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Abstract

In their 1963 classic *Scarcity and Growth* Howard Barnett and Chandler Morse argued that resource scarcity did not threaten economic growth. A second investigation in the late 1970s, *Scarcity and Growth Reconsidered,* reached largely the same conclusion. The 25 years since that work was published have witnessed many developments. The message of *Scarcity and Growth* that depletion of market resources was not a problem has given way to a concern that "new scarcities" of environmental quality, global climate, and biological diversity are emerging. Resources for the Future recently assembled a distinguished group of international scholars to again address scarcity and growth. This paper describes their charge and summarizes their findings. Technological progress may hold the key to overcoming the scarcity of environmental resources. Market forces may not be enough to motivate the required innovations, which must instead be social and institutional as well as technical and will be constrained by interlinking complexities.

Key Words: history of economic thought, technological change, renewable resources and economy

JEL Classification Numbers: B12, B20, N50, O13, O14, O33, O47, Q20, Q32

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Introduction

One of the most famous and influential books ever published on resources and the human prospect appeared in 1963. In *Scarcity and Growth*, Howard J. Barnett and Chandler Morse interpreted the extensive data assembled by their colleagues Neal Potter and T. Francis Christy, Jr., in another seminal work, *Trends in Natural Resource Commodities* (1962). From those data Barnett and Morse made a compelling case that scarcity of the resources to which they devoted most of their attention did not yet, probably would not soon, and conceivably might not ever halt economic growth.

The interplay between scarcity and growth is an issue of perennial concern, however. Only a decade after Barnett and Morse published their work, pundits, politicians, and activists announced the arrival of an "energy crisis." Consumers accustomed to decades of the declining resource prices Barnett and Morse had documented found themselves waiting in long lines and paying skyrocketing prices to purchase gasoline. Academic researchers dusted off the writings of scholars such as Harold Hotelling (1931) and M. King Hubbert (1949), looking for insights into the causes and implications of rediscovered scarcities.

At roughly the same time, other types of scarcity were being recognized. Concern was growing over resources for which Barnet and Morse could not present data on prices and quantities. For much of human history, air, water, and land were employed for waste disposal with little thought for the consequences. When people were few and unspoiled lands plentiful, the consequences of waste were manageable. As these circumstances changed, however, the consequences of pollution mounted. A human population that stood at less than a billion in 1800 had climbed to 2.5 billion by 1950. By the 1970s some commentators were making apocalyptic

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projections for continued growth to be followed shortly by catastrophic decline (Ehrlich 1968). Humanity found itself increasingly unable to avoid the consequences of living with its own refuse. As Kenneth Boulding put it, the cowboy economy was becoming a spaceship economy (Boulding 1966).

Modern refuse was a more potent witch's brew than our ancestors were capable of producing. The concentrated wastes of humans and their animals have always been a breeding ground for disease, and packing ever-larger populations into cities compounded these risks. With the Industrial Revolution, however, new poisons came into broader circulation. Smoke from the coal burned in her "dark Satanic mills" stained "England's green and pleasant land." Another fossil fuel, petroleum, caused further problems. From Los Angeles to Athens to Tokyo, cities were increasingly smothered by the exhaust of their motor vehicles. Paper, metalworking, chemical, and other industries fouled air, water, and land.

So in addition to being the occasion of renewed concern regarding the scarcity of energy resources, the early 1970s also saw some of the first broad manifestations of concern with what we will call in this volume the New Scarcity: the limitations on the environment's capacity to absorb and neutralize the unprecedented waste streams of humanity. From celebration of the first Earth Day on April 22, 1970, to the first United Nations Conference on the Environment in Stockholm in 1972, to the enactment of broad-reaching environmental protection acts in many nations, citizens expressed their concerns over environmental degradation, and governments responded.

Scholars also weighed in. The Club of Rome's controversial 1972 volume *Limits to Growth* predicted that such limits were fast approaching and that global society ignored them at our collective peril (Meadows et al. 1972). Others were quick to fault the analysis in *Limits to Growth* (e.g., Nordhaus 1974). New scholarship appeared on the economics and management of natural resources (e.g., Dasgupta and Heal 1974, 1979; Solow 1974; Stiglitz 1974; Clark 1976).

In fall 1976 Resources for the Future held a conference to again investigate the topic of scarcity and growth. In many respects *Scarcity and Growth Reconsidered* (Smith 1979), the volume of collected papers and commentaries from that conference, echoes the optimism of its predecessor. That optimism had been buffeted somewhat by the events of the 1970s, however. Moreover, as one might expect from a volume combining the contributions of a dozen authors, *Scarcity and Growth Reconsidered* had a less synoptic perspective than its predecessor. Not only did some contributors raise doubts as to whether Barnett and Morse's relatively rosy perspective was justified, several also raised concerns regarding the limitations of received economic theory as a tool for analyzing scarcity and growth. And it must be said, *Scarcity and Growth Reconsidered* evidences some groping on the part of the practitioners and innovators of received theory to determine what their models could, in fact, say on the topic. Several of its chapters focused on determining what it was that available data could tell us about scarcity and growth, rather than on making pronouncements regarding long-term prospects from such data.

More than a quarter of a century has now passed since the chapters constituting *Scarcity and Growth Reconsidered* were collected. New modes of analysis have been developed in many disciplines. New empirical understandings have come to the fore. New questions have arisen. Even if we are no closer to a final resolution of questions of scarcity and growth, we are in a position both to bring new tools and facts to bear on them and to consider nuances that must now be addressed in answering them.

To investigate these issues, Resources for the Future, with generous assistance from the Vera I. Heinz Endowment, the Netherlands' Ministry of the Environment, and the European Commission, again assembled a panel of distinguished economists, natural scientists, and others to discuss scarcity and growth. On November 18–19, 2002, authors presented their draft papers and discussed them with other participants. Following these discussions the authors revised their contributions extensively.

Before reviewing these contributions, however, let us briefly discuss further the background and motivation for this undertaking.

Scarcity and Growth: The Long View

Before detailing our reasons for again revisiting a classic, we might first take inspiration from it and give the reader a broad overview of the issues, both historical and current, motivating continuing interest in scarcity and growth. Barnett and Morse displayed a genuine erudition that is sadly absent from much of what the economics profession produces today. Many readers remember *Scarcity and Growth* for its extensive quantitative and diagrammatic analyses. However, its first 100-odd pages are dedicated to an extensive, authoritative, fascinating, and in contrast to much that has been written on the subject in the years since, refreshingly jargon- and mathematics-free account of what great thinkers of earlier eras and many disciplines had to say about scarcity and its implications for continuing human well-being. Thus, when Barnett and Morse proceeded to present their quantitative analysis in the last two-thirds of *Scarcity and Growth*, the reader had been afforded a very complete introduction to the topic.

We cannot duplicate Barnett and Morse's introduction. We commend Barnett and Morse to the reader both for their careful scholarship and as an introduction to the perennial questions that remain as relevant as they were in the year *Scarcity and Growth* was published. We will also, however, in the space of the few pages available now for the purpose, attempt both to radically condense and to slightly update their introduction for readers of this volume.[1]

Perhaps the single most important point the original *Scarcity and Growth* established is that world views have changed remarkably in the past two centuries, particularly among economists. Thomas Carlyle bestowed on economics the sobriquet "the dismal science" in response to the writings of classical economists.[2] It is ironic that, some 200 years later, economists have come to be seen by some as Panglossian apologists for business-as-usual scenarios in which the invisible hand of the market will solve all problems: some early economists argued that our problems were insoluble.

There have, of course, always been both optimists and pessimists. Quintus Tertillianus, writing in A.D. 200, was surely not the first to suppose that the world was in decline. "We are burdensome to the world," he wrote. "The resources are scarcely adequate to us…Truly, pestilence and hunger and war and flood must be consider[ed] as a remedy for nations, like a pruning back of the human race" (quoted in Johnson 2000).[3]

Others, of course, had rosier perspectives—and such perspectives could claim an even more ancient pedigree. God himself might be supposed to have been a resource optimist, if one credits the Old Testament account of his directives. He created man in his image, to have "dominion over . . . all the earth… and over every living thing that moveth upon the earth" (Genesis 1:26, 28). The Almighty did not seem worried about the limitations of the earth's resources when he promised that the descendants of Abraham

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[1] The scale of our debt to Barnett and Morse in preparing this introduction is reflected in part by the fact that most of the passages quoted from famous economists in this section are taken from *Scarcity and Growth*.

[2] Somewhat surprisingly, given the widespread belief in the contrary notion, Carlyle was commenting on the racial views of John Stuart Mill, rather than Thomas Malthus's theory of population, when he wrote the remark. See Dixon (2002) and Levy and Peart (2003).

[3] D. Gale Johnson (2000) notes that Quintus "includes nearly all the modern complaints about the environmental effects of excessive population on environment—deforestation, loss of biological diversity, farming unsuitable land, drainage of the natural refuges for wildlife—as well as the massing of people in cities."

Joel Cohen (1996) provides an illuminating review of perspectives on the perils of overpopulation from Assyrian times to the present.

would proliferate "as the stars of the heaven, and as the sand which is upon the sea shore" (Genesis 22:17).[4]

Even if one were not entirely comfortable relying on divine Providence to improve the lot of humanity, the notion that human ingenuity would save the day also has a long history. Condorcet wrote in 1795 (1955) that

> …nature has set no term to the perfection of human faculties; …the perfectibility of man is truly indefinite; …the progress of this perfectibility, from now onwards independent of any power that might wish to halt it, has no other limit than the duration of the globe upon which nature has cast us.

Yet a very different view of the human prospect dominated many writings of the classical economists of the era. In his 1798 *Essay on the Principle of Population,* the British economist and cleric Thomas Malthus advanced his well-known theory that population tends to increase geometrically while food production can be expected to grow, at best, arithmetically. As a consequence, humanity tends inexorably to approach what came to be dubbed, almost two centuries later, the limits to growth, often with catastrophic consequences.

The early economists were a dismal bunch.[5] Even Adam Smith, the founder of the modern discipline, opined, "Every species of animals naturally multiplies to the means of their subsistence, and no species can ever multiply beyond it." Malthus's contemporary David Ricardo is remembered for his theory of rent. Resources are in short supply, and those lands favored by location or other attributes command high prices ("rents") and are quickly appropriated and exploited. This leaves latecomers on the economic scene with meager pickings from which to choose. As Robert Heilbroner remarked, "Anyone who was not sufficiently depressed by Malthus had only to turn to David Ricardo" (1967, 86).

Ironically, one of the fundamental insights of economic analysis led the classical economists to their misguided or—to give them the greatest benefit of the doubt and to suppose with today's pessimists that the case is not yet closed—*premature* dismal pronouncement. The principle of diminishing returns explains a tremendous amount in economics. The more there is

[4] We do not mean to suggest that Christian theology—of indeed, any religion—promotes profligate growth or resource use. Many modern theologians interpret the injunction to "have dominion" as to be good stewards of resource rather than to waste them (see, e. g., Daly and Cobb 1989).

[5] It is interesting to note, in fact, that Darwin credited Malthus with the fundamental insight motivating his theory of evolution. The scarcity of resources leads to the survival of the fittest.

of something, the less productive is still more of it. If natural resources are limited, we can expand the human workforce and manufactured capital employed in combination with them. Without more resources, though, our gains from employing more of other factors of production will be progressively smaller. It is the principle of diminishing returns that underlies the use of marginal analysis in economics, and it is marginal analysis that resolved the greatest puzzle in economics: the paradox of value. Why are some things, like water, both so useful and so cheap relative to things like diamonds, which are neither? Because of diminishing returns. In most times and places there is so much water relative to diamonds that a little more water is of little incremental, or marginal, value.

The principle of diminishing returns is, then, central in economics. Yet its straightforward implication is that economies relying on fixed stocks of land and other resources are, at best, destined for stagnation. At worst, population growth in combination with profligate resource use and a lack of foresight spells doom for the majority of mankind.

Many believed that. The great figures of early economics were often inaccurate prognosticators. William Stanley Jevons, who first formalized marginal analysis, is famous for his predictions concerning the calamities that awaited when coal was exhausted. His dire predictions now have a faintly comic tone; among other things, Jevons stockpiled reams of writing paper in anticipation of its eventual shortage.

The following might have been written by a modern conservationist:

> The world is really a very small place, and there is not room in it for the opening up of rich new resources during many decades at as rapid a rate as has prevailed during the last three or four. When new countries begin to need most of their own food and other raw produce, improvements in transport will count for little.

That quote is not taken from any consensus report of the recently concluded World Summit on Sustainable Development. It was, rather, the opinion of Alfred Marshall,[6] among the most important economists of a century ago.

Marshall did, however, also point the way out of the resource-constrained cul-de-sac. He went on to write that "the Law of Diminishing Returns can be opposed only by further

6 *Memorials of Alfred Marshall,* A.C. Pigou, ed. (1925), p. 326, as cited in A.J. Youngson, *Possibilities of Economic Progress* (London: Cambridge University Press, 1959), p. 33.

improvements in production; and improvements in production must themselves gradually show a diminishing return." Marshall was adopting the wisdom expounded by John Stuart Mill, the greatest economist between his generation and that of Malthus and Ricardo. Mill amended Smith, Malthus, and Ricardo by noting that the law of diminishing returns might "be suspended, or temporarily controlled, by whatever adds to the general power of mankind over nature; and especially by any extension of their knowledge."

Subsequent generations have yet to determine whether the implications of diminishing returns have actually been "suspended" or merely "temporarily controlled" by the "extension of knowledge." As economics evolved, however, statistical evidence seemed to show that knowledge was accumulating at an impressive rate (we will discuss a little later whether the evidence does in fact show this). Robert Solow, one of the leading economists of the post–World War II generation, is associated with the "residual," to which his name is often attached. The Solow residual is the share of output growth that cannot be explained by an increase in the use of inputs.

The gross domestic product of the United States grew at an average annual rate of some 3.4% between 1950 and 2000. We can decompose the growth of output from one year to the next as follows. It is the rate at which output grows in response to increases in labor hours times the change in labor hours, plus the rate at which output changes with changes in equipment used times the change in equipment used, and so forth, for all inputs. Economic theory holds that the rate at which output changes with changes in the quantity of an input is proportional to the price of that input. We can, then, decompose changes in output into constituent elements: the change in output due to change in labor plus the change due to change in capital equipment, and so on, weighting each by its price. Solow noted that these changes fall short of adding up. There is a residual, something left over—a difference between observed rates of overall growth and measurable changes due to changes in input use. In the decomposition we have just described, there is a missing term for the rate at which output changes with changes in unmeasured inputs times the proportional change in unmeasured inputs. This residual, commonly called multifactor productivity growth, averaged about 1.2% per year between 1950 and 2000.

The reason the residual is missing from the calculation we have described above is, of course, that it cannot be measured. In Moses Abramowitz's (1956) memorable phrase, the residual is "A measure of our ignorance." It is, by definition, what's left over when the effects of all measurable explanatory variables have been calculated. Despite this fundamental uncertainty, the productivity residual is often interpreted as the effect of technological progress. To foreshadow an issue we will discuss below, however, we should note other possibilities. The missing input the residual represents could also be an increase in the unmeasured consumption of resources that are not traded in markets, a category in which we might also include degradation of the environment.

One of the editors (RUA) has recently put forward another hypothesis. The observed growth in productivity might be explained by historical increases in the efficiency with which one particular input is used. That input is available energy (or more concisely, "exergy"). The efficiency with which raw resources are converted into what physicists call "useful work" has improved markedly over the past few centuries. This finding is entirely consistent with the results derived by Barnett and Morse and later optimistic authors. If, however, progress is tied to the consumption of particular resources rather than being "disembodied," the scarcity of such resources would constrain growth. Moreover, as may now be a more realistic concern, if other scarcities associated with the consumption of such resources (we have in mind here primarily global climate changed induced by anthropogenic carbon dioxide emissions) are more constraining that is the physical availability of the resource *per se*, growth would be limited.

What does productivity growth mean? If we take the rosy view that it can be extrapolated into the indefinite future, it means that we have little to worry about. Recent work by Martin Weitzman (1997) suggests that, if we assume that productivity growth will continue at its historical level *ad infinitum*, conventionally measured national income *understates* true welfare by as much as 40%. A more nuanced interpretation might arise if technological progress were tied with the use of particular resources that were in short supply or occasioned unacceptable environmental consequences. If we take the view that the residual reflects profligate waste of unmeasured resources, productivity growth would represent an ominously mounting account payable.[7]

The optimistic view has dominated the economics profession in recent decades. The dismal science has reversed direction since the dire predictions of Malthus and many who followed him through at least the early years of the past century. Diminishing returns remain a fundamental element of the economics canon, but many believe that their long-run implications

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[7] We should note some logical limitations on this pessimistic view, however. To suppose that measured productivity growth is predicated on deterioration of natural resources would require that such deterioration continued year after year. After a certain point it would be implausible to maintain that degradation was fueling productivity, as a sufficiently long stretch of productivity growth would have to mean that the resources in question were fully depleted.

have been more than offset by an equally fundamental element. Majority opinion is that over substitution possibilities obviate resource scarcity, with solutions to what some might see as long-term resource constraints arising in surprisingly short spans of time. Diminishing returns still provide reasonably robust explanations of many microeconomic phenomena (e.g., why demand curves slope down). Over any appreciable sweep of time, though, optimists believe that the implications of the scarcity of any particular resource are obviated by the abundance of potential substitutes, an abundance that grows as technology evolves.

In writing the original *Scarcity and Growth,* Harold Barnett and Chandler Morse noted that among the classical economists "the doctrine of diminishing returns per capita became embedded in economic theory as a self-evident fact, requiring neither precise formulation nor analytical investigation" (1963, 51). The tables may have turned in the modern era. Some regard the fact that dire predictions have not come true as almost a proof by induction that they never will.

One reason the classical economists' emphasis on diminishing returns may have been misplaced is found in the passage quoted from Alfred Marshall above. He asserted that "improvements in production must themselves gradually show a diminishing return." On this point he is explicitly contradicted by J.M. Clark (1923), whose remark is more often quoted: "Knowledge is the only instrument of production not subject to diminishing returns."

It is difficult to verify Clark's assertion in the absence of an operational measure of a notion as intangible as knowledge.[8] Knowledge is, however, different from most other economic goods in one important respect. It is *nonrival*. There is no physical reason why my possession of certain knowledge precludes your use of the same knowledge (there may, however, be legal reasons, since intellectual property law governs patents, copyrights, and the like). In this respect, we see an interesting parallel between knowledge—often touted as the ultimate solution to problems of scarcity—and the New Scarcity that provides much of our motivation for again revisiting *Scarcity and Growth*. Environmental pollution and the depletion of global ecological assets are also nonrival. The same smoke that makes my eyes water and lungs burn will have a similar effect on you, and the accumulation of atmospheric carbon dioxide and diminution of global biodiversity may affect people all over the world.

[8] This is not impossible. Many modern approaches to economic growth theory have employed the Dixit-Stiglitz (1977) model of differentiated products. If knowledge is defined as "the number of products we know how to make," then there can, in fact, be increasing returns to scale in knowledge.

Markets do not allocate nonrival goods efficiently. Too little knowledge is likely to be produced, as innovators often generate spillovers that others can appropriate and from which they can benefit.[9] Too much pollution is likely to be produced as polluters generate wastes that spill over into the public domain. One might say, then, that the ultimate resolution of scarcity and growth depends on the resolution of two policy issues. First, can we as a global society do enough to restrict the negative spillovers we impose on ourselves through pollution? Second, can we do enough to promote innovation that generates positive spillovers through the augmentation of knowledge, given diminishing returns over time to any particular channel of innovation?

Scarcity and Growth Today

There are now—as there no doubt always will be—differing opinions concerning the adequacy of resources for a growing population seeking a higher standard of living. A generation ago, *Silent Spring* (Carson 1964), *The Population Bomb* (Ehrlich 1968), and *Limits to Growth* (Meadows and Meadows 1972) announced the dangers of pesticides, overpopulation, and resource depletion, respectively. Such works have been succeeded by tomes detailing evidence of climate change (IPCC 2001) and biodiversity loss (Wilson 1992). And just as the late Julian Simon disputed the pessimism of earlier writers, commentators such as Gregg Easterbrook in *A Moment on the Earth* (1995) and Bjorn Lomborg in *The Skeptical Environmentalist* (2000) have argued that things are not so bad, and are arguably getting better (many contributors to this volume tend to the more pessimistic view).

If there is a trend to be noted in the debate between optimists and pessimists, it is not so much that one or the other is prevailing as that the terms of the discourse are deteriorating. Titles tell a great deal: Paul and Anne Ehrlich called their broadside against "brownlashers" who downplay environmental concerns *The Betrayal of Science and Reason* (1996). On the other side of the issue, Ronald Bailey titled his own contribution to the debate *Ecoscam: The False Prophets of Ecological Apocalypse* (1994).

Still, for all the vitriol loosed in recent debates among the optimists and the pessimists, it is difficult to say from a review of the evidence whether our generation might be more or less

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[9] It is, however, possible that a common-pool effect can end in the opposite result. If one innovator's product can supersede or obviate another's, one rival's investments in innovation can be stranded by another's success. If the successful innovator does not take account of this effect, she may devote too much effort to producing new and better products.

concerned than were its predecessors concerning the state of the planet we inherited from our parents and will pass along to our children. While recognizing, with Oscar Wilde, that one might be accused of knowing the price of everything and the value of nothing, let us begin by reporting economic statistics. It has been estimated that the aggregate value of global economic production was something less than \$700 billion in current dollars in 1800. It had increased to about \$2.5 trillion a century later, \$5.3 trillion in 1950, and was nearing \$35 trillion at the turn of the new century (Maddison 2002).

One would, of course, want to know something about how these figures translate into per capita terms before making any judgments concerning what they say about the human prospect. World population has also increased at a dizzying pace. It was not until the early 19th century that population reached 1 billion, and not until after World War I, nearly 120 years later, that it passed 2 billion. Since then, during the space of a single, not exceptionally long lifetime, world population has tripled.

Economic performance has, however, kept pace with this explosive growth and has itself increased at an increasing rate. On average, each of the billion people on the planet two centuries ago got by on an income that, estimated as best we now can, totaled between \$600 and \$700 per year in today's dollars. By 1900 this had increased to well over \$1,000 a year. It exceeded \$2,000 per year in 1950 and now stands at nearly \$6,000 per year.

It is, of course, extraordinarily difficult to translate into contemporary dollars the income of someone who lived without electric lights, motorized transportation, even the most rudimentary of medical treatment, or any of the host of other conveniences many of us have come to regard as necessities. A measure of per capita income is intended to convey some notion of the standard of living a person can afford, and it is difficult to make a comparison between such different consumption possibilities as those our ancestors faced and our own.

Several authors have suggested a compelling thought experiment, however. It demonstrates that the pace of economic development has (*on average*, it is important to point out) accelerated markedly in recent decades. Although many of the same problems of measurement bedevil comparisons over shorter time periods, we might have more confidence in saying that average per capita income has roughly tripled in the past 50 years. Extrapolate that rate of growth back 2,000 years and one arrives at a per capita income of far less than a penny ($\$6{,}000/3^{40} = 5 \times 10^{-16}$!). Even allowing for huge problems of measurement, a human being simply could not survive on so little. The fact that humans did survive the poverty of our race's first thousand millennia establishes that the pace of economic progress has increased dramatically.

Let us return to the population growth figures for a moment. Extrapolation of growth at the rates of the past half-century quickly leads to surreal results. If population were to continue growing at 1.5% per year for another two millennia, the human population would weigh more than does the earth itself! This would, of course, be a physical impossibility. Demographers and others have long recognized that continuing faster-than-exponential growth would sooner or later—but probably "sooner"—lead to a catastrophic collapse. There can be no serious dispute of this conclusion. What reasonable people may disagree upon, however, is the point at which collapse is likely to occur and the extent to which humanity is likely to regulate its own expansion. Perhaps the only answer to the first question is "nobody knows for sure," although many commentators seem to concur that the answer is probably "when there are more people than there are now." As Joel Cohen (1996), who has written the definitive tract—*How Many People Can the Earth Support*?—notes, the issue may not be so much how many people *can* the earth support as what kind of earth is consistent with a human population of any given size.

Although world population rose over the past decade at roughly the same average annual rate of 1.5%, there also seems to be emerging evidence that the rate of population growth is slowing. A United Nations 2002 report, *World Population Prospects,* predicts a population of some 8.9 billion in 2050. This increase of nearly 3 billion over the current total represents more additional people than the total number who were alive in 1950, but it also reflects a significant reduction in growth rates: it implies an average annual rate of growth over the next half-century of less than half the current growth rate. Even this rate overstates the long-term trend, as most experts agree that population growth will slow to a halt at some point in the next century or two (if, that is, numbers do not first decline).

The prediction of a stable (as opposed to collapsing) population itself reflects some optimism concerning the ingenuity or self-discipline of humanity. This optimism arises in large part from the experience of the world's wealthier nations. There is a pronounced, if imperfect, correlation between nations' wealth and their population growth rates. Poor nations tend to have high rates of population growth—despite often appalling rates of infant and overall mortality. In contrast, some rich nations are now facing potential fiscal crises as their aging populations reach retirement age with few young workers to take their places. Immigration may be required if the elders of today's wealthy nations are to retain their standard of living.

So, taken in aggregate, world economic performance has increased, the perception of improvement survives translation into per capita figures, and there is reason for hope that we will not overwhelm the planet with our sheer numbers. Even these observations do not point to entirely rosy prospects, however. As we have just noted, population growth rates tend to be higher among the poorer nations. And the plight of the poor remains heartbreaking. Average figures mask the fact that the distribution of income remains highly skewed. Well over a billion people now eke out the best living they can on an income of about a dollar a day. Recall that this is about half of world per capita income in 1800.

The plight of the poor raises two disquieting worries: either the poor may become wealthy, or they may not. Though it may seem a wonderful thing for the world's poor to become wealthy, the prospect brings the issues of scarcity and growth into stark relief. A billion or so wealthy people are now exposing the earth to unprecedented environmental threats. Can the planet tolerate *8 billion* people living the lifestyle of the wealthy?

Or, as no less a humanitarian than Jesus himself said, "ye have the poor with you always" (Mark 3:8). Millennia ago, a few thousand wealthy nobles enjoyed greater material wealth than did a few million struggling peasants. Now a billion-odd denizens of the wealthy industrial countries enjoy far greater health, wealth, and prospects than do the billions who live hand-to-mouth. Philosophers might debate whether current inequities are more troubling than historical ones, but no one would suggest either is ideal. It is troubling that there is little compelling evidence that the world's poor are catching up to the wealthy (Pritchett 1997). Would we be satisfied living in a "sustainable" world if most people were frozen in a status in which they struggled to achieve subsistence?

Such questions beg the larger question of what we mean by economic growth. If economic growth were necessarily linked with increases in the physical insults we impose on the earth, it seems clear that indefinite growth would not be desirable—or even possible. If economic growth among the poor meant that tomorrow's poor would exactly replicate the production processes and consumption possibilities of today's wealthy, we might also conclude that such growth is either illusory or a contradiction in terms.

Yet economic growth has in fact been as much a qualitative as a quantitative phenomenon. The optimistic view of the improvements in productivity we have discussed means essentially that every year we acquire the ability to make greater physical quantities of outputs using smaller physical quantities of inputs. Moreover, every year we acquire the ability to make *different* outputs. Automakers may have made different choices than environmental advocates might have wanted them to as they refined their designs, but cars today are very different than they were 50 or 75 years ago and, if we impose the standard of value-per-dollar-spent or hours-worked-to-acquire, qualitatively better than their predecessors. The same might be said of airplanes, communications, fabrics, electric lights, office equipment, and virtually any other purchased good or service we might name.

A problem is captured in the limitation "any other *purchased* good or service," however. Any number of *unpurchased* goods and services deteriorated as incomes rose, populations increased, and the activities captured in the measured economy increased. Progress has undoubtedly been made in controlling the production and release of many pollutants. Researchers have identified an environmental Kuznets curve under which countries' emissions of some pollutants first increase, then decrease, as their per capita wealth increases (Grossman and Krueger 1995). One might hope that airborne particulates, organic wastes in water, and other common pollutants would be controlled as incomes increase.

This may be too optimistic a prognosis in several respects, however. First, there may be a composition effect in the income-pollution relationship. Wealthier societies often concentrate their own economic activity in high-technology and service industries, relegating—or perhaps even "exporting"—dirtier industries to less developed countries. Moreover, such composition effects may better explain the observed pattern of industries and pollution across countries at different income levels than the aggregate global emissions over time. It seems unlikely that *every* country will devote its economy to low-emissions manufacturing and services: someone will need to specialize in the industries in which pollution is more difficult to control.

Second, not all pollutants can be expected to follow the inverted-U relationship of the environmental Kuznets curve. It is not clear exactly how dependent modern industrial economies are on fossil fuels, but wealthier countries generally consume more of them. Such fuels are the primary contributors to greenhouse gas emissions, which in turn drive global climate change. It seems unduly optimistic to suppose that the world as a whole will simply grow its way out of concern with climate change.

Finally, greenhouse gases are an example of a process that cannot be quickly reversed. They are cumulative pollutants. It has been estimated that the atmospheric concentration of carbon dioxide (CO_2—the most important of the anthropogenic greenhouse gases) was more or less stable at around 280 parts per million (ppm) for thousands of years.[10] It began to increase following the Industrial Revolution, reaching 315 ppm in 1957 and some 362 ppm now (Vitousek et al. 1997). Even if all further CO_2 gas emissions were to stop tomorrow, it would take quite some time for the atmospheric concentration to return to preindustrial levels.

Changes in atmospheric chemistry may be slow to reverse. Losses in biological diversity are, on any reasonable scale, completely irreversible.[11] It will make little difference to the preservation of biodiversity, then, if in 10, 100, or 1,000 years' time human societies have found ways to reduce the chemical pollution, overharvesting, transport of exotic species, climate change, and most important, destruction of indigenous habitats that now threaten the species with which we share the planet.

No one is certain how many species now live on earth. Estimates range from a few million to many tens of millions. New species come into being through a combination of geographical separation and genetic mutation. Existing species are extinguished when then cannot adapt to changes in habitat or compete with existing or introduced rivals. Recent estimates suggest, however, that human activities are multiplying the rate of extinction by many times its "background" level (Raven 2002).

Our digressions concerning climate change and biodiversity underscore important aspects of the New Scarcity. Both climate and biodiversity provide global public goods. Everyone on earth is affected by changes in climate. Everyone on earth may be affected by changes in biological diversity and the ecological services diverse natural ecosystems provide. As we will detail in a moment, the spatial and temporal scale of the problems create tremendous challenges for policy. In the original *Scarcity and Growth* and in *Scarcity and Growth Reconsidered,* the general sense was that the mechanisms of markets were adequate to the task of allocating resources in an efficient and sustainable way. Most of the attention was on resources traded in markets, however—resources subject to traditional scarcity. In this volume the focus has largely shifted to the adequacy of our social mechanisms for coping with the New Scarcity.

Let us now turn to the ways in which our authors have addressed these matters.

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[10] This can be inferred from its concentration in polar icecaps, as the snow that fell millennia ago has been insulated from the atmosphere by subsequent accumulations.

[11] During each of the five episodes of mass extinctions that have been identified in the geological record, large fractions of extant species were extinguished. Species diversity eventually recovered after each and eventually reached new highs, but the time span for restoration measures in the millions of years (Wilson 1992).

The Contributions

In their contribution David Menzie, Donald Singer, and John H. DeYoung, Jr., survey a subject that was of tremendous importance in the first *Scarcity and Growth*: the physical availability of resources. These authors reach some conclusions that echo those of earlier investigators. They conclude that the supply of minerals per se is not a limit to growth. Yet causes for concern persist. Although abundant quantities of many resources remain, they are becoming progressively more remote. It is only natural that mineral (and fuel and biological) resource stocks were most intensively exploited first in the areas closest to where they were used. As demands increased, exploration and eventually extraction took place across oceans, in inhospitable climates, and for minerals and fossil fuels especially, deeper and deeper beneath land and water.

This situation again raises the classic tension between the depletion of (easily accessible, at least) resources on one hand and exploration- and extraction-cost-reducing technological progress on the other. Many of the facts Menzie, Singer, and DeYoung present can be seen as analogous to a glass either half full or half empty. Per capita consumption of many minerals has remained relatively steady in the developed nations, despite talk of the "dematerialization" of economies dominated by high-technology and service industries. As less developed countries become wealthier, their consumption may be poised to increase to levels comparable to those of the industrialized nations. An optimistic view is that resource scarcity has yet to decrease use in an ever-wealthier and more populous world. In fact, an optimist might be further buoyed by the observation that wealthy countries have not even been compelled to resort to substitutes for common mineral commodities (of which optimists would suppose there to be many). A more pessimistic view is that we simply do not have adequate reserves to suppose that ever-growing numbers of people can *all* consume at the level to which the wealthy have grown accustomed.

Recent trends in exploration effort might also motivate similarly dichotomous views. Menzie, Singer, and DeYoung note with some concern declines in mineral exploration budgets, research expenditures, and training. Here a pessimistic view would be that this lack of preparation could reflect, at best, a lack of foresight, and at worst, a recognition that such effort would be futile given the existing state of depletion. Yet one might as easily take the contrary view that the reason for a decline in exploration is to be found in the recognition that known stocks will be adequate, and new ones can be identified as needed.

One thing that does come through clearly, however, is that society is increasingly recognizing the nonmarket costs of mineral extraction. More and more land is being placed off-limits to such activities, either in appreciation for the unique services provided by pristine landscapes or in recognition of the incompatibility of mining and residential uses. Moreover, similar concerns arise with respect to the residuals arising from mining: society is less willing to tolerate the pollution and degradation that unrestricted extraction can impose.

Here again one might take either an optimistic or a pessimistic view. The pessimist may see the increasing environmental restrictions placed on mining as further evidence of the constraints resource scarcity places on us: both minerals and pristine ecosystems are becoming scarce, and scarcity of one imposes further pressure upon the other. A world confronted with such interlocking constraints simply cannot afford to continue in its ways. The optimist could reply that the fact that the world has continued in its ways indicates that we have the means to continue our material consumption while preserving our environment.

Optimists of a different stripe might take another tack, however. Whether or not the preservation of natural landscapes proves compatible with continuing our level of physical consumption or, more generally, our overall well-being, the fact is that something has been done to preserve natural landscapes. Voters have voted, legislators have legislated, and as Menzie, Singer, and DeYoung note, nongovernmental environmental interest groups have taken action to restrict environmental harms. Reasonable people can differ as to whether such developments represent overreactions or an instance of too little too late, but they do suggest that there is a marketplace of ideas and policies in which the New Scarcity has begun to be discussed and addressed.

Jeffrey Krautkraemer surveys some of the same territory as do Menzie, Singer, and DeYoung in his contribution, titled "Economics of Scarcity: State of the Debate." He also marshals extensive economic as well as physical data on resources. In updating many of the figures presented by Barnett and Morse, he generally confirms their findings after a span of some 40 years. The real prices of *most* commodities have declined since 1960.

Krautkraemer's figures highlight some other important developments, however. Researchers could not have argued that resource prices were generally falling in 1980. Many mineral and food prices peaked at approximately the same time as did those of fossil fuels. Although different commentators express different opinions, it seems again that conflicting conclusions might each be supported by the data. On one hand, one might assert that the 1970s and early 1980s were a historical aberration in the long-run trend of declining real resources prices. On the other, one might say that the past two decades have been the aberration, a temporary—and perhaps final?—respite from inexorable scarcity.

The pessimism of the latter conclusion might be refuted by reference to futures markets and the prices of underlying assets. If it is generally felt that resource prices will increase over time, rational investors will bid up the current prices of, for example, oil leases and mining sites. Although confidence in the rationality of investors is an article of faith among many economists, observers from other disciplines draw different conclusions. That confidence has surely been shaken by the economy's recent experience with "irrational exuberance" in other asset markets.

The evidence from existing markets for assets that have entered the market economy is, then, generally positive but admittedly mixed, and subject to the skepticism of those reluctant to accept economists' common postulate that markets reflect the foresight of rational participants. Krautkraemer also surveys some physical evidence concerning the state of resources that are not traded in markets. There is greater cause for concern over the status of air, water, climate, and biological diversity. Again, however, the question remains open as to whether emerging institutions and instruments for the allocation and preservation of these nonmarket resources will be adequate to the task of securing a sustainable future in the face of the New Scarcity.

This question is taken up in greater detail by David Tilman and Stephen Polasky. Their contribution, "Ecosystem Goods and Services and their Limits: The Roles of Biological Diversity and Management Practices," details concerns with what may be one of the most profound but perhaps least understood changes humanity is working on the planet. Paleobiologists have identified five episodes of mass extinctions in the geological record. Each was likely caused by volcanic or astronomical cataclysm. The most recent occurred some 65 million years ago, when an asteroid impact plunged the earth into darkness and exterminated the dinosaurs, among many other less well-known forms of life.

Many natural scientists now warn that we are entering a sixth "extinction crisis." This, in contrast to the first five, is believed to be caused by the increasing dominance of a single species: *Homo sapiens*. The numbers we have cited above concerning the growth of human population and of our economies may have a darker side in terms of our impact on the other forms of life with which we share the planet. An often-cited article by Peter Vitousek and his colleagues has estimated that humanity appropriates either directly or indirectly 40% of the world's accumulation of biomass in plants (known formally as "net primary productivity"). Other indices of our impact are as alarming. It has been estimated that the natural background rate of species extinction is one species per million per year. Some scientists suggest that the current rate of extinction exceeds the background rate by a factor of 1,000.

Biodiversity loss stems from many causes—human-induced factors in addition to natural threats from competition and predation. Some species (such as passenger pigeons and dodos) have been hunted to extinction, or nearly so (blue whales, otters). Others, particularly on islands, have been outcompeted or preyed upon by exotic species introduced by human travelers. Chemical pollution threatens still others. The effects of climate change on biodiversity are difficult to predict but potentially profound. Many biologists believe, however, that the single greatest threat to biodiversity today comes from the conversion of natural habitats to alternative human use. The native forests, prairies, and wetlands of the world are being felled, plowed, and drained for factories, homes, and farms. When natural habitats disappear, so do the organisms that depend upon them.

What does this "cost" us? To many people, such a question will either seem crass ("How can we put a price on life!"), or its answer obvious ("It is costing us our soul!"). There are more pragmatic answers to the question, however. Although economists and ecologists have not yet been able to provide any concise dollars-and-cents answers, Tilman and Polasky have been at the forefront of efforts to provide quantitative estimates of the effects of biodiversity loss.

Less diverse habitats are demonstrably less productive by various measures that both ecologists and economists might think important. Tilman and Polasky report the results experiments in which less diverse habitats have been shown to produce less biomass, leach more nutrients, and otherwise perform worse than do more diverse natural assemblages. The authors also present some simple conceptual models explaining why such results might arise.

The observation that more diverse habitats are, in some sense, "better" than those converted to other human uses begs some questions, of course. Obviously, if everyone thought natural landscapes superior to simplified and managed landscapes everywhere, no natural landscapes would be converted to alternative uses. The problem, then, arises if *too many* natural landscapes are converted, or used too intensively. That is, there is a problem if those who convert natural landscapes to artificial ones for their own benefits impose additional costs and burdens on others.

This, however, is precisely what the problem with biodiversity loss may be. The people who clear the land that shelters biodiversity derive private benefits from doing so, but most of the costs of biodiversity loss may be spillovers accruing to other people at other locations. This would be the case with ecosystem services—water purification, habitat for organisms that control pests and pollinate crops, prevention of erosion, and a host of others.

More generally, everyone in the world may be rendered spiritually poorer for the loss of the other species with which we share the planet. Barnett and Morse quoted at some length from John Stuart Mill's writings in *Scarcity and Growth*. Let us repeat a shorter passage here:

> Nor is there much satisfaction in contemplating the world with nothing left to the spontaneous activity of nature; with every rood of land brought into cultivation, which is capable of growing food for human beings; every flowery waste or nature pasture ploughed up, all quadrupeds or birds which are not domesticated for man's use exterminated as his rivals for food, every hedgerow or superfluous tree rooted out and scarcely a place left where a wild shrub or flower could grow without being eradicated as a weed in the name of improved agriculture.

This sentiment is perhaps even more valid today that it was when Mill wrote it a century and a half ago. Tilman and Polasky remind us that we ignore our relationship with dynamic creation at peril to both our physical and spiritual well-being. Regrettably, there is probably less attention to the biological aspects of the New Scarcity than to the chemical.

The chemical aspect of the New Scarcity that has attracted the greatest attention in recent years is global warming. The Swedish chemist Svente Arrhenius predicted as early as 1896 that the anthropogenic release of carbon dioxide from the burning of fossil fuels would lead to global warming via a greenhouse effect. A potpourri of gases have been identified as having such effects, but carbon dioxide is the most important anthropogenic greenhouse gas because the mass of its anthropogenic releases is greatest. Burning fossil fuels—petroleum-based distillates, coal, and natural gas—releases carbon dioxide to the atmosphere. So does felling forests. Both activities take place on a huge scale.

Christian Azar considers policies to address climate change in his contribution, "Emerging Scarcities—Bioenergy-Food Competition in a Carbon Constrained World." His message illustrates a combination of both possibilities and concerns that exemplify the challenges embodied in the New Scarcity. Although it is clearly possible to do something about the problem of climate change, the generation and adoption of new technologies could have profound effects on the concentration of greenhouse gases in the atmosphere.

The challenges are daunting, however. First, let us consider the magnitude of the problem. People in the United States produce approximately 17 times as much CO_2 per capita as do people in the developing nations of Africa and the Asian subcontinent. Stabilizing CO_2 concentrations in the atmosphere would require that the per capita emissions of the wealthy countries plummet to the current levels of the world's poorest nations. If business continues as usual, it seems more likely that the emissions of the poor countries would increase to the levels of the wealthy.

This need not be the case, however. There are technological alternatives that might yield comparable quantities of usable energy without further increasing greenhouse gas concentrations. The theme of Azar's chapter, however, is that we should be careful not to create or exacerbate one set of problems in our attempt to solve another. Consider, for example, greater reliance on nuclear power. This might represent a Faustian bargain: the current generation would be producing highly poisonous spent fuel whose safekeeping would need to be passed on to future generations. Although technological fixes may arise, supposing that they *will* seems unwarrantedly optimistic.

Moreover, nuclear technology raises uncomfortable issues concerning the poorly understood aspects of social relationships. Howard Barnett may have again been prescient when in 1979 he offered his perspective in *Scarcity and Growth Reconsidered*. Among many other observations, he noted that

> [t]he nuclear nightmare is rooted in military and political affairs and violence, not in economic growth. The dangers…are societal terrorism, violence, mass destruction, and related political problems.…The solutions for environmental pollution are relatively simple and at hand…this cannot be said of nuclear dangers.

If the "solutions for environmental pollution" are not, in fact, "relatively simple and at hand" in an era in which climate change and biodiversity loss create problems of global scope, it is hard to disagree with his assessment of the dangers of "societal terrorism, mass destruction, and related political problems." In 1945 the world's wealthiest nation produced its first atomic weapons. Little more than half a century later, India and Pakistan exploded nuclear devices—and made ominous threats to use them against each other. Recent events have led the world to doubt that even "peaceful" nuclear programs would prove entirely benign. Presidents and prime ministers around the world spend sleepless nights worrying about nuclear weapons falling into the hands of terrorists.

What may seem a more benign solution to the problem of climate change is to meet our energy needs in a renewable and sustainable way. Azar provides some rough estimates of what would be required if the world were to avert climate change by relying to a greater degree on biomass—crops grown for their energy value. Could it be done? Perhaps. What would be the consequences? Most likely, a sizable increase in the amount of the globe placed under cultivation and with it, an appreciable increase in the price of food to the developing world, as well as further reduction in the amount of relatively unspoiled habitat maintained to support biodiversity.

There is perhaps no better source of far-fetched anecdotes than the projections that "experts" of previous decades or centuries made of the circumstances of their descendants. Azar's calculations are offered with appropriate modesty. Regardless of whether his particular scenarios come true—or whether the options he identifies are chosen over others—he illustrates a general principle. The New Scarcity is actually a complex of interrelated scarcities that cannot be considered in isolation. If the potential of the atmosphere to absorb greenhouse gases without overheating is truly limited, we must look to alternatives that may themselves reduce arable land and biological diversity, increase the need for international oversight of nuclear programs, and induce other major social and physical changes virtually *ad infinitum*.

Having said all this, we know that hope springs eternal and need not always be disappointed by harsh realities. We employ technologies our great-great-grandparents never imagined, and our great-great-grandchildren may regard our circumstances as similarly rustic. Still, Azar's chapter reminds of us several things. One is simply that we are confronted by emerging and overlapping scarcities. A second is that resolution of these scarcities requires careful consideration of social policies, either for addressing them directly or developing technological alternatives.

A third issue is that inventing new technologies may involve unleashing genies from bottles. Nuclear power and weapons are perhaps the foremost examples, but the advent of biotechnology is another. The techniques of genetic modification may allow spectacular advances in medicine, agriculture, and industry. They also spark fears of ecological catastrophe and, in the hands of the insane or disgruntled, could lead to the creation of terrifying epidemics—"the poor man's nukes," as some worried strategists call them. It may be worth remembering that we do not always appreciate the ramifications of our technologies initially.

Most of what we have said thus far involves, in one aspect or another, notions of "sustainability." This term has been used increasingly frequently since it entered the popular lexicon at the time of the Brundtland Commission's report in 1987. As John Pezzey and Michael Toman note in their contribution, "Sustainability and Its 'Economic' Interpretations," however, part of the appeal of the term is its lack of precision. It is difficult to be opposed to a concept that essentially means "intergenerational fairness," especially if the person proposing it is not required to say what she means by "fair."

We might all agree that fairness means that no one should be treated better than anyone else. Beyond that, however, we run into a number of difficult philosophical problems. Pezzey and Toman distinguish "weak" from "strong" sustainability. The former essentially means that earlier generations are not better off than are later. The latter seeks to guarantee that outcome by ensuring that later generations do not have to make do with depleted assets relative to those enjoyed by their ancestors.

Such definitions beg many questions, however. Strong sustainability, if taken to an extreme, admits a *reductio ad absurdum*. Even if a society took the strongest possible measures to preserve all aspects of its natural, technological, and social assets for posterity, it would be impossible to accomplish this end literally. Just as one cannot step into the same river twice, natural processes alone will ensure that there are *some* differences in the constellation of assets available from one generation to the next. Defining a sustainable world as one in which "natural" processes are free to run their course begs the question of what is natural when humans take conscious steps to intervene or not intervene in natural processes.

Much of the debate surrounding sustainability concerns the possibilities for substitution among assets. Advocates of a "strong" form of sustainability generally argue that opportunities for substitution between natural capital, such as that represented by diverse natural ecosystems and the climate moderation and waste disposal services of the atmosphere, and anything that humanity can manufacture are, at least under the conditions in which we now find ourselves, very limited. Further reductions in natural capital could prove catastrophic, as there is no alternative to its use.

These are the types of questions that arise in the tricky navigation among concepts and criteria of sustainability. In Pezzey and Toman's chapter, two other major issues arise. The first concerns when a market economy is sustainable. To some this will seem a rather strange question. Under some restrictive conditions that we will discuss further below, a market economy can be shown to satisfy certain optimality conditions. What would it mean if an economy were optimal but not sustainable?

Pezzey and Toman suggest that the paradox of an unsustainable market economy can be resolved by postulating dual roles for individuals, as both consumers and citizens. I can, as a consumer, behave as the textbook *Homo economicus* who maximizes his satisfactions by undertaking economic transactions. As a citizen, however, I may have a different outlook and pursue different objectives. I may manifest a concern for future generations that belies the maximize-discounted-present-value objective economists presume and, perhaps, private consumers pursue.

The idea that we pursue different agendas as consumers than as citizens is not really that unusual and leads into the second major issue in discussing the sustainability of market economies. As citizens, those of us fortunate enough to live in democratic societies regularly vote to express our preferences for public policies to restrain our excesses as consumers and producers. A market economy can achieve a socially optimal allocation of resources across time without resorting to any central system of command and control if there are no externalities—costs or benefits generated by one party that accrue to others, and for which no payment is rendered. Such externalities are the very essence of the New Scarcity. When there are externalities, there is no guarantee that a free market will allocate goods optimally over time, or even across consumers in a given period. It is not, then, necessarily a contradiction in terms, nor does it reflect a philosophical inconsistency, to ask whether our economy achieves socially desirable outcomes or sustains our long-run well-being.

The next several contributions investigate the processes by which technological innovations are generated and applied. Robert Ayres's perspective is largely historical. In "Resources, Scarcity, Technology and Growth," he traces the development of important technologies of the 18th through 20th centuries. In the cases of coal-fired steam engines, the development of practicable technology for aluminum smelting, and the rise and spread of electrification, he identifies common themes. One is that one innovation begets another, leading eventually to feedback loops. An early application of the steam engine was pumping water from coal mines. This made it possible to mine deeper, leading to greater availability of coal, which led in turn to wider application of this relatively compact source of energy to industry and transportation. Railroads brought coal to steel mills, where it was used fire furnaces from which were forged more rails and parts for larger and stronger steam engines. Similar feedback loops among innovations characterize the development of other industries.

These cycles of development have interesting attributes. One is that they often drive a rebound effect in which scarcity of a resource motivates an innovation that, through cycles of synergies and recombinations with other innovations, eventually results in far more consumption of the resource whose perceived scarcity drove the original innovation. Steam engines were first used to facilitate the recovery of coal. Once the steam engine had been developed and applied to transport and industry, it spurred the creation of innumerable other innovations, and far more coal was mined and consumed than before its invention.

Ayres emphasizes that innovation displays a fundamentally episodic character, with relatively narrow sectoral impacts in most instances. Major innovations, such as the development of the steam engine, appear as discrete events in the historical record. Such breakthroughs constitute major, discontinuous changes in possibilities. Between breakthroughs, long periods of incremental improvement occur. Eventually, however, the momentum of the breakthrough innovation dissipates and the pace of change slows until the record is punctuated with another breakthrough.

Such a pattern might be explained by a more sophisticated depiction of the process of innovation than that we sketched above. Although innovations are nonrival goods in many important respects, the scope over which spillovers can occur may be limited. Innovations build upon a core technology and are, to some extent, specific to it. Extended periods of innovation and growth are observed, but eventually possibilities for further improvement are limited by the core technology upon which they build.

Ayres suggests that another form of New Scarcity is coming into focus: scarcity of attractive opportunities for extracting traditional natural resources and turning them into finished materials or "useful work," such as electric power. Such useful work is, in turn, an input into many other downstream goods and services. Ayres finds the example of electric power especially compelling in this regard. The efficiency of electric power production from the heat of combustion increased very rapidly during the first half of the 20th century and resulted in rapid price reductions that stimulated new applications and industries. This progress has slowed dramatically since 1960.

New knowledge has accumulated much more rapidly in other fields, such as information technology. Despite the widespread enthusiasm for the "new economy" of the 1990s, however, it is far from clear that information technologies will fuel continued productivity growth. Ayres cautions that economic growth may not continue indefinitely at historical rates—or that there could be a prolonged slowdown before the rates of the past century are matched again.

It is surely too early to label the general economic decline since 2000 a long-term slowdown, but the prospect that we might be entering such a period concerns Ayres. Energy resources are limited both by their own inherent scarcity and by their environmental consequences. Our age needs a breakthrough that will not only reduce our dependence on nonrenewable energy and the environmental consequences of its use, but also enable or create new applications and industries. Ayres sees no such options imminently available. A breakthrough might require massive investment, and public intervention may be called upon to finance and motivate it.

That last notion provides an apt lead-in to Sjak Smulders's contribution, "Endogenous Technical Change, Natural Resources, and Growth." One of the most important developments in economics since the contributions to *Scarcity and Growth Reconsidered* were written has been a closer investigation of determinants and consequences of innovative activity. As we noted above, innovation and environmental improvement share a distinctive feature: providers of each generate benefits that they typically cannot fully internalize themselves. Hence, there is a *prima facie* case for public intervention to encourage socially beneficial improvements.

Smulders takes up this theme in his chapter. He makes several points for students of technological change as it relates to resource scarcity. First, one should not automatically jump to the conclusion that technological innovation is a panacea for coping with resource scarcity. Technological advances may create opportunities for substituting away from scarce resources. They might also, however, result in the more rapid degradation of such resources. As an example, one need only consider many of the world's fisheries: "better" technologies have led to the more rapid decline of fish stocks.

That example highlights the importance of policy interventions. In the case of fisheries, steps need to be taken to reduce the "common property" problem that arises when fish stocks are open to exploitation by whoever can first capture them. As we have already remarked, a similar but opposite problem arises in innovation: since the benefits of innovations may be appropriated by people who do not pay for their generation, innovations may be undersupplied. This observation again underscores the main point. Policy interventions will generally be required first, to prevent the overexploitation of the resources whose degradation is the subject of the New Scarcity, and second, to provide the impetus for innovations that will further reduce pressure on such resources.

Smulders notes another interesting issue. What are the long-term prospects for humanity if we are, in fact, confronted with an insurmountable limit on our material resources? As we saw above, economists have had very different perspectives on these matters over the years. Classical economists applied the principle of diminishing returns in conjunction with the assumption of fixed resources and concluded that our long-term prospect was for stagnation, if not decline. Later economists, buoyed by evidence that productivity continued to increase even as resources generally declined, came to more optimistic conclusions.

Still, it may be naively optimistic to suppose that technological innovations will fall as manna from heaven in perpetuity. Innovation is, as Smulders points out, an economic activity like any other. Innovative activity responds to incentives. In economic analysis, the returns to one factor of production are an increasing function of the quantities of others. Thus, if natural inputs remain a constraint, even incentives for further innovation could someday dwindle. This unhappy state of affairs might still be averted even if we do not benefit from a rain of innovation in perpetuity, however. Knowledge itself may be a capital stock that grows over time to offset the constraints imposed by natural resources. In this scenario the growing economy pulls itself up by its own bootstraps.

The subjects Smulders surveys are very much at the cutting edge of modern economic research, and progress on these topics has had a profound effect on our understanding of the economy. Yet these topics are also very much in a long-standing tradition in economic thought, in which forward-looking agents respond in rational fashion to economic incentives. In his contribution, titled “Evolutionary Analysis of the Relationship between Economic Growth, Environmental Quality and Resource Scarcity,” Jeroen van den Bergh explores a different perspective. Economists often assume that observed behaviors can be explained as maximizing the welfare of the individuals displaying them. Biologists, on the other hand, generally assume that observed behaviors are those passed along by individuals whom nature has selected to survive and reproduce. Van den Bergh describes an evolutionary approach to economics that adopts principles from both disciplines but also generates new insights.

Evolution depends on several elements: variety, innovation, selection, and inheritance. A major challenge in developing an evolutionary economics is to identify the mechanisms that generate these elements. To the extent that this can be done, however, the results can prove quite edifying. Van den Bergh demonstrates that an evolutionary perspective can be particularly enlightening when we are considering how a group of organisms—humanity in this case—shapes, and is shaped by, its environment.

From such a perspective, certain common notions in economics become less clear-cut. Much of what is written about the virtues of markets concerns the ability of individual “optimizers” to produce “efficient” outcomes. From an evolutionary perspective, however, an “optimum” may at best be a transient and local phenomenon. The outcome at any point in time may depend upon the path by which it was reached, and multiple selection factors are at work. Moreover, the adaptation resulting from selection only converges to a long-term steady state if the natural environment shaping evolution is static. When social and natural systems coevolve, it is problematic to describe developments in the former as progress when we are necessarily unsure as to the effects they will have on the latter.

An evolutionary perspective may also motivate a different view of policy formulation. It is common in economics to suppose that social planners are just another set of rational optimizing agents, defined as maximizers of some social. Even if we can speak meaningfully of a role for rationally directed policymakers in a model in which selection occurs by the application of exogenous standards of fitness to agents whose attributes have been randomly generated, such policymakers may have a different role in evolutionary than in traditional models. The maintenance of variability is important in providing for the selection of fit types in rapidly changing environments. Perhaps the objective of policymakers should not be so much to identify winning ideas as to retain enough of the also-rans to provide options should conditions change.

Debates about the capacity of technology to alleviate scarcity of natural and environmental resources normally center on technical feasibility in resource substitution. Sometimes they extend to consider whether a new technology will account for more or less harm or good to natural resources and environments than the old. A prototypical example of such debates is the application of genetically modified organisms in agriculture, where individuals of different persuasions debate the ability of these organisms to sustain increases in agricultural productivity and reduce chemical inputs versus their potential to harm other organisms. Nuclear power offers another example—a source of electricity without conventional pollutants or greenhouse gas emissions but with a legacy of nuclear waste that is toxic to the environment and to humans as well as hard to manage.

More recently, concerns about the use of technology vis-à-vis broader questions of social progress and stability and risk management have been on the upswing. For example, both nuclear and genetic recombination technologies can be seen as posing risks not just because of their unintended environmental consequences, but also because of their potential for deliberate and malicious misuse. As technologies grow more complex, moreover, questions increasingly arise about the public's ability to understand and compare their risks, and even whether the various risks and benefits are comparable. Yet it seems that in much of the modern literature on scarcity and growth, technologies are simply means by which to expand society's production possibilities. Much less concern is generally expressed over how technology and society relate in a broader sense.

In her reflections on these subjects, Sylvie Faucheux brings to bear many of the concepts of strong sustainability that have become central in the European community of ecological economics. She argues in particular that the evaluation of technology's risks and benefits cannot be undertaken apart from the social context in which they are experienced, requiring therefore more place-based analysis and public participation in assessment and decisionmaking. She also argues that with the growing complexity of technological and other risks faced by citizens, the premise that all risks and rewards can be put into a common comparison is increasingly open to question. There are reasons to believe that individual people exhibit a kind of risk aversion that puts a premium on avoiding major and uncertain changes to the status quo of complex natural systems. This line of argument puts Faucheux at odds with the mainstream of natural resource and environmental economics, especially in the United States. Even if one does not accept her other conclusions, however, it is difficult to dispute the point that reducing the conditions that cause social instability—poverty and injustice—may be as valuable in the portfolio of social investments as expanding technological capacities.

David Pearce and Molly Macauley consider policy choices from more conventional, albeit not entirely standard perspectives. In "Environmental Policy as a Tool for Sustainability," Pearce investigates the problem of how society should deal with the New Scarcity of environmental resources. Pearce begins by noting the similarities and differences between the old and new scarcities. Concerns over the Old Scarcity revolved around the adequacy of stocks of mineral, fuel, and other resources. Many commentators dismissed such concerns by noting that these resources were traded in markets. As resources became scarce, their prices would increase to reflect that scarcity, and three responses would arise: consumers would economize on their use, substitutes would be identified and exploited, and new technologies would be developed to further economize on use and introduce more substitutes.

In addressing the New Scarcity of environmental resources, it may seem natural, then, to emulate the markets in which other natural resources are traded. If environmental assets are, in fact, growing scarce, the prices assigned to their further degradation will rise, and we can expect the same pattern of economizing on use, employment of substitutes, and investment in innovation to arise.

As Pearce points out, however, such a scenario presumes that certain prerequisites have already been met. Suggesting that, to cite the environmental economist's mantra, we "get the prices right" presumes, first, that society has determined that environmental resources are in fact growing scarce, and second, that this scarcity has risen to a level of concern in which public sector involvement is required. Having made these determinations, we can turn to the details of how to structure environmental policy. In many nations, however—particularly the poor countries of the developing world—there is as yet no social consensus that environmental problems actually motivate the sacrifices required to address them.

It is not surprising that there is a sort of geographical hierarchy determining which problems are addressed first in developing countries. Water pollution, for example, is often a relatively local problem that can be addressed with relatively simple measures, such as improving sanitation systems. Air pollution may be both more widespread and more complex: emissions of greenhouse gases and losses of biodiversity arise from local action but have global consequences. We would expect—and evidence seems to confirm—that generating the social consensus required for action on these problems will be more difficult than addressing environmental problems at more local levels.

In a sense, the stages of development of environmental policy Pearce proposes overlap. A society is more likely act on its recognition that the scarcity of environmental resources has reached critical proportions if it recognizes relatively low-cost ways in which to ameliorate such scarcity. Moreover, we might suppose that a society otherwise committed to the principles of a market economy might be more willing to address its environmental issues if it could apply to them the apparatus of the market economy.

Those observations emphasize the central paradox Pearce's essay investigates: why is it that market-based instruments (MBIs) are, as yet, so rarely employed? Pearce is careful not to overstate the case. There are enough instances of fuel and effluent taxes and tradable permits in air pollutants as to establish MBIs as more than experimental approaches to environmental policy. Still, given the enthusiasm expressed for them among economists (and, increasingly, elements in the environmental advocacy community), MBIs remain largely conspicuous by their absence.

The reasons for this paucity are myriad. First and perhaps most obviously, many countries, particularly those of the developing world, have few environmental regulations of any kind. Once sufficient social pressure mounts to implement *some* such regulations, newly empowered regulators often find themselves in dire circumstances. It is then time to do something clear and definite, rather than fumbling with the niceties of guessing what economic measures will yield which physical results. The certainty attached to requiring specific measures may often be preferred to what may seem the less tangible benefits of implementing more flexible incentives.

Once an environmental administration is established with an emphasis on technical, as opposed to economic, concerns, it may be difficult to reverse the culture of the organization. It is only natural that bureaucrats will seek to perform their duties in such a way as to maximize the demand for their own expertise. One advantage often claimed for MBIs is that they decentralize environmental decisionmaking by leaving the specifics of compliance to private agents. Viewed from a bureaucrat's perspective, however, eliminating the need for her own management expertise may seem less of an advantage.

Other factors in determining public policy toward the environment may be still more malign. Although much of the focus in environmental policymaking is on improving on policies that are already good, in the sense that they tend to improve environmental performance, great progress might also be made by reforming policies that are demonstrably bad. Many commentators bemoan the continuing existence of perverse subsidies—payments that, by encouraging profligate use of resources, result in their greater degradation. While lamentable, it is, perhaps, not surprising that perverse subsidies continue. Large economic players wield political clout. Environmental degradation is a problem in large part because important elements of society realize private gain—albeit at the expense of losses to the broader public—by engaging in activities that degrade the environment. It should not be surprising that such major players find ways to underwrite their activities with public funds.

That last observation may be offset in part if conventional wisdom is valid: that environmental improvement tends also to be a popular cause among the wealthy. However, this constituency may be more often motivated by fervor than by careful economic analysis. Efficiency per se has a limited constituency (Stroup 2003), a view that Pearce echoes in noting that aside from academicians, there is limited lobbying for MBIs.

The *form* in which environmental policy is implemented may seem a matter of less importance in responding to the New Scarcity than the question of whether to institute *some* form of environmental policy. However, Pearce suggests that activists will not begin to achieve their goals until they come to some accommodation with economic interests. Halting economic development is simply not an option. Overcoming resistance to cost-effective environmental regulation is, then, in some respects tantamount to overcoming resistance to environmental regulation generally.

Molly Macauley's contribution, "Public Policy: Inducing Investments in Innovation," addresses the other aspect of public policy that bears strongly on the resolution of scarcity: technological innovation. Governments have provided incentives for innovation almost as long as there have been governments. The motivation lies in the characteristics of innovation that Robert Ayres explores in his chapter: new ideas often generate spillovers that can spread far beyond the industry or sector in which the original innovation was applied, and important technological innovations tend to reinforce each other. As we have also noted, the incentives for public underwriting of innovation are doubled when innovations ease the constraints imposed by the New Scarcity of environmental resources.

The generality of the possible effects of broad-reaching spillovers can create wide opportunities for abuse, however. If we cannot predict the ultimate applications to which a particular innovation might be put, should society subsidize *every* innovation? For that matter, can we even distinguish innovation from other undertakings? Although Macauley states the conventional case for public support of innovative activity, she also points out the pitfalls of taking this principle too far. Publicly funded research may ease environmental problems, but it may also induce rent seeking among would-be recipients of public funds and generate wasteful "pork."

Macauley buttresses her conclusions with examples drawn from case studies. Governments have underwritten any number of research ventures in energy, resources, and environment (among other fields) with what have to be regarded as decidedly mixed results. There have been some successes, but there have also been spectacular failures, such as the U.S. synthetic fuels program. In that case, it appears that private industry more accurately predicted long-term price trends in fuels than did the government, which initiated a slap-dash program to combat an energy "crisis," which two decades later had largely disappeared. It remains to be seen if other crises turn out to be more serious or enduring, but the synfuels program illustrates the pitfalls of devoting large sums of public money to poorly conceived ventures.

Public policy can motivate innovation in other ways, however. Innovation may be motivated by the carrots of public research subsidies but can also be prompted by sticks, such as regulatory restrictions and taxes on pollutants. Conventional wisdom has it that MBIs are superior to other forms of regulation because they leave open to the regulated parties the issue of how best to reduce their costs of polluting. If regulated parties can accomplish the goal most efficiently by devising better modes of production and effluent control, MBIs will allow them to do so.

That observation brings us back to the theme of Pearce's paper: that MBIs, while perhaps becoming increasingly common, remain conspicuous by their general absence. Macauley adds another important cautionary note to Pearce's recitation of the reasons for these circumstances:

the regulator who seeks purely to maximize social welfare in the absence of market failures is as much a fiction as is the perfect market of the introductory economics textbook. Idealized depictions of economies are useful as pedagogical devices and benchmarks against which to measure actual performance. The same might be said of idealized depictions of regulatory programs. Macauley reminds us, however, that policies must be made on the basis of comparisons of actual economic conditions and actual regulatory capacity and performance. Comparisons between ideals are generally irrelevant, and those between the actual performance of an unregulated economy and an unobtainable regulatory ideal are deceptive and can prove counterproductive.

Although the authors of the contributions we have surveyed thus far make some mention of the importance of environmental resources in poor countries, their emphasis is largely on economic, social, and physical conditions in the wealthier countries. Yet there is widespread agreement both that the consequences of environmental degradation and resource scarcity are greatest for the poor, and that the greatest environmental challenge of our era is to raise the living standard of the poorest of the poor without further degrading the global environment.

The final two contributions extend the analysis of scarcity and growth to the developing world. In "Intragenerational versus Intergenerational Equity: Views from the South," Ramon Lopez elaborates on the theme of sustainability. He encapsulates a very telling point in a question: "Will governments that systematically neglect the welfare of the vast majority of the current population…consider the interests of those not yet born?"

Lopez argues that much of the existing debate on sustainability ignores two crucial issues, both of which are raised in his question. First, sustainability is essentially a question of equity, and one cannot consistently espouse concern with *inter*generational equity without also evidencing a corresponding concern with *intra*generational equity. We should be at least as concerned with the plight of today's poor as we are with that of tomorrow's.

Lopez's second observation is that *governments* systematically neglect the welfare of the vast majority. Understandably, economists writing on the prospects for sustainable development emphasize economic policies and forces in their analyses. Yet in much of the world, the institutional underpinnings for well-functioning market economies are largely absent. Markets facilitate trade in goods and services, but the efficiency- and welfare-enhancing properties claimed for trade in goods and services do not arise from their appropriation or theft. Elite minorities in many developing countries appropriate their nations' resources for their own benefit while employing the private wealth they acquire to insulate themselves from the consequences of environmental degradation.

To Lopez, then, effective policy intervention to institute sustainable development cannot be limited solely to working within the economic system to “get the prices right.” We must first get the institutions of governance right. Until we do the latter, there will be little incentive to do the former.

Partha Dasgupta begins the final contribution by noting a revealing semantic distinction. Environment is, in the wealthier countries, an amenity or luxury good that comes to be in greater demand as income increases. This view leads to a one-sided policy prescription: since wealthier people demand cleaner environments, the solution to the developing world’s environmental problems lies in promoting its economic growth.

This perspective and prescription are problematic in a couple of respects. With regard to the semantic point, Dasgupta argues that natural resources and environmental “amenities” are not luxuries, but rather necessities. Poor people have no substitutes for the filthy water and smoky air of their communities. Second, in prescribing economic growth as an antidote for environmental degradation, we need to be very careful about measuring growth.

Dasgupta has titled his contribution “*Sustainable Economic Development* in the World of Today's Poor” (we have added the emphasis) and returns to themes introduced in Pezzey and Toman’s chapter on sustainability. An appropriate measure of yearly income is one reflecting the consumption possible at present without compromising future prospects. In both theory (as developed by Weitzman 1976) and practice, national income is calculated by adding together the market value of consumption and net investment.[12] Suppose that the latter was markedly negative—that the country whose national income was being calculated was liquidating its capital stock or allowing it to depreciate without replacing it. In such circumstances one should subtract the value of the lost capital stock from the value of consumption in calculating income.

Amending accounts in this way is straightforward when the value of consumption and value of investment can be measured by simple accounting exercises. The value of consumption is typically the sum of all consumption goods produced, with each weighted by its market price.

[12] The formula can be further elaborated to include government expenditure and net exports.

The value of investment is typically calculated in a parallel fashion, summing quantities weighted by prices.[13]

Problems arise in attempting to do accounting in the absence of prices. Yet this is the situation, by definition, when nonmarket goods are involved. In the absence of actual prices, one must infer shadow prices from other markets or information. Dasgupta acknowledges the many practical impediments to estimating such prices but, making some heroic assumptions in the interest of illustration, presents figures that offer a sobering perspective on the true economic performance of the developing world. Nations that appear to be making substantial progress in rising from poverty may, on closer reflection, be accomplishing illusory growth by degrading their natural assets. In some of the world's poorest regions, the outlook is dismal indeed. Official economic statistics indicate stagnation. When such assessments are amended to reflect environmental degradation, the scenario is worse yet.

Dasgupta also demonstrates that similar concerns dog estimates of productivity. Imagine, for example, a nation that fuels its economy by felling ever larger portions of virgin forest. If there is no official market for trees (stumpage, in the forestry vernacular), it may appear that the economy is making more with less each year—until the trees run out. Thus, whether measured as high income growth rates or growing productivity, official statistics may not represent economic progress so much as the imminence of a bill coming due.

Dasgupta notes that *institutional* changes can induce progress as much as can innovations in physical processes. Resources will be used more efficiently when institutions evolve so as require users to pay the full costs of their use; that is, the private costs of their current provision, the costs that may fall on future generations if such resources will no longer be available, and the costs that users of the resources may impose on other members of society because of the pollution, biodiversity loss, etc., they may occasion. Even though a society that makes more efficient use of its available resources will better serve the interests of its citizens in the long run, it may appear to be performing less well in the short run. This is because some resources are underpriced. The measured costs of production must increase when the prices of resources increase.

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[13] Year-to-year variations in price levels are accommodated by dividing aggregates by price indices, although the construction of such indices can be problematic.

That leads us again to the critical question of when and how society—or societies—will decide to acknowledge the New Scarcity and take steps to offset it. This is a fitting point on which to begin to sum up our themes.

Scarcity and Growth in the New Millennium: A Synthesis

The contributors are an eclectic group, and they come at a host of issues from a variety of perspectives. In her or his own way, however, each has addressed the essential question of how scarcity affects the prospects for growth.

To organize our summary, let us consider how scarcity might constrain growth, and which scenarios seem most likely.

- In the worst-case scenario, absolute limits on physical capacities might condemn humanity to stagnation—or worse. If an essential resource could not be renewed, we would, in the fullness of time, be doomed.
- Slightly more favorable would be a situation in which an essential resource is renewable but only at a relatively slow rate. Although a sustainable path might be open to us, even an economy in which this essential resource is privately owned might not choose to follow it.
- If essential but renewable resources are not traded in complete markets in which all aspects of their extraction, production, and use are incorporated in their prices, disaster could ensue unless public action is taken to address problems of pollution and degradation.
- If no resources are essential, or if essential resources reproduce at a sufficiently rapid rate, a market economy could follow a sustainable path with no public oversight.

None of our authors espouse the extreme views represented in the first and last possibilities above. None are saying that humanity is doomed, or even that a human population of the current size is doomed, nor are any saying that a laissez-faire policy in which all resource allocation decisions are left to private actors will ensure a rosy future. Although John Pezzey and Michael Toman consider the prospect raised in the second scenario— that a market economy could follow a path that is both optimal and unsustainable—they and most other authors devote most of their attention to the third scenario.

In short, the most pressing question of scarcity and growth is, "What public action is required to address the New Scarcity of nonmarket environmental resources?"

A natural inclination—among economists, at least—is to mimic markets. If environmental resources are becoming scarce, government action can lead private actors to reflect this scarcity in their decisions by taxing emissions, setting quotas on them, or otherwise making markets where they did not exist before. As David Pearce shows, however, market-based incentives are, by and large, conspicuous by their absence.

Why is that? In addition to the reasons Pearce offers in his chapter, we might consider other factors. Ramon Lopez reminds us that the institutions of the economy are subsidiary to those of governance more generally. We should not be surprised to identify market "failures," when such failures may, in fact, represent tremendous successes for the governing elites that perpetuate them. David Tilman and Stephen Polasky's work on biodiversity reveals that part of the problem of crafting incentives, even in an otherwise well-structured society, is complexity. Exactly *what* would we make subject to a tax or quota in order to preserve the world's species? This complexity is amplified by the fact that scarcities interlock in a global society that has grown so large. As Christian Azar points out, we could put a sizable tax on carbon dioxide emissions—which could well lead farmers to plant renewable energy crops and in the process expand land under cultivation, reduce biodiversity, and further compound the challenges facing the world's poor. Even the resolution of the Old Scarcity raises issues with regard to the New. David Menzie, Donald Singer, and John H. DeYoung, Jr., note that compliance with environmental restrictions is likely to be as important to the mining industry's performance in coming years as is physical depletion. A similar message emerges from Jeffrey Krautkraemer's chapter: markets seem to have been adequate to the task of allocating exhaustible natural resources such as oil and minerals over time. The more difficult it becomes to establish ownership over resources, however, the less satisfactory has been performance. Fisheries—which are inherently more difficult to own because the fish themselves can move—are declining, and a host of environmental issues remain problematic, especially those being played out at a global scale.

Is the answer to the New Scarcity to launch bold programs to achieve major technological breakthroughs? Robert Ayres finds in the historical record several major episodes in which radical new technologies have transformed the world through spillovers and feedback loops. He argues that new breakthroughs are required to achieve similar breakthroughs to overcome the scarcity of energy and the environmental consequences of its use. Sjak Smulders provides conceptual support for this notion by reviewing an influential literature that emphasizes the similarities between environmental and technology issues. Each may motivate public involvement to counteract the nonrival aspects of the goods in question. Yet Molly Macauley's chapter provides a cautionary note: the actual performance of many public programs intended to spur breakthroughs in environmental and resource technology has left much to be desired. As Macauley notes, real bureaucrats may be a good deal less efficient in achieving socially desirable ends than are their representations in idealized models.

Of course, it is only to be expected that the realization of emerging scarcities and the evolution of policies to counter them will involve fits and starts. Although many credit private markets with resolving issues pertaining to the Old Scarcity of marketed natural resources, the history of metals, minerals, and fuels markets is replete with uncountable bankruptcies, bubbles, and miscalculations. We chose the phrase "*evolution* of policies" in the first sentence of this paragraph deliberately, as we mean to evoke the principles covered by Jeroen van den Bergh. If a thriving and, one would hope, increasingly equitable economy is to survive a brush with the limits of the planet's finite carrying capacity, there must be some experimentation by which "fit" strategies for survival are winnowed from those that will not see us through. As Sylvie Faucheux points out, the criteria for fitness ought not to be limited to those factors that are easily incorporated in analytical models. Economists often suppose either that technology evolves exogenously or can be treated as an outcome of economic activity no different than any other, but Faucheux suggests that our long-term prospects may be determined by the complex, multidimensional relationship between society and its creations.

In closing, we might consider Partha Dasgupta's observations on the experience of communities around the world that lived close to nature. Survival was, for them, a matter of learning the limitations of their environment and living within them. It would be comforting to know that this is, in fact, the natural progression of mankind. Regrettably, the historical record suggests that it is not inevitable. There is a selection bias in that the traditional societies that survived to modern times are those that solved the problem of living within their ecological means. Societies now known only by their archaeological artifacts may not have.

It remains an open question whether our increasingly global society can muster the technological, economic, and perhaps most importantly, social wherewithal to address the implications of the New Scarcity. We have not yet, as a race, run into the limits imposed by reserves of the things we regularly buy and sell. The ultimate question on which all the authors' essays agree concerns whether we will be as successful in managing resources that have, to date, largely remained outside the realm of the market economy. Although economic prescriptions might be suggested for addressing the question, we suspect that the ultimate deciding factors will prove to involve the wisdom, compassion, and vision we can bring to our collective choices.

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