainable damage range. Where nonsustainable damage has already occurred, drastic regulatory and punitive (negative incentive) action is justified. Examples include the fines and damage judgments incurred from oil spills and the damage assessments against hazardous waste disposal under the U.S. Superfund program (Kopp and Smith 1993).

It should be noted that a variant of this approach has already been applied in the Netherlands (Anderson et al. 1990). Farmers are permitted to discharge the manure equivalent of 125 kg of phosphate per hectare per year without charge. However, beyond that level, they are then charged the equivalent of 0.1 ECU ($0.11) per kg from 125 to 200 kg per hectare. Above 200 kg, the charge increases progressively to 0.2 ECU ($0.22) per kg per hectare per year, with a typical charge per farm of about

730 ECU ($810) annually. This innovative policy instrument, though similar in many respects to the tripartite approach suggested in this chapter, utilizes in place of a regulatory level of capped maximum discharges a level of increased emission charges at twice that in what is termed here the incentive zone. The two approaches can be made to converge formally by raising the emission charge in the zone of unacceptable damages to a prohibitively high level. Like the proposals here, the practice in the Netherlands diverges from the strict efficiency rule of taxing each unit of emission at the same price in order to provide some equity consideration to emitters.

In recent years, an increasing number of countries have introduced a carbon tax in order to achieve a low-emission carbon economy. These efforts include (1) state-based actions (UK), (2) national-based actions (European Union), (3) province-based actions (Canada), and (4) sector-based actions (Japan on fossil fuels; India on coal; New Zealand on forestry, stationary energy, transport, liquid fossil fuel, and industrial processes; Ireland on oil and gas; Costa Rica on hydrocarbon fuels, among others). Other countries are planning to introduce a carbon tax in the near future including China (state-based), Brazil (in Rio de Janeiro) (SBS 2013), and Dominican Republic (sector-based).

4.5 Examples of Policies, Instruments, and Institutions

4.5.1 Expanding the "Commons Sector"

Most resource allocation done today is through markets, which are based on private property rights. Private property rights are established when resources can be made "excludable," that is, one person or group can use a resource while denying access to others. However, many resources essential to human welfare are "nonexcludable," meaning that it is difficult or impossible to exclude others from benefiting from these resources. Examples include oceanic fisheries (particularly those beyond the economic exclusion zone), timber from unprotected forests, and numerous ecosystem services, including the waste absorption capacity for unregulated pollutants. A proposed Earth Atmospheric Trust could help to massively reduce global carbon emissions while also reducing poverty (Box 4.7). This system would comprise a global cap-and-trade system for all greenhouse gas emissions (preferable to a tax, because it would set the quantity and allow the price to vary); the auctioning of all emission permits before allowing trading among permit holders (to send the right price signals to emitters); and a reduction of the cap over time to stabilize atmospheric greenhouse gas

BOX 4.7 THE WORLD BANK'S RETREAT FROM DIRECT POVERTY REDUCTION AND BACK TO TRICKLE-DOWN INFRASTRUCTURE GROWTH

The World Bank is backing off sustainable development and instead is now refocusing on infrastructure and growth—this time, an undefined "responsible" growth. They are reverting to depending on the trickle-down theory* of big infrastructure. That means less direct poverty reduction by the soft sectors, such as education, health, and nutrition. The bank prefers infrastructure and so do the industrial countries that get most of the procurement benefits. Certainly, infrastructure is needed to raise output for domestic processing, for job creation, and to facilitate development. But the bank's contribution to infrastructure is minuscule, whereas its erstwhile poverty reduction can make a big difference. The private sector often builds infrastructure (e.g., factories) better than the bank/government can.

If "responsible growth" meant prudence and care by ensuring social and environmental quality, or clear responsibility for the poor and their environment, there would be some merit in the concept. But the opposite seems more likely. The decadal gutting of the social and environmental safeguard policies is almost complete. The two 1993 energy policy papers promoting energy conservation and renewable energy, least-cost planning, transparency, and emphasis on demand-side management have been demoted. They were rarely complied with but now are no longer policies. The World Bank's 1995 "Carbon Backcasting" study found that had the cost of carbon emissions been set above zero, renewable energy would have burgeoned and coal loans would have been phased out. The 1999 "Fuel for Thought: Environmental Strategy for the Energy Sector" although weak on environment, also was ignored. The 2000 World Commission on Dams (WCD) recommendations to phase down

* "Trickle-down" is a theory of economic development, according to the *Dictionary of Economics* (Rutherford 2000), which asserts that "….development follows the traditional growth patterns with the richest benefiting first and most, with prosperity coming only gradually and last to where it is needed most—the poorest members of society." Trickle-down also has been used to suggest that the spending of the rich raises the incomes of the poor. Trickle-down prevailed almost unquestioned until about the 1980s–1990s, when it was realized that although it may occasionally have worked to a limited extent, it was exceedingly indirect in alleviating poverty (which had been stagnant or barely reduced by trickle-down until the early 2000s in many developing countries; Asia is the only exception). In addition, trickle-down did nothing to reduce income inequality and may even have exacerbated it.

big dams have been dismissed and reversed. The bank actively pressured governments to reject WCD's findings. Big dam lending resumed a year later, and big high-risk water projects were prioritized in the 2003 Water Sector Strategy. The 2004 independent Extractive Industry Review (EIR) of the World Bank Group's oil, gas, and mining portfolio urged extending the moratorium on coal, phasing out of oil, and boosting lending for renewables. The bank rejected nearly all EIR's conclusions and promptly resumed lending for coal (EIR 2003; Goodland 2003). President Wolfowitz opened the door for financing nuclear energy in 2004, especially for India. This was emphasized in 2006 by the bank's "Energy Framework" paper prepared in response to the 2005 Gleneagles G-8 call for reducing climate change risks.

Switching from the widely accepted "sustainable development" of the 1987 Brundtland Commission, and the two UN Earth Summits (Rio de Janeiro 1992; Johannesburg 2002), to "responsible growth" surely cannot be muddled thinking; it must be a deliberate paradigm shift. "Responsible growth" halts the trend over the last decade of emphasizing sustainable development, as in the bank's "Beyond Economic Growth" (Soubbotina 2004) and direct poverty reduction of the Millennium Development Goals (MDG). As soon as the bank adopted the United Nations MDG in 2000, it undermined them by emphasizing trickle-down (The World Bank 2002).

The sole intellectual underpinning for the recent regression away from the MDGs/direct poverty reduction and back to trickle-down growth in infrastructure is the 2000 World Bank paper by David Dollar and Aart Kraay "Growth is Good for the Poor" (Development Research Group, Washington, DC) advocating free market fundamentalism. It is a weak reed on which to hang such an immense policy switch away from MDGs and back to trickle-down. The Dollar/Kraay paper has been roundly rejected (e.g., Mark Weisbrot, Oxfam, Ed Amann, David Woodward, and Andrew Simms). Of every $100 worth of growth in world income per person, only $0.60 is contributed to reducing poverty. To achieve a single $1 of poverty reduction requires $166 of global production and consumption, an extreme form of environmental and economic inefficiency. Rich countries benefit handsomely from the World Bank's reversion to trickle-down infrastructure, much more than from the MDG approach of direct poverty reduction through health, water supply, education, rural electrification, and nutrition.

There is no inkling that aggregate growth is not improving livelihoods. No recognition that 178 member countries recorded negative average growth between 1990 and 2001. No mention that the costs of growth are undercounted and in an increasing number of countries exceed the benefits.* No attempt to target growth for the 30% poorest in a nation. Redistribution is still anathema to doctrinaire economists just like corruption, debt relief, and military expenditures were until recently.

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* Where national indicators of national economic and social welfare have been calculated, they show OECD nations' costs exceed benefits in most cases.

concentrations at a level equivalent to 350 parts per million of carbon dioxide. The revenues resulting from these efforts would be deposited into the Earth Atmospheric Trust, administered transparently by trustees who serve long terms and have a clear mandate to protect Earth's climate system and atmosphere for the benefit of current and future generations. A designated fraction of the revenues derived from auctioning the permits could then be returned to people throughout the world in the form of a per capita payment. The remainder of the revenues could be used to enhance and restore the atmosphere, to invest in social and technological innovations, to assist developing countries, and to administer the trust (Costanza and Farley 2010).

In the absence of property rights, open access to resources exists—anyone who wants to may use them, whether or not they pay. However, individual property rights owners are likely to overexploit or underprovide the resource, imposing costs on others, which is unsustainable, unjust, and inefficient. Private property rights also favor the conversion of ecosystem structure into market products regardless of the difference in contributions that ecosystems and market products have on human welfare. Hence, the incentives are to privatize benefits and socialize costs.

All *scarce* resources are *rival*, meaning that use by one person leaves less of the resource (in quality or quantity) for others to use. Many resources, however, are nonrival, which means that use by one person does not leave less for others to use. When this is true, there is no competition for use and the resource is not scarce in an economic sense, even if total supply is inadequate. Examples include streetlights, many different ecosystem services (e.g., climate stability, flood regulation, scenic beauty), and information. Price rationing in this case reduces use and hence value to society without affecting quantity, which is inefficient. For example, if someone develops a cheap, clean solar energy technology and then patents it (which makes it excludable), it can be sold at a price. A positive price will reduce use, leading to less substitution away from competing energy sources, such as coal, and society as a whole suffers. Markets will only provide nonrival resources if they are made excludable and can be sold at a price, but this creates artificial scarcity. Paradoxically, the value of nonrival resources to society is maximized at a price of zero, but at that price markets will not provide it (Kubiszewski et al. 2010).

The solution to these problems lies with common or public ownership. Public ownership can be problematic due to the influence of money in government, which frequently results in the government rewarding the private sector with property rights to natural and social assets. An alternative is to create a commons sector, separate from the public or private sector, with common property rights to resources created by nature or society as whole and a legally binding mandate to manage them for the equal benefit of all citizens, present and future. The misleadingly labeled "tragedy of the commons" (Hardin 1968) results from no ownership or open access to resources, not common ownership. Abundant research shows that resources owned in common can be effectively managed through collective institutions that assure cooperative compliance with established rules (Pell 1989; Feeny et al. 1990; Ostrom 1990).

Resources that are rival but nonexcludable would need to be "propertized" (made excludable) to prevent overuse (Barnes 2006). Governments—or in the case of global resources such as atmospheric waste absorption capacity or oceanic fisheries, a global coalition of governments—are generally required to create and enforce property rights but could turn these rights over to the commons sector as a common assets trust (CAT) (Barnes 2006). The trust would cap resource use at rates less than or equal to renewal rates, which is compatible with inalienable property rights for future generations. Because the resources under discussion were created by nature, and enforcement of property rights requires the cooperative efforts of society as a whole, rights to the resource should also belong to society as a whole. Individuals who wish to use the resource for private gain must compensate society for the right to do so. This could be achieved through a cap-and-auction scheme, in which the revenue is shared equally among all members of society or else invested for the common good (Barnes et al. 2008). Preventing the resale of the temporary use rights would reduce the potential for speculation and private capture of rent. Under common ownership, costs and benefits accrue to society as whole, and the two are likely to be brought into balance. Taxes on waste emissions and resource extraction can serve the same purpose as a cap-and-auction system.

When a resource is nonrival, excludable property rights are inappropriate, but lack of property rights eliminates private sector incentives to provide the resource. The solution is common investment and common use. The commons sector must invest in the provision of nonrival ecosystem services and in green technologies that help provide and protect such services. Everyone would be free to use the nonrival ecosystem services but not to degrade the ecosystem structure that sustains them. The means to invest in nonrival resources can be obtained from auctioning off access to rival resources. For example, the CAT could auction off the right to greenhouse gas absorption capacity and then invest the revenue in carbon-free energy technologies.

When a resource is privately owned but generates economic rent, or is used in a manner that socializes costs and privatizes benefits, taxation can achieve the same goals as common ownership, as discussed in Section 4. Table 4.1 summarizes appropriate property rights for different categories of resources.

If the public sector shirks its duties to manage our shared social and natural inheritance for the common good, we require a commons sector to ensure sustainability and a just distribution of resources. Once these two goals have been achieved, the market will be far more effective in its role of allocating scarce resources toward the products of highest value and then allocating those products toward the individuals that value them the most.

4.5.2 Communication in Society

Between the ninth and twelfth centuries, reading and writing was mostly restricted to monasteries, "accessible only to the rare elect of God who knew how to read and draw" (Morgan 1996). A paradigm shift occurred with the introduction of papermaking by China in the twelfth century. With accessibility to paper, libraries and schools were now able to turn this time period into the exploration of knowledge and the development of science. However, it also led to much confusion and conflict between the church and the populace.

TABLE 4.1

Rivalry, Excludability, and Suitable Institutions for Allocation

	Excludable (*Rationing Is Possible*)	**Nonexcludable (*Rationing Is Not Possible*)**
Rival and scarce (rationing is desirable)	*Potential market resources*: Price rationing may be appropriate, rent should be captured for commons sector by taxes or royalties. Examples: land, timber, oil, absorption capacity for regulated wastes, use of airwaves	*Open access resources*: "Propertization" via collective action is required. Private use rights can be auctioned off by commons sector. Examples: many aquifers, oceanic fisheries, absorption capacity for unregulated wastes
Rival and abundant (rationing is not desirable, except to prevent scarcity)	*Club or toll good*: Price rationing may be appropriate to prevent scarcity; rent should be captured by commons sector. Examples: toll roads, golf courses, ski resorts, private beaches, parks with entrance fees, etc.	*Public good*: Economic growth and ecological degradation are likely to increase scarcity over time. Common sector management is appropriate to prevent scarcity. Examples: oxygen, public beaches
Nonrival (rationing is not desirable; value maximized at a price of zero)	*Inefficient market good*: Price rationing causes artificial scarcity. Common sector provision and ownership would be more efficient. Example: patented information	*Public good*: Commons sector must ensure adequate provision by preventing degradation or investing in provision. Examples: open source information, many ecosystem services

This conflict was only extenuated in the 1450s when Johannes Gutenberg invented the printing press. The popularity of the printing presses was such that by around 1500, around 250 cities were using their own printers (Verhoogt and Schriks 2007). Such widespread access to printed material allowed a new class of previously unschooled to emerge, creating a larger class of lay intellectuals (Morgan 1996). Clerks, merchants, physicians, noblemen, and even manual workers were now able to discuss political and religious theories with each other without the need to go through an authority (Morgan 1996). But beyond the ability to read ideas dictated by the authorities, this new class was given the opportunity to put their own ideas on paper for others to evaluate.

Although the print media remains a key aspect of society, a new form of communication was developed in the late nineteenth century allowing voice to be carried over distance. The radio became a household item in the 1920s due to Guglielmo Marconi's innovation of sending sound over the airwaves. Many radio organizations were established at the time in Europe and the United States, including the British Broadcasting Corporation (BBC).

Television soon followed. It was introduced during a time when the economy was strong, providing the United States with the ideal conditions to experience a "television boom." By the late 1950s, around 90% of households owned a television (Baughman 2001). Broadcasting networks such as the National Broadcasting Company (NBC), Columbia Broadcasting System (CBS), and American Broadcasting Company (ABC) began appearing.

Just like the radio industry in the United States, broadcast stations and networks carrying programs were privately owned. In the early days, many programs were paid for and produced by advertisers, with minimal oversight from the United States Federal Communications Commission (FCC). However, as television became more popular, more and more advertisers entered the market, creating a system where most programs had multiple sponsors (Baughman 2001).

Other countries initially took a different approach to broadcasting. In Britain, for example, the government had strict control over the development and production of programming, ensuring it provided information, education, and entertainment, at an affordable price to the entire population (Gripsrud 2001). Governments created independent broadcasting authorities that relied on receiver fees rather than advertising. However, due to the significantly greater income of U.S. networks, eventually many countries, especially those developing, shifted toward the advertising system (Baughman 2001). "The 'have-not' nations stand practically defenseless before a rampaging Western commercialism" (Schiller 1971).

With the introduction of cable into the industry in the 1970s, the availability of channels rose from about four to fifty. With the increase in the amount of channels, the FCC relaxed most rules regarding public affairs programming and network ownership of entertainment programs, initially established due to the scarcity of service. The introduction of cable also benefited advertisers by introducing stations and programs geared toward a specific audience, allowing advertisers to target a very specific demographic.

Unlike the printing press, which had practically no barriers to setting up, television stations are tremendously expensive to establish. This large cost permits only corporations, governments, or exceptionally wealthy individuals to own stations and produce programming. Hence, the networks owners are able to dictate their own ideas through the programming and to promote their own best interests to the population at large. This also opened the door for targeted programming and advertisement and enabled the networks to emphasis or ignore perspectives they deem appropriate.

In 2004, MoveOn.org attempted to use the power of advertising to draw attention to the nation's growing federal deficit being created by President Bush by purchasing a 30-second time slot during the Super Bowl.

CBS did not air their commercial stating that it did not want to air advertisements with "controversial issues of public importance." However, a commercial supporting the White House's National Drug Control Policy, a highly controversial issue at the time, did air during that Super Bowl. When looking at past dealings between the White House and CBS, it was found that the White House took CBS's side a few months prior to the Super Bowl when dealing with FCC regulations (Nichols 2004). The ability for the government, or large corporations, to have such influence on networks creates a tremendous bias in the programming.

4.5.2.1 Advertising

Television has been inducted into the forefront of our society through the use of a financial model relying on advertising revenue. However, this advertisement has also ushered in and sustained a culture of consumerism and materialism (Richins 1991). It has brought national brands into the forefront of consumer consciousness, creating great inelasticity by presenting the belief that there are few substitutes for a given brand (Muniz and O'Guinn 2001). It has also been shown that advertising has a tendency to create a belief in individuals that a higher than actual rate of "ad problems" exist, things such as gingivitis, athlete's foot, or bad breath (O'Guinn 2001). Many economists have been encouraging advertising due to its ability to increase GDP (Borden 1947), although others have come to see it as a promoter wastefulness (Packard 1960) (Box 4.8).

Advertising also has other effects on our culture. Some studies have found television programming and advertisement to be a detriment to women, minorities, and other marginalized groups (Seiter 1995) and to have also reduced social capital within families by eliminating the time they spend communicating, even though families spend more time in the same room together.

Political advertisements have also been used to sway the populace in elections. Studies have found that exposure to a 30-second television advertisement can increase the candidate's vote totals by 4 to 10 points (Ansolabehere et al. 1999). Similar results have been found when correlating campaign spending and amount of received votes. They show that a candidate can receive a vote for approximately every $10 they spend (Jacobson 1978; Gerber and Green 1999). This creates a system of "one dollar, one vote" (Frank 1991).

Many candidates receive significant portions of the campaign funds from corporations hoping to secure their role in government through that candidate. Those candidates are then obligated, once in office, to support and advance that corporation's best interests, which may not be in the best interests of the general population. By passing or vetoing regulations affecting that corporation, a candidate hopes to ensure future funding

BOX 4.8 THE IMPACT OF INEQUALITY

RICHARD WILKINSON AND KATE PICKETT

Social and economic inequality increases the power and importance of social hierarchy, status, and class.[1] As a result, a long list of problems more common further down the social ladder—in poorer neighborhoods, for instance—are much more common in societies with larger income differences between rich and poor.[2–4] Although the effects of inequality tend to be largest lower down the social ladder, outcomes are worse even among the better-off because inequality damages the whole social fabric of a society—increasing social divisions, status insecurity, and status competition.[2] Indeed, it is because a large majority of the population—not just the poor—are affected by inequality that the differences in the performance of more and less equal societies are so large. The scale of the differences varies from one health or social problem to another, but they are all between twice as common and ten times as common in more unequal societies compared to more equal ones.

Although in the rich, developed countries, income inequality is related to indicators of health and social well-being, levels of average income (gross domestic product [GDP] per capita) are not. Reducing inequality is the most important step these countries can take to increase population well-being. In the developing and emerging economies, *both* greater equality and improvements in standards of living are needed for populations to flourish (Figure 4.3).

BODY OF EVIDENCE

A large and well-established body of evidence shows that very large income differences within countries are damaging. Analyses include cross-sectional research and studies of changes in income distribution over time. Key examples follow:

Health

- Life expectancy is longer, and mortality lower, in more equal societies.[3,5–9]
- Rates of infant mortality, mental illness, and obesity are two to four times higher.[4,10–13]
- In developing and developed countries, HIV infection prevalence rises with inequality.[14,15]

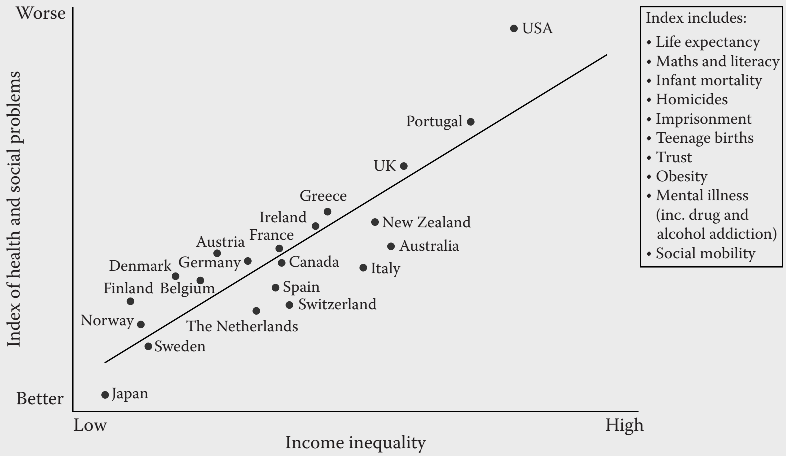

FIGURE 4.3
Health and social problems are worse in more unequal countries. (From Wilkinson, R. G., and K. Pickett, *The spirit level: Why greater equality makes societies stronger*, Bloomsbury Press, New York, 2009.)

Social Relationships

- Levels of social cohesion, including trust and social capital, are higher in more equal countries.[16–20]
- Indicators of women's status and equality are generally better.[1,21]
- Rates of property crime and violence, especially homicides, increase as income differences widen.[17,22–27]

Human Capital Development

- The UNICEF Index of Child Well-Being is significantly higher in more equal societies.[28]
- Educational attainment is higher, fewer young people drop out of education, employment, and training, and fewer teenage girls become mothers.[4,28,29]
- Social mobility is restricted in very unequal societies—equality of opportunity is shaped by equality of outcomes.[4,30]

Economic Progress and Stability

- Poverty reduction is compromised by income inequality.[31,32]
- The International Monetary Fund states that reducing inequality and bolstering longer-term economic growth may be "two sides of the same coin."[33]

- In rich and poor countries, inequality is strongly correlated with shorter spells of economic expansion and less growth over time.[33,34]
- Inequality is associated with more frequent and more severe boom-and-bust cycles that make economies more volatile and vulnerable to crisis.[34]

Sustainable Economies

- Inequality drives status competition, which drives personal debt and consumerism.[1,35–38]
- More equal societies promote the common good—they recycle more, spend more on foreign aid, and score higher on the Global Peace Index.[1]
- Business leaders in more equal countries rate international environmental agreements more highly.[39]

REDUCING INEQUALITY

Income differences can be reduced via redistribution through taxes and benefits or by reducing differences in pretax incomes. The international evidence suggests that greater equality confers the same benefits on a society whether it is achieved through one of these approaches or the other.[1]

In general, top tax rates, which in many countries—including the United States—were more than 80% in the 1970s, have been reduced dramatically. Dealing with tax havens and other methods used by rich individuals and large companies to avoid tax is crucial; the amount of money lost by developing countries to tax havens exceeds all international development aid.[40,41] This not only increases inequality but also means that a higher proportion of public expenditure has to be funded by taxpayers in lower income groups. In many countries, taxation has ceased to be significantly redistributive.

ECONOMIC DEMOCRACY

Forms of economic democracy, such as employee ownership, employee representation on boards, employee share ownership, mutuals, and cooperatives, tend to reduce the scale of income inequality.[42] The highly successful Mondragon group of employee cooperatives in Spain, employing around 84,000 people, has a maximum pay differential of 15:1. These forms of business institutions also provide a more stable basis for community life and perform well in ethical terms.

INDICATORS FOR SUCCESS

A core objective of the post-2015 development framework and the sustainable development goals should be to reduce inequality within countries.[42] The frameworks should include a top-level goal to reduce inequalities, including income inequalities in particular. This should be in addition to disaggregated indicators and targets in every other goal to ensure equitable progress across different social groups toward agreed-upon development objectives.

An inequality target could be based on Palmas ratio of the income share of the top 10% of a population to the bottom 40%. In more equal societies, this ratio will be one or below, meaning that the top 10% does not receive a larger share of national income than the bottom 40%. In very unequal societies, the ratio may be as high as seven.[43] A potential target could be to halve national Palma ratios by 2030, compared to 2010, and dramatically reduce the global Palma ratio, which is currently 32%.

Prioritizing the need to tackle inequality in this way will ensure that development is truly inclusive and can drive human progress to sustainability and well-being.

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from that corporation. With such a system in place, both candidates and corporations have no incentives to change the system to one that ensures the well-being of the general public.

4.5.2.2 One- versus Two-Directional Communication

With the development of the printing press, individual citizens were presented with the opportunity to exchange ideas, discuss theories, and to contribute to knowledge. Today, television is a more accessible source of information than any other in history, but overall it has reduced information transfer among the population. Instead of promoting two-way communication, it dictates information at the audience, without presenting any means for the audience to respond. "Individuals receive, but they cannot send. They absorb, but they cannot share. They hear, but they do not speak. They see constant motion, but they do not move themselves. The 'well-informed citizenry' is in danger of becoming the 'well-assumed audience'" (Gore 2008).

We are again on the cusp of another media paradigm shift. Over the past decades, the personal computer and the World Wide Web have become defining aspects of society. They have altered every facet of our lives, from personal relationships and professional way of life to our modes of transportation and education system.

However, unlike television, no technological or financial imperatives exist within the Internet to centralize information or technology. It has provided users more control over information distribution and allowed services previously overseen by a single group or corporation to be shaped by the entire population. Multivolume printed encyclopedias, television news networks, and television sitcoms are being replaced by Wikipedia.org, Encyclopedia of Earth, Facebook, YouTube.com, and millions of blogs and forums, all created by billions of people who are also the audience for the content.

However, humans have a need to form communities, share experiences, and look for reliable guidance when massive amounts of information are presented (Gripsrud 2001). Some argue that this provides an opening for those with the skills and knowledge of the Internet to create a new class of experts and organizations to centralize and control information (Dutton 2001).

4.5.2.3 Sustainability through Media

We are now at a turning point where the World Wide Web, the Internet, and other communication technologies are reaching critical levels of development and dissemination. At this point, the tide can shift toward a societal change where everyone has a say in our societal evolution or it can shift toward a more controlled and inflexible society.

To create a true democracy, in which no one entity maintains ultimate control, we need to ensure that no centralization of information or technology occurs that would provide the government and corporations with the opportunity to control the information presented to the public. Regulations ensuring freely accessible and unbiased information will become crucial in this new information age.

An issue known as "network neutrality" has been a heated topic of discussion over the past decade. Proponents are attempting to ensure that no restrictions are placed on content, Web sites, or platforms by Internet service providers (ISPs) to enhance their own self-interest by encouraging regulations designed to mandate neutrality. Opponents, on the other hand, believe such regulations will eliminate incentives for corporations to develop further technology and network upgrades. Without such regulations, corporations and the government will be able to influence accessibility to information present on the Internet.

4.5.2.4 Electronic Democracy

With the invention of television, political advertisements became a critical outlet for candidates to dictate their message and sway voters. However, the decentralized nature of the Internet "allows citizens to gain knowledge about what is done in their name, just as politicians can find out more about those they claim to represent" (Street 2001). Because the Internet is a two-way means of communication, it provides voters with the ability to speak out within their government without leaving their homes. For the Internet to transform the idea of electronic democracy, universal access is critical. Currently technological, financial, and social barriers still exist that make such complete accessibility unattainable (Street 2001). However, this is quickly changing through the use of mobile phones. In many countries where computers and landlines are not available, mobile phones are providing Internet access to the remotest of regions.

4.5.3 Education

Our evolving system of higher education has been undergoing a paradigm shift since the 1980s. Some universities have shifted away from unidirectional, instructor-focused teaching to a more distributed, student experience. Likewise, most medical schools in the United States began using problem-based curriculum decades ago and improved results in student performance followed (Schmidt et al. 2006). Business schools are slowly beginning a similar shift.

This shift toward more interactive, problem-based courses is crucial when combined with the possibilities that the Internet has begun to make available internationally. Full or partially online courses are becoming routine, especially at the master's level. Some universities are even providing entire degrees online, many of which are also at the master's level. In the United States, more than 5.6 million students were taking at least one online course in the fall semester of 2009, an increase of more than one million students from the previous year (Allen and Seaman 2010a).

What if this trend was to be taken further by envisioning an international collaboration of universities—a "MetaUniversity" that shares online courses, pared with expanded problem-based courses, and is truly global?

The recent, and quite explosive, trend toward online courses stems from a variety of factors within society. These include technological shifts such as significant improvements in global access to the Internet and development of more sophisticated online tools but also societal shifts such as globalization and an economic downturn creating increased competition between universities (Dykman and Davis 2008).

Outside the university structure, massively open online courses (MOOCs) have become very popular over the past few years as part of the open educational resource movement. MOOCs are courses structured similarly to a traditional university course but often do not offer credit, are free, and have no prerequisites, but may offer some form of a certificate of completion. The first such course was offered in 2011 on the topic of artificial intelligence (AI) and had 160,000 registered students, 23,000 completed the 10-week course (Martin 2012). Since then, MOOCs have been offered on numerous topics all over the world.

And yet, although the amount of information is increasing, universities are struggling financially. Tuition is increasing steadily, reaching around $200,000 for four years at some U.S. private institutions, while state funding is being drastically cut to most public universities around the world. This is forcing faculty members to teach more courses, with more students, and less help from teaching assistants. This trend is eroding the overall student experience and the degree of interaction with professors. Professors also have less time to do research and service within the community as more of their time is taken up by teaching and grading.

The expectation of many universities is that online education can provide a solution to their financial problems. They anticipate that more students will bring in more funding while requiring less faculty time. However, this has proved more difficult than many have anticipated. The creation of high-quality online courses has a large, up-front cost, both financially and in terms of instructor time. This cost often exceeds the benefits that the university receives from the courses. In 2008, around 50% of universities in the United States reported that online courses were an overall financial loss, while only 25% said that they made money for the university (Allen and Seaman 2010b).

The advantage of building a high quality online course is that once it is built, it is very inexpensive to distribute, share, and use. This is a main reason that MOOCs can be offered freely and are often very successful. However, many universities continue to think about basic information as they have for hundreds of years, as proprietary and inaccessible to those who do not pay. But the Internet has changed that mentality in the public. Most people are unwilling to pay for information because they can usually find what they need freely available.

Such a mindset regarding information has a large impact on higher education in developing countries. Much of the credible, peer-reviewed content these educators seek is inaccessible due to large fees. With no other options, they resort to potentially less credible information that is passed down to the students.

Although many of the pieces of a new education paradigm have been attempted, these concepts have not all been brought together in a practical model. It is time to consider a redesign of the university system in a way that takes advantage of recent Internet technology developments and addresses some of the social and economic problems surrounding higher education.

4.5.3.1 The Next Phase in Higher Education

Historically, universities have retained much of their autonomy, providing courses in isolation of other universities. This has changed to a certain degree over the past decade as collaborations have begun to form. Many of these collaborations are around specific degrees or programs in which the universities are all interested or around certain areas of research. There are a few that have begun sharing online course content or use one shared platform to offer their courses.

Creating an international consortia of universities, sharing not only course content but also the teaching of courses, could potentially move higher education to a new phase of development. Such a collaboration could be managed by an independent third party, most likely a nonprofit organization, that would help with communication and organization—think of it as a MetaUniversity—connecting the partner universities.

The MetaUniversity would help facilitate two types of courses: (1) online courses that are analytical and tool based and (2) synthesis courses that are face-to-face, on-the-ground, and focused on solving real world problems. Although the Internet has advanced to the point that the majority of what we know can be imparted via the Web, learning the higher-order skills of problem solving and critical thinking must be done in person. The combination of these two types of courses will provide students with the opportunity to not only understand how to use analytical tools but also how to apply and communicate them in appropriate ways depending on the situation and audience to solve problems.

Analysis courses provide a fundamental base of a quality education through content that focuses on existing knowledge and on teaching the tools and skills required to solve problems. Today, they are often prescriptive and usually convey information in one direction, from the professor to the student. This feature allows analysis courses to be packaged online in a way that imparts the crucial information to students in a potentially more dynamic way than traditional classroom teaching. Through the use of recorded lectures, interactive animation, models, hands-on exercises, discussion boards, video chats, and other Web-based tools, students can learn at their own pace while still having access to lectures and student-to-student interaction in a fashion similar to a face-to-face course.

University professors, or the experts in a field best qualified and having the most dynamic content, would produce the online courses. These courses could be produced by one or a group of professors and updated regularly because their production would be peer-reviewed community efforts.

The content would be credible and up-to-date with the most recent information and freely available on the Web.

The MetaUniversity would facilitate the production and maintenance of these courses. This would ensure that the best possible courses are available online. All the course content would be peer reviewed and accredited before being made available. Once approved, they would be freely available to the public for anyone to use on their own. They could also be taken for credit with faculty involvement. The online courses, and the professors teaching them, would be pre-approved by the individual universities prior to use. Professors from one university, or experts in a field, would be able to teach students simultaneously at a variety of universities internationally. This approach would showcase the strengths of each university, while allowing other universities to teach those subjects they were strongest in. This would allow a reduction in duplication of effort and resources. It would also give the students a more holistic education, with a more international perspective on the subject. Such a shift would also leave faculty more time to do research and participate in on-the-ground, problem-based, synthesis courses, described here.

Today's college generation has grown up with the Internet, with the idea that information is available, for free, at their fingertips. Many are unwilling to pay for information because alternative free sources usually are available. Hence, when universities charge tuition, they do not charge for the information or knowledge provided, but for the faculty interaction and the certificate of accreditation that they provide at the end of the program. The analysis courses, or online courses, would take advantage of this situation and would be available on three distinct levels, depending on the requirements and interests of the students taking the courses. The three levels include:

1. **Independent Learning (Level I):** This level will be available to everyone who would like to obtain the knowledge within the course but who does not need university credits, faculty interaction, or a certificate of completion. It will allow individuals to complete the course asynchronously and for free, with all of the content available online. This level will not provide any faculty interaction but will facilitate interaction with others taking the course. One of the biggest benefits of this level will be the availability of the content to people in developing countries. It will provide them peer-reviewed information to teach with and to utilize free of charge.
2. **Certificate of Completion (Level II):** This level will be for professionals, or anyone in the public, who would like to receive a certificate of completion but who does not require university credits. The certificate of completion would be granted by the MetaUniversity, with the backing of the universities within the collaboration, for

a small fee. Such professional certifications are in high demand because employers are requiring additional knowledge and skills from their employees as markets and situations shift. Unlike Level I, this level will provide some faculty interaction and can be taken asynchronously or on a semester schedule.

3. **University Credit (Level III):** The third level would be for those students who would like to receive university credits for a course. Course credits would be required for anyone who wishes to receive an accredited university degree. These degrees would come directly from the university in which the student is enrolled. The courses they would be required to take would also be determined through the requirements set by the university they were enrolled in. The courses could be offered by one or more faculty members, but students from any university within the collaborative would be able to take the course. This level would provide full faculty interaction and give students an experience that would match or exceed that of a traditional face-to-face course.

Synthesis courses will allow students to apply the tools and skills that they gain through the analysis courses. These synthesis courses will be dynamic, on-the-ground, solution-oriented courses that send students and faculty into the community to address urgent, real world problems and help identify and implement solutions with broad policy implications. They will address real world problems on multiple temporal and spatial scales. They will do this by involving students and faculty from a broad range of disciplines and universities that are part of the MetaUniversity consortia as well as community stakeholders and decision makers to collaboratively find whole-system solutions. Because these courses require creativity and interactive communication among the professor, students, and community members, they cannot be taught online, but require in-person interaction.

Being involved in such an exercise will provide students with the guidance they need to use the knowledge they have obtained through the analysis courses in the real world, but with faculty oversight and guidance. These courses will provide both the faculty and students with an unforgettable educational experience, the opportunity to do on-the-ground practical research, a potential publication, and to help a community with a problem. They will also provide students with the opportunity to learn and practice their communication skills. Students will have to learn to communicate and interact not only with a broad range of community stakeholders throughout the project but will have to communicate their results to the appropriate audience. This may take the form of a peer reviewed publication, pamphlets, a press release, a Web site, or any other media appropriate to the project. Students will receive university credit from the universities they are enrolled in.

The main elements of these courses include: (1) transdisciplinary, problem-based learning; (2) community-client sponsorship; (3) stakeholder participation; (4) blurring of the distinction between faculty and student, research and education; (5) adaptive management and flexible working groups; and (6) appropriate and practical communication of results (Cowling et al. 1997; Campbell et al. 2000).

4.5.3.2 Potential Obstacles

Although many aspects of such a system have been tested on smaller scales, potential difficulties may arise on a larger, international scale. Managing time zones and overcoming language barriers are just two of the obstacles that need to be addressed.

Certain fundamental aspects of higher education will also need to be addressed. One deals with the property rights assigned to content created by professors. Currently, all course content produced by faculty is owned by the university. For these consortia to work, course content will need to be shared among the universities and may require more flexible copyrights, such as a creative commons license (Lessig 2002). This license allows the creator to retain credit for the production of the content but with more allowances for certain types of usage. This content can be produced by faculty members of the collaborative universities, academic societies, or independent scholars. All courses will require approval before being accessible to students and the public.

The teaching of courses may also need to be rethought. Currently, it is inefficient for students to transfer credits. Simplifying the exchange of credits between universities may be the first step in enabling the sharing of faculty among the collaborative in a way that benefits the students and the universities. One potential way to make this happen is to have the collaborative, or the universities themselves, approve courses that their students would take at other universities and for which they would receive credits toward their degrees.

There are many other challenges that will be encountered within such a new system. However, through cooperation, such obstacles can be overcome.

Our higher education system needs to adjust to a quickly changing world. The traditional role of universities as storehouses of knowledge and the source of delivery of that content is becoming overshadowed by the massive availability of information on the Internet. Technical skills become quickly obsolete as technology changes. The university of the future will need to teach students the tools they need and how to think critically and creatively regardless of what job they have or what problem they are asked to solve. Education is the key to solving our global problems. As Albert Einstein once said: "a new type of thinking is essential if mankind is to survive and move to higher levels" (Einstein, 1946, p. 7). This will require an educational structure that changes our way of thinking to one that allows us to focus our global intellectual capital on solving the multitude of problems we now face.

4.5.4 Patents and Copyrights

We live in the age of information and global markets. Markets play an important role in the generation and distribution of new information. They decide on what information to produce, which scarce resources are allocated toward that production (e.g., scientists, laboratory equipment, computers), and once produced, who can use it. Governments and universities also play an important role in the generation of new information; however, through the passing of the Bayh-Dole act in recent decades, the U.S. government has pushed academic centers to produce information with commercial applications (Sampat 2006). Before such change in priorities and throughout much of the twentieth century, universities avoided direct involvement with copyrights and patents. Universities now are patenting and copyrighting new information at an unprecedented rate.

Society increasingly relies on markets to produce and allocate information. At the same time, society also faces a number of serious problems that may be unsolvable without new information to generate new technologies. For example, many experts believe that if we fail to significantly reduce CO_2 emissions, atmospheric carbon stocks will continue to climb, resulting in runaway climate change and ecological catastrophe. However, our society is currently so dependent on fossil fuels that reducing emissions by 80% could result in mass starvation and economic collapse. However, *not* reducing emissions could also cause mass starvation and economic collapse. In economists' terms, if the marginal costs of CO_2 emissions (the supply curve) fail to intersect with the marginal benefits of fossil fuel use (the demand curve), then there is no *economic* solution to the climate change problem *with current technologies.* Given the urgency of the climate change problem and other critical problems that information can help to solve, it behooves us to closely examine the effectiveness of markets in producing and allocating information.

There is a vast literature regarding the economic market's inability to efficiently produce and allocate information (Foxon 2003; Stern 2007). On the allocation side, a market's maximum efficiency is when the marginal cost of producing a good equals its marginal benefit and price. Because the marginal cost using existing information is negligible, efficiency demands that the price also be negligible, and any higher price creates a dead-weight loss in society, reducing efficiency. Paradoxically, the economic surplus from information, which is essentially the monetary value of the total use of that information, is maximized when the price is essentially zero (Daly and Farley 2004). However, at a price of zero the market will not produce information. On the production side, it can be difficult to make information excludable, which in turn makes it difficult to sell. If those who produce information cannot recoup at least the costs of production, they are unlikely to produce it (Arrow 1962a). If information is not created in the first place, it of course generates zero economic surplus.

In the 1970s, Rothschild and Stiglitz (1976) showed that markets for information suffer from a paradox. For a market to function efficiently, all parties must understand the nature and effects of the good or service being traded to the fullest extent possible. There must be complete information. However, if a buyer of information were to have access to a piece of information before the transaction occurs, there would be no protection for the seller if the buyer decided to utilize that information without paying. Without complete knowledge of the information before the transaction, the transaction cannot be completely efficient, but if the information itself is the good or service being traded then it is impossible to make it both excludable and the trade efficient at the same time (Greenwald and Stiglitz 1986). Nonetheless, a reduction in economic surplus is preferable to no economic surplus, which has led most market economies to create intellectual property rights (IPRs) to information in the form of patents and copyrights. IPRs provide incentives for the production of information, but in exchange create artificial scarcity and inefficiencies in consumption for the duration of the patent or copyright.

Unfortunately, IPRs fail to solve the production problem, because they are inevitably incomplete. New technologies build on old ones regardless of IPRs through reverse engineering or illegal copying. Information generates positive externalities and hence tends to be underprovided by markets (Arrow 1962a). One strategy for addressing this problem is through stronger IPRs, as promoted by the World Trade Organization, allowing a greater return on investment by firms and developing countries (Park and Lippoldt 2008). A second strategy, justified by the positive externalities of information production, is to lower R&D costs by publicly funding or subsidizing R&D while still allowing firms to patent and sell the resulting technologies. Almost all market economies currently provide at least some public support for R&D (Deutch 2005; Stern et al. 2006). A third strategy is to recognize the additive nature of information and to manage it as a global public good, with publicly funded production and open access consumption (Stiglitz 1999a,b; Bollier 2003; Daly and Farley 2004).

In this book, we argue that the changing nature of the problems that global society confronts has increased the disadvantages of using conventional markets to produce and allocate information. The market is unable to meet society's desirable ends and creates a system that encourages competition instead of collaboration, decreasing the opportunity for innovation. Alternative institutions may be better equipped for managing the flow of information. Information should therefore be managed, as Stiglitz suggests, as a global public good.

Originally, when the current economic paradigm was created, with its assumptions and conventions, material wealth was the limiting factor to improving well-being. That has now changed in many countries, where there is an excess of material goods, but a poor distribution of those goods and a dearth of social and natural capital (Beddoe et al. 2009). This has become a global problem that requires global information exchange to solve. And yet this paradigm has persisted due to a lack of alternative options and the benefits it provides to a key minority (Stiglitz 2002). We are now using the market to deal with completely different problems, and we need information that is no longer revolving around material production and consumption but around solving global public goods problems on the social and natural level. The development and the allocation of this type of information for a greater social good have a different level of responsibility associated with it. This requires that the focus be placed on the social good instead of the private gain.

Economics is conventionally defined as the allocation of scarce resources among alternative desirable ends. This definition can guide us as we assess the effectiveness of markets for allocating information. It follows from the definition that the first task is to determine the desirable ends of economic activity, or in our case, the most desirable ends we should pursue through the creation of new information. We must then assess the characteristics of information relevant to allocation. Only then can we decide if markets generate the type of information most important for modern society, if they are the most cost-effective mechanism for producing that information, and once the information is produced, if they are the most effective mechanisms for maximizing the value of that information. We explain our methods for assessing each of these criteria as we proceed.

This book shows that much literature exists on the shortcomings of markets when dealing with the production and allocation of information. The literature also attempts to identify means of altering the economic market in such a fashion as to allow for greater revenue or efficiency. However, the majority of the methods suggested work within the market and try to protect market goods. In this book, we recognize that information needs to be treated as a public good that improves with use. Hence, this requires alternative institutions to manage it and to achieve society's desirable ends.

4.5.4.1 Alternative Incentive Structures

Because the market is unable to (1) properly allocate resources toward public goods that are most likely to be the desirable ends in today's world of climate change, fossil fuels, water scarcity, and so on; (2) increase production costs for restricting access to information, rent seeking behavior, or transaction costs; and (3) decrease consumption benefits through price rationing that creates artificial scarcity, alternative incentive and allocation mechanisms are required. Throughout history, various incentive schemes have been used to successfully encourage development of specific technologies or of solutions to specific scientific problems. Here we review some of these systems and propose some new ones.

Prizes: One of the most popular alternative allocation methods has been rewarding innovations with monetary prizes and then releasing the information into the public domain; this includes France offering a prize for the development of the workable water turbine in the seventeenth century (Reynolds 1983); a century long reward, around the same time, for the development of a method to calculate longitude while at sea (Sobel and Armstrong 1995); or more recently, a prize for sending the first private astronaut into space (Schwartz 2004). The use of monetary prizes as an incentive to develop specific information has certain advantages over the use of intellectual property rights. It allows society, and not just the market, to decide on which innovations would be most beneficial. Because corporations would be rewarded monetarily through the prize, patents would no longer be necessary for the innovations, allowing the information to be released into the public domain and to be utilized by more researchers (Stiglitz 1999a,b). However, this approach does fail to address the issue of firms competing for a prize instead of collaboratively working together during the production process, thus losing the gains to cooperation during the process.

Nonmonetary incentives: Certain industries do not use monetary incentives as a reward structure. Open source software has recently reemerged as a strong competitor to patented software and in certain circumstances significantly exceeding its quality (e.g., Firefox vs. Internet Explorer) (Bitzer et al. 2007). Within this open source community and many academic fields, a type of incentive structure exists based on an individual's reputation among his colleagues for contributions to the field. System rewards are based on how quickly discoveries are made and how quickly they are published within the community (Dasgupta and David 1994).

In academia, mathematical theorems cannot be patented, and yet many mathematicians continue to work on their development. The extent of the reward given to an academic working within this system is determined by the community as a whole. The community assesses the quality of the discovery, after its publication, on the criteria of how much it benefits that community and how much it furthers that community's knowledge. The rewards may be monetary in the form of a promotion but commonly consist of such things as honorific awards, positions at more prestigious universities, tenure, large citation numbers, colleagues' esteem, and overall status. The size of the reward is dependent on how much the discovery benefits the community, or in other words, how much it advances the community's efforts toward a single goal or vision. This communal vision is established not by the market but by the community as to what the most desirable ends are.

Besides advancing knowledge in the entire community, the act of publication also serves two other purposes. First, it ensures that the discovery does not remain within the confines of a group that may not have the resources or ability to utilize that discovery to its fullest. Second, it allows peers to evaluate the discovery, significantly minimizing the opportunity for errors (Dasgupta and David 1994). However, once a discovery is completely disclosed to the community through publication, it becomes easy for others to copy portions of the published work and to claim to have also independently done the research. Consequently, academia does not reward second place discoveries, encouraging academics to collaborate instead of to compete to discover and publish first.

The passing of the Bayh-Dole Act of 1980 provided universities an impetus toward commercial innovations, creating an increasing trend in patenting as a means of additional monetary rewards (Mowery et al. 2003; Sampat 2006). Subsequent policies have strengthened privatization of research results by giving priority to anyone involved in a project that wants to patent information over the objections of anyone who believes the discovery should be placed in the public domain (Eisenberg 1996). Moving away from monetary incentive structures and toward those dependent on peer opinion would provide strong impetus to release all information into the public domain.

Capping salaries: Historically, inventors worked independently in either the pursuit of profit (e.g., Thomas Edison) or to contribute to the public good (e.g., Nikola Tesla). Today, the majority of scientists work with defined salaries. The rights to any patents they procure are assigned to the organizations that they work for, eliminating much of the incentives for the individual scientists to research one type of information over another. By capping salaries among the different sectors, scientists would have no incentive to work for corporations such as Bristol Meyers Squibb over the National Institutes of Health. A natural cap could be forced by taking away the right of major corporations to patent drugs that are beneficial to society. Through their choice of organizations, scientists would have the discretion of deciding on how the results of their research were to be utilized. By offering competitive salaries, the government would have the opportunity to promote the type of research most beneficial to society.

Research consortium: A global research consortium should determine appropriate technologies for alternative energy, agroecology, green chemistry, industrial ecology, and so on in collaboration with those who would use them. These new technologies could be "copylefted" (as opposed to copyrighted), meaning that they would be freely available for anyone to use as long as derivative products are available on the same terms (Bollier 2003). This would allow the consortium to determine that the research priority included finding alternative, clean sources of energy, protecting the ecosystem services, managing fresh water efficiently, or feeding the world's hungry. This institution would consider the global well-being of the population instead of purely economic demand.

Publicly funded research: Potential also exists to move away from the market in funding certain types of research. In the 1950s and 1960s, the government funded much more than half of all research and development, but by 2006, it funded only 28%. By increasing the proportion of publicly funded research and placing all information obtained through publicly funded research into the public domain, monopoly pricing on this technology would no longer be an option, creating open information and competition for further advancements, two critical aspects to the proper functioning of the market. It would also eliminate "me too" research, using resources more efficiently. Taxpayers would still be required to fund further advancements in research through the price of goods; however, that price would be set by a market instead of by a single corporation. Patents also provide a strong incentive to research information that is potentially commercializable, hence disincentivize basic research (Salter and Martin 2001) or research that could provide and protect public goods, which has historically been an important resource for other researchers in the public and private sectors (Scotchmer 1991). Placing information into the public domain would take the focus away from commercializable items and would refocus research on those areas most necessary for solving society's problems (Stiglitz 1999a,b, 2002; Stern et al. 2006).

Large governmental grants can also be used to bring together top researchers in specific fields from multiple corporations, universities, and governmental agencies to work toward common goals. Besides placing the most people knowledgeable about a certain topic together to exchange ideas, it would also create collaboration among different institutions and would avoid the competition that usually occurs. The information produced would be released into the public domain, allowing the entire world, including developing countries, to benefit. Such systems were used to spur the Green Revolution and to get humans to the moon, creating remarkable scientific advancements in short periods of times—and in one case deterring a mass famine.

Additional public funding for R&D could be made available through the taxing of certain excludable goods within specific industries. As an example, the computer industry has been having significant difficulties in stopping the pirating of software. Software, due to its nature, should not be an excludable good because after it is developed, the creation of an additional copy has insignificant marginal costs associated with it. This creates a significant social inefficiency. If a system were established in which the hardware was taxed and the revenues used to fund software development that was provided freely to the users, this would eliminate the social inefficiency. Similar taxes can be placed on the energy industry. Technologies based on fossil fuels and on the use of the fuels themselves could be taxed (or permits auctioned) and that money could be directed toward the development of alternative energy technologies. Such a tax would have multiple advantages, including the reduction of greenhouse gas emissions (Barnes et al. 2008).

4.6 Governance

4.6.1 Strong Democracy

Satisfaction of basic human needs requires a balance among social, built, human, and natural capital (and time). Policy and culture help to allocate the four types of capital defined earlier as a means for providing these opportunities.

One institution that helps build social capital is a strong democracy. A strong democracy is most easily understood at the level of community governance, where all citizens are free (and expected) to participate in all political decisions affecting the community. Interactive discussion plays an important role. Broad participation requires the removal of distorting influences such as special interest lobbying and funding of political campaigns (Farley and Costanza 2002). In fact, the process itself helps to satisfy myriad human needs, such as enhancing the citizenry's understanding of relevant issues, affirming their sense of belonging and commitment to the community, offering opportunity for expression and cooperation, strengthening the sense of rights and responsibilities, and so on. Historical examples include the town meetings of New England or the system of the ancient Athenians (with the exception that all citizens must be represented, not simply the elite) (Prugh et al. 2000; Farley and Costanza 2002).

Participating in society demands that attention be paid to the underlying human and social resources required for this task. Creating resilient social communities is particularly important in the face of economic shocks. Specific policies are needed to create and protect shared public spaces; to strengthen community-based sustainability initiatives;

to reduce geographical labor mobility; to provide training for jobs in sustainability; to offer better access to lifelong learning and skills; to place more responsibility for planning in the hands of local communities; and to protect public service broadcasting, museum funding, public libraries, parks, and green spaces (Jackson 2009).

4.6.1.1 Living Democracy

Living democracy is comprised of a "set of system values and conditions" that ensure cooperation, fairness and empathy: "(1) The continuous dispersion of power; (2) transparency in human relations; and (3) cultures of mutual accountability" (Lappe 2013). Living democracy accounts for the fact that we may not have the necessary tools and skills to address an issue but that we can learn to do so. We develop and create together a living democracy based on the set of values and conditions described earlier. In a living democracy, citizens create/develop and help disseminate information and knowledge (e.g., community-based management projects). It also promotes different ideas for citizen involvement and empowerment (e.g., deliberative polls) (Lappe 2013).

4.6.1.2 Deliberative Democracy

Deliberative democracy has been defined as "any one of a family of views according to which the public deliberation of free and equal citizens is the core of legitimate political decision-making and self-governance" (Bohman 1998, 401).

This approach is based on the belief that citizens need to be educated about the issues that matter to them in order to make well-informed decisions. The idea behind this approach is that preferences and opinions are not fixed and hence can be changed/shifted through a deliberative process. The process of deliberative democracy involves: (1) sharing of information and policy options among a set group of individuals, (2) the process of deliberation among the group, and (3) the socialization and dissemination of the results of this process (Held and Hervey 2009; Herbick and Isham 2010).

Some of the institutions that have developed and promoted this approach are the Center for Deliberative Democracy, America Speaks, the Consensus Building Institute, and Deliberative Democracy Consortium, among others.

4.6.1.3 Lisbon Principles

The key to achieving sustainable governance in the new, full world context is an integrated (across disciplines, stakeholder groups, and generations) approach based on the paradigm of "adaptive management," whereby policy making is an iterative experiment acknowledging uncertainty rather than a static "answer." Within this paradigm, six core principles (the Lisbon principles) that embody the essential criteria for sustainable governance have been identified (Costanza et al. 1998). The six principles together form an indivisible collection of basic guidelines governing the use of common natural and social capital assets (Box 4.9).

BOX 4.9 THE LISBON PRINCIPLES OF SUSTAINABLE GOVERNANCE

ROBERT COSTANZA

At a workshop held in Lisbon, Portugal, in July 1997, sponsored by the Independent World Commission on the Oceans (IWCO) in conjunction with the Luso-American Development Foundation, a group of 16 scientists developed a core set of principles for sustainable governance of the oceans (Costanza et al. 1998). These six principles are general enough to apply to the governance of our natural capital assets generally and are reproduced as follows:

Principle 1: Responsibility. Access to environmental resources carries attendant responsibilities to use them in an ecologically sustainable, economically efficient, and socially fair manner. Individual and corporate responsibilities and incentives should be aligned with each other and with broad social and ecological goals.

Principle 2: Scale-matching. Ecological problems are rarely confined to a single scale. Decision-making on environmental resources should (1) be assigned to institutional levels that maximize ecological input, (2) ensure the flow of ecological information between institutional levels, (3) take ownership and actors into account, and (4) internalize costs and benefits. Appropriate scales of governance will be those that have the most relevant information, can respond quickly and efficiently, and are able to integrate across scale boundaries.

Principle 3: Precaution. In the face of uncertainty about potentially irreversible environmental impacts, decisions concerning their use should err on the side of caution. The burden of proof should shift to those whose activities potentially damage the environment.

Principle 4: Adaptive management. Given that some level of uncertainty always exists in environmental resource management, decision-makers should continuously gather and integrate appropriate ecological, social, and economic information with the goal of adaptive improvement.

Principle 5: Full cost allocation. All of the internal and external costs and benefits, including social and ecological, of alternative decisions concerning the use of environmental resources should be identified and allocated. When appropriate, markets should be adjusted to reflect full costs.

Principle 6: Participation. All stakeholders should be engaged in the formulation and implementation of decisions concerning environmental resources. Full stakeholder awareness and participation contributes to credible, accepted rules that identify and assign the corresponding responsibilities appropriately.

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4.7 Conclusions and Prospects for the Future

In retrospect, some obvious conclusions can be drawn about the human efforts to date to manage our global habitat. The adoption of industrial technology has satisfied and, with positive feedback, accelerated human appetites for material consumption, thereby generating throughputs of materials and energy far in excess of the capacity of the Earth's ecosystems to assimilate sustainably. Exponential expansion of human populations has crowded out other species. The 40-year armament race during the Cold War absorbed resources, which might have been devoted to environmental protection, and weakened the resolution needed for reversing centuries of damage to the global habitat. The end of the Cold War unveiled a heritage of nuclear and toxic wastes that leaves vast areas still at risk or even uninhabitable in the East and the West.

But the end of the Cold War also created a historic worldwide opportunity to reallocate resources away from looting the planet and toward restoring a sustainable human habitat. The former global competition for dominance precluded serious efforts to replace economic growth with sustainable development (qualitative improvement without increasing throughput). The barriers to acceptance of sustainable development are well-entrenched consumer materialism in developed societies and the understandable aspirations of the Third World to emulate Western material affluence. Success in meeting and overcoming these barriers will require learning from the historical record, avoiding the mistakes of the past, and creating innovative solutions for the future. One mistake of the past to be avoided is that of letting appetites for material consumption blur our sensitivity to the conditions essential for sustainable development. Another lesson we must learn with respect to population growth is that a positive exponential growth rate, no matter how limited, of any variable (such as population) in a closed system (such as the Earth) will eventually overpower the system and cannot be sustained. Kenneth Boulding warned during the height of the Cold War that citizens of all nations are passengers on a single, finite spaceship Earth, whose continued existence is totally dependent upon a more fundamental understanding of its owner's manual and operating instructions. Among the most important of the Earth's operating instructions are the policy instruments we use as tools for maintenance, safe operation, and repair. In the past, we have attempted to make do with a tool kit of insufficient and faulty tools.

Our tools and instruments for operating our spaceship have been designed too much for administrative regulation of what comes out of smokestacks and not enough for providing economic incentives for limiting throughputs of energy and materials to sustainable levels. Our management of habitats has been based excessively upon highly entropic conversion of land, forest, and water resources with unsustainable levels of harvesting and cultivation and has been based too little upon scientific understanding of the complexity of ecological interrelationships. Our management of species diversity has been dominated more by market exploitation of open-access resources than by responsible stewardship of our common heritage and infrastructure. Our debate over human population growth has been dominated more by doctrinaire ideological confrontation and defense of male power structures than by a good-faith search for common ground. Our management of energy resources has been based too much upon short-run market considerations, excessive discounting of the interests of future generations, and too little sensitivity to either intergenerational equity or intragenerational justice.

In short, the historical record indicates that our efforts to protect our earthly environment have been defective with respect to scientific understanding, economic efficiency, and equity as among individuals, regions, and generations. The early warning indicators and their combined patterns as perceived by Rachel Carson, Kenneth Boulding, and others suggest that if we continue on the current trajectory of growth, the probable ultimate consequence will be an overshoot and collapse of painful proportions. More recently, the stark warnings of, for example, the Stern report (2007) and IPCC (2013) show that overshoot and collapse from climate disruption is the most urgent and grave problem of our times. The world has dithered and tinkered with feeble and largely unimplemented climate policies. Our choices lie between using our educational and democratic institutions for gaining acceptance of consensual solutions or of continuing on into disaster and social chaos, from which democratic processes are unlikely to survive. Forging a new set of policies and tools capable of meeting these new challenges is urgent. We are in a race between educating ourselves about how the planet functions and destroying it through acts of greed and hubris, against which the better part of human wisdom has warned since the time of the Greeks. Forging a new set of policies and tools capable of meeting these new challenges will require the emerging science of complex systems, the search for true economic sufficiency that acknowledges nature as an equal partner, and the concern for fair and participatory democratic processes that have been emphasized throughout this work.

Clearly, the momentous adjustments required for moving onto a path of sustainable development will require a global commitment by all nations. Daly has emphasized the opportunity offered by a global social contract between North and South. The North, which accounts for most of the global throughput, should undertake to abandon mindless quantitative growth in favor of sustainable qualitative development. The North should also emphasize intragenerationally equitable distribution by aiding the South to achieve levels of welfare that will permit a demographic transition to stable populations and intergenerational equity through restoring the stock of natural capital. The South, in response, could undertake to stabilize human populations and to provide permanently protected habitats needed for assuring species diversity.

Making this transition from the present unsustainable course of plundering the Earth to a sustainable course is the major challenge to humankind today, but it can be accomplished by learning from past mistakes and by overcoming the failures we have discussed throughout this book. Although many of our institutions have served us well, we must continue to reduce the economic failures in markets, the intervention failures in governments, and even the failures in the nongovernmental organizations that we have created to offset failures in markets and in governments. Above all, and in many ways most difficult of all, we must confront *personal failure* in our individual choices about consumption, lifestyles, habitation, and work styles, and recognize that these are the decisions that ultimately determine environmental quality. Furthermore, the more affluence and education we are privileged to enjoy, the greater our opportunities and moral responsibilities are for making personal choices consistent with a sustainable civilization for the planet.

The transdiscipline of ecological economics attempts to draw wisdom from our past in order to provide new generations with the capability to envision a desirable and sustainable future and the navigational instruments with which to find the way. The world is at a critical turning point, especially from impending climate change. This turning will not come overnight, however. In fact we are probably already in the middle of it.

Now is the time of real choices: (1) we can attempt to continue business as usual, pursuing the conventional economic growth paradigm that has dominated economic policy since the end of World War II; (2) we can pursue an environmentally sensitive version of this model and attempt to achieve "green growth"; or (3) we can pursue a more radical departure from the mainstream that does not consider growth to be the real goal at all but rather sustainable human well-being, acknowledging uncertainty and the complexity of understanding, creating, and sustaining well-being. This book has described option 3, which entails a change in worldview, vision, and goals that would have far-reaching implications and will demand a substantial departure from business as usual. However, we believe it is the only option that is both sustainable and desirable on our finite planet.

In this book, we have sketched a vision of what this "ecological economics" option looks like and how we might get there. We believe that this option can provide full employment and a high quality of life for everyone into the indefinite future while staying within the safe environmental operating space for humanity on Earth. Developed countries have a special responsibility for achieving those goals. To get there, we need to stabilize population; more equitably share resources, income, and work; invest in the natural and social capital commons; reform the financial system to better reflect real assets and liabilities; create better measures of progress; reform tax systems to tax "bads" rather than goods; promote technological innovations that support well-being rather than growth; establish "strong democracy," and create a culture of well-being rather than consumption. In other words, a complete makeover.

These policies are mutually supportive and the resulting system is feasible. It is not merely a utopian fantasy. In fact, it is business as usual that is the utopian fantasy. We will have to create something different and better or risk collapse into something far worse.

The substantial challenge is making the transition to a better world in a peaceful and positive way. There is no way to predict the exact path this transition might take, but we hope that painting this picture of a possible end point and some milestones along the way will help make this choice and this journey a more viable option.

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