The Economics of Sustainability: A Review of Journal Articles

John C. V. Pezzey and Michael A. Toman

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Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202–328–5000
Fax: 202–939–3460
Internet: http://www.rff.org

Abstract

Concern about sustainability helped to launch a new agenda for development and environmental economics and challenged many of the fundamental goals and assumptions of the conventional, neoclassical economics of growth and development. We review 25 years' of refereed journal articles on the economics of sustainability, with emphasis on analyses that involve concern for intergenerational equity in the long-term decisionmaking of a society; recognition of the role of finite environmental resources in long-term decisionmaking; and recognizable, if perhaps unconventional, use of economic concepts, such as instantaneous utility, cost, or intertemporal welfare.

Taken as a whole, the articles reviewed here indicate that several areas must be addressed in future investigation: improving the clarity of sustainability criteria, maintaining distinctions between economic efficiency and equity, more thoroughly investigating many common assumptions in the literature about prospects for resource substitution and resource-enhancing technical change, and encouraging the empirical investigation of sustainability issues.

Key Words: economic efficiency; intergenerational equity; social optimality; sustainable development

JEL Classification Numbers: Q20, D60, D90

Contents

The Economics of Sustainability: A Review of Journal Articles

John C. V. Pezzey and Michael A. Toman*

Background

Concern about sustainability is almost as old and enduring as the dismal science itself, even though the word itself has come into fashion only in the past decade or so. In 1798, Malthus (1798/1976) worried about how Britain's apparently inexorable rise in population could be sustained from a finite amount of land. In 1865, Jevons (1865/1977) wondered how Britain's ever-increasing energy consumption could be sustained from finite supplies of coal. In 1952, the President's Materials Policy Commission (1952) was concerned about the sustainability of the American economy's postwar growth, given its prodigious wartime increase in the consumption of nonrenewable minerals from apparently finite supplies. In 1972, Meadows and others pondered the sustainability of the whole of industrial civilization, given the ultimate finiteness of the planet's capacities to provide material inputs to modern economies (and to assimilate their waste outputs) in *The Limits to Growth*.

The Limits to Growth, and the general fear of "running out" that it inspired in some quarters, provoked a response from mainstream economists, especially Dasgupta and Heal (1974), Solow (1974), and Stiglitz (1974). Their analyses of the impact of nonrenewable resources on existing theories of economic growth have continuing significance for the economics of sustainability; in retrospect, it seems a little surprising that the debate largely rested there for the next decade, apart from a few noteworthy developments. Economists interested in sustainability issues returned to the scene in the late 1980s with the publication of *Our Common Future* by the World Commission on Environment and Development (WCED 1987). This publication helped to launch a new agenda for both development and environmental economics. It voiced new and urgent environmental concerns (deforestation, desertification, the loss of biodiversity, the enhanced greenhouse effect, and the effects of poverty on the environment in mainly developing countries) that were especially relevant to developing countries and the global environment. It thereby challenged many of the fundamental goals and assumptions of the conventional, neoclassical economics of growth and development. In addition, it propelled the ideas of "sustainability" and "sustainable development" to the forefront of public debate.

* This article will be the introductory chapter in *The Economics of Sustainability*, a collection of previously published journal articles, to be published by Ashgate (Aldershot, U.K.) in May 2002.

However, sustainability proved a remarkably difficult concept to define and use precisely. Overlapping and conflicting definitions rapidly proliferated. One result was that words such as "sustainability" and "sustainable" became common buzzwords—motherhood-and-apple-pie concepts mouthed approvingly by anyone from media moguls to multinational mining companies—that often meant nothing more than "environmentally desirable," if that. Indeed, when comparing successive versions of official environmental policy documents of the late 1980s and early 1990s, one can almost attribute the proliferation of sustainability rhetoric to a mere find-and-replace operation.

Selection, Organization, and Presentation

Scope of Our Approach to Sustainability

In this review of refereed journal essays on the economics of sustainability, we have taken a focused approach. For our purposes, *sustainability* involves some concern for intergenerational equity or fairness in the long-term decisionmaking of a whole society; some recognition of the role of finite environmental resources in long-term decisionmaking; and some recognizable, if perhaps unconventional, use of economic concepts such as instantaneous utility, cost, or intertemporal welfare. However, the concern for intergenerational equity may not involve explicit use of the word "sustainability" in any form; many other formulations are possible. It also may be quite indirect, as with a strand of the literature focused on the ecological or physical feasibility of continued economic expansion with finite resources.[1]

For reasons of space and coherence, we decided to omit several topics that might have been included within a broader definition of sustainability. These topics include sustainable production within specific resource sectors (agriculture, forestry, and so on); macroeconomic "sustainable growth models" with no environmental components, which include most of the mainstream endogenous growth literature; the practical and philosophical impact of population growth on sustainability; purely ecological models of sustainability; methods and practices for accounting for "green" income; and studies of economic growth and the environment.

Selection Criteria

Any selection of reviewed papers contains some subjective elements. Our focus on refereed journal articles inherently imposes a constraint, because a great deal of the economic writing of the activists, campaigners, and communicators who have had the most direct influence on policy has appeared in

[1] Our focus thus builds on the survey in Toman and others (1995).

books, book chapters, conference proceedings, and "gray" literature. Therefore, we have attempted to weave citations of some key nonjournal literature into our discussion. Also, many sustainability ideas originated primarily as a challenge to conventional economic thinking, rather than as new ideas within mainstream economics. We thus have reviewed an eclectic selection of papers—including some that mainstream economists consider quite flawed—to provide readers a full range of perspectives on the intellectual debate that surrounds the economics of sustainability.

Within the journal literature, we aim to cover key topics in and contributors to the economic debate on sustainability. We focus mainly on primary papers, rather than surveys.[2] To achieve a balance of topical coverage, we have biased the selection somewhat toward including empirical papers. Real measurement of sustainability is fraught with difficulties of principle and practice, so there are understandably, though still disappointingly, few published empirical papers.

Organization

Three possible criteria for organizing our discussion in a coherent way are topic, methodology, and date. Because one paper can contain a range of topics and methodologies, neither of these two criteria offers clear-cut boundaries. Therefore, we primarily ordered the papers by date.

Even so, it is worth flagging the main topics and methodologies under which classification might be attempted, because we occasionally found it worth departing from chronological order to discuss closely related papers together. For clarity, we present them as simple, discrete questions; however, reality is usually more complex, particularly in empirical papers. These questions naturally progress from issues related to societal goals to issues involving the natural and technological constraints encountered in attaining those goals.

- Is explicit attention paid to inequality within generations, either as an undesirable outcome in itself or as something that has a harmful effect on aggregate sustainability? Do the three goals of environmental sustainability, economic sustainability, and social sustainability all have to be achieved in some sense for overall sustainability to be achieved, or does sustainability permit any trade-offs among these three goals?
- Is the paper's main focus on sustaining overall social welfare or on sustaining some measure of the performance of the physical and biological systems that support society? The latter

[2] Lele (1991) and van den Bergh and Nijkamp (1991) cover a range of topics related to sustainability in their synthesis papers.

focus includes studies of physical or thermodynamic limits and ecological economic analyses of resilience.

- Is unlimited (not the same as perfect) substitutability assumed between natural resources and human-made capital (what is often called the weak sustainability approach), or is limited substitutability assumed (leading to the strong sustainability approach)?
- Is technical progress exogenous, endogenous, or absent?
- To what extent should other disciplines (such as physics, ecology, or psychology) be used to inform the kind of production and utility functions that are used in the economics of sustainability?

In addition to these broad issues, several more specific questions define the scope of different papers:

- Are the natural resources considered mainly renewable or nonrenewable?
- Are the effects of international trade considered?
- Is pervasive uncertainty considered, or ignored in favor of determinism?
- Are preferences assumed to be fixed, or can they evolve?

The different methodologies used to study these topics are rather easier to classify. Many papers could be reasonably described as empirical (some processing of real data), analytical (a mathematical model but no data), or verbal/philosophical (no data processing or mathematics, but possibly some closely argued logical reasoning) in approach. Some papers combine more than one of these approaches, but not always satisfactorily, for example, when purely verbal pieces claim to resolve inherently empirical questions about substitutability. In addition, several analytical frameworks figure prominently, including the representative agent or overlapping generation (OLG) frameworks for describing intertemporal production and utility.

Discussion Format

For the reader's convenience, we provide the full titles of the papers that are the primary focus of our discussion in the text as well as in References. Mathematical notation is used sparingly, and when it is, we use a standard notation (explained later) throughout, rather than the different notations used in each reviewed paper.

1974–86: Responding to "Limits to Growth"

The first three papers are classics: "The Optimal Depletion of Exhaustible Resources" by Dasgupta and Heal (1974), "Growth with Exhaustible Natural Resources: Efficient and Optimal Growth Paths" by Stiglitz (1974), and "Intergenerational Equity and Exhaustible Resources" by Solow (1974). All three papers came from a symposium published in the *Review of Economic Studies*, inspired by the debate following the publication of *The Limits to Growth* (Meadows and others 1972) on the nature of economic growth when a nonrenewable natural resource, as well as (human-made) capital, is a significant input to aggregate production. These three papers form an important theoretical starting point for our review, even though they rarely used terms such as "sustainability."[3]

In all three models, natural resources are finite, nonrenewable, and essential to production instead of being ignored altogether, as they largely had been in economic growth theory until then. However, (human-made) capital is indefinitely substitutable for resources via a Cobb–Douglas production function. To summarize the main points of these papers, we present the following analytical formulation:

$$\max_{C(t),R(t)} \int_0^\infty U[C(t)]\phi(t)dt \tag{1}$$

where

$$U(C) = C^{1-\theta}/(1-\theta)$$

$$C = F(K,R,t) - \dot{K} - \delta K - \xi R = K^{\alpha} R^{\beta} e^{\pi t} - \dot{K} - \delta K - \xi R$$

$$R = -\dot{S} + G(S)$$

$$K(0) = K_0 > 0$$

$$S(0) = S_0 > 0$$

$$0 < \alpha, \beta < \alpha + \beta \le 1$$

$$\xi \ge 0, \delta \ge 0$$

$$C, R, K, S \ge 0$$

[3] An even earlier starting point would include the seminal papers by Krutilla (1967) on long-term environmental valuation with irreversibility, and by Ayres and Kneese (1969) on materials balance in what we would now call ecological–economic systems.

and *U* is instantaneous utility; *C* is consumption flow; ϕ is the utility discount factor; *R* is the rate of resource depletion; θ is a parameter governing the curvature of the utility function; *F* is output flow; *K* is capital stock; δ is the rate of capital depreciation; ξ is the per unit cost of resource extraction; τ is the rate of exogenous technical progress; *S* is the resource stock; *G*(*S*) is renewable resource growth; and $\alpha, \beta, \xi, K_0, S_0$, are exogenous parameters.

In Dasgupta and Heal (1974) and in subsequent refinements by the same authors (Dasgupta and Heal 1979) and by Pezzey and Withagen (1998), the utility discount rate is constant: $\phi(t) = e^{-\rho t}$, where $\rho > 0$ is the rate of time preference. So, society's objective is what we refer to here as *PV optimality*, that is, the maximization of the present value (PV) of the representative agent's instantaneous utility using a constant discount rate. Just as crucially, technical progress is absent (τ = 0), and the resource is a fixed nonrenewable stock (*G*(*S*) = 0 for all *S*).[4] Less crucially, the depreciation rate and extraction costs are ignored (δ = 0, ξ = 0).

A key finding from Dasgupta and Heal's 1974 analysis was that the PV-optimal outcome is grim for far-distant generations. After perhaps an initial peak, consumption and utility eventually approach zero in the very long run. However, this outcome is *not* because sustained consumption and utility are technically infeasible. It is instead the direct consequence of a positive utility discount rate, combined with the inherent scarcity of the nonrenewable resource. Under these circumstances, consumption is concentrated in earlier years of relative resource plenty, and capital investment is not adequate to offset the effects of resource depletion on output. By almost anyone's standards, this consequence does not represent sustainable development.

Stiglitz (1974) points out that one way to avoid to this undesirable outcome is ongoing technical progress. In his model, the rate of exogenous technical progress is assumed to be large enough to offset the effects of resource depletion. This assumption implies that the PV-optimal path can have sustained increases in per capita consumption (even with a growing population, which is omitted from Dasgupta and Heal's model).

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[4] In the economics of nonrenewable resources, many models have addressed discovery and development of new reserves as well as resource extraction. Simple models represent an undiscovered resource stock that might be found in the future (for example, Dasgupta and Heal 1979 and references therein). More complex models allow for the possibility of continuous additions to new reserves at ever-increasing unit costs (for example, Pindyck 1978; Bohi and Toman 1984 and references therein). Additions to reserves forestall rising real resource scarcity, but they do not fundamentally change the results discussed below.

In the context of Stiglitz' model, the Cobb–Douglas production function—with isoquants asymptotic to the axes for resource flow and capital services—is inconsistent with minimum energy and material requirements. The same could be said of a sustained exponential rate of technical change. Instead, some ultimate limit to production possibilities would need to be defined in relation to the flow of renewable resources. Such limits are not addressed in the models we review in this paper, and the empirical relevance of these constraints remains hotly debated.[5]

Solow (1974) finds that the solution to Dasgupta and Heal's problem is implicitly a moral one. However, Solow's direct focus is on conditions under which constant consumption is feasible. In the challenging case when technical progress is absent, Solow shows that with Cobb–Douglas production (and a constant population), constant consumption could be sustained despite declining resource flow by a suitable path of capital accumulation. Solow shows that to achieve constant consumption, it is necessary to have $\beta < \alpha$, which means the resource flow accounts for less than half the value of production.[6] Even though Solow speaks directly of neither sustainability nor PV optimality, his was the first widely read paper to suggest, in the context of formal economic growth theory, a sustainability-like objective for society quite different from PV optimality.

Solow justifies his focus by referring to Rawls' (1971) principle of maximizing the minimum realized consumption level. However, the constant path also can be seen as the intertemporally efficient outcome of maximizing discounted utility in Model (1) above with a nonconstant—indeed, monotonically decreasing—discount rate (Takayama 1985, 188). Taking this perspective brings the paper closer to the others we review in this paper. But this formulation begs another question, namely, the consistency of such an objective function with individual preferences. This issue echoes to this day in debates about the appropriate role for and means of discounting future benefits and costs.

For our purposes, the sequel to Solow's 1974 paper was from Hartwick (1977): "Intergenerational Equity and the Investing of Rents from Exhaustible Resources." This paper, and later extensions (Hartwick 1978a, 1978b), show what came to be known as Hartwick's rule: Under many circumstances in an economy with depletable resources, the rent derived from resource depletion is exactly the level of capital investment that is always needed to achieve constant consumption over

[5] See the exchanges in the September 1997 special issue of *Ecological Economics* devoted to the contributions of Nicholas Georgescu-Roegen (for example, Cleveland and Ruth 1997).

[6] Note that this condition does not address the point made earlier about the inconsistency between the Cobb–Douglas production function and minimum energy and resource requirements. On the other hand, Solow (1974) deliberately stacks the deck against himself by not incorporating renewable resources in the model.

time. In the economy of Model (1), this level is sales revenue ($F_R R$) minus both the value of natural resource growth [$F_R G(S)$] and the value of extraction costs (ξR). For constant consumption to be feasible when the resource is nonrenewable, some kind of unlimited capital resource substitutability is needed [as with the Cobb–Douglas production function in Model(1)], so in recent times, Hartwick's rule has come to be known as a *weak sustainability approach*. And because capital investment minus resource rents is the net investment in all the economy's productive stocks, the rule also reads as, "Zero net investment forever results in constant consumption forever."

In either form, Hartwick's rule is probably the single most powerful influence on sustainability policy that is clearly derived from an economics journal article. Many governments and multilateral institutions have invoked it, consciously or not, when declaring the importance of investing rents from natural resource depletion in building up capital in the rest of the economy. However, governments rarely have been clear on how much should be invested, or how much should be invested by the private sector versus some public "trust fund for future generations."

Nor have governments realized what a departure from current, broadly free market policies on growth and investment Hartwick's rule might imply. As discussed earlier in connection with "Intergenerational Equity and Exhaustible Resources" (Solow 1974), the constant consumption path results from a modified PV objective with declining discount rates. If one takes the view that market investment behavior is driven by a conventional PV objective, then Hartwick's investment rule in effect requires massive government intervention in capital markets (unless technical progress makes the issue moot, as Stiglitz 1974 suggests). This issue—in effect, about the desirability of a sustainability objective—is one that runs, sometimes implicitly but always uncomfortably, through much of the sustainability literature. Hartwick's rule has additional shortcomings as a practical policy tool, as discussed in "The Beginnings of Empirical Sustainability Work" later.

Our next paper from this period is "On the Intergenerational Allocation of Natural Resources" (Solow 1986). Solow shows that Hartwick's rule, which we already know achieves constant consumption always, is also equivalent to maintaining aggregate wealth or "some appropriately defined stock of capital … including … resources" [which would be $K + F_R R$ in Model (1)] at a constant level over time. But despite an accompanying comment in the same journal by Svensson (1986), it is often overlooked that this result assumes a constant interest rate and thus does not actually apply to the economies of Dasgupta and Heal (1974) or, more importantly, of Solow (1974). In those analyses, never-ending capital accumulation and resource depletion cause a falling interest rate, hence the need for aggregate wealth to rise over time, so that the product of the interest rate and aggregate wealth can maintain constant output and consumption. As a practical matter, moreover, problems arise in calculating the prices needed to compute wealth or aggregate capital. (We discuss these problems later in The Beginnings of Empirical Sustainability Work). Finally, by giving no motivation or mechanism for a sudden introduction of Hartwick's rule after an initial period of PV-optimal development with lower savings rates and unsustainably high consumption, Solow does not address the policy conflict between a PV-optimal economy and the imposition of Hartwick's rule.

The combination of capital accumulation, resource depletion, and a falling interest rate also plays a role in our last paper from 1974–86, "Hartwick's Rule in Open Economies" (Asheim 1986).[7] Asheim's analysis begins with a closed economy divided into three classes of people: workers, capitalists, and nonrenewable resource owners. He shows that Hartwick's rule cannot, then, be decentralized. Resource owners use a rising resource price to offset their diminishing stocks and achieve constant consumption while investing nothing. In contrast, the price facing capitalists (the interest rate) is in fact falling. So, to maintain its consumption, this class has to augment its capital stocks. As a result, capitalists do all the investing, even though their own resource consumption is zero. (More generally, resource rents in different parts of the economy need to be invested in proportion to ownership of human-made capital, not in proportion to resource stock ownership.)

The closed-economy analysis is then neatly transferred and extended to different open economies. Sustainability for all countries requires resource-rich economies to invest less than their own resource rents, and resource-poor economies to invest more. The basic Hartwick's rule does not apply to open economies, because the underlying assumption of "stationary" technology is violated when gains from trade are taken into account. A corrected analogue to Hartwick's rule for open economies is developed and applied to a model of capital accumulation and resource depletion. This result is important because confusion has arisen regarding the implications of resource extraction for the sustainable income of an open, resource-exporting economy.

Several other important theoretical contributions during this period addressed growth, resource use, and intergenerational equity—notably, articles by Riley (1980), Becker (1982), and Dasgupta and Mitra (1983)—although none of them stimulated any extensive empirical work. Another paper of the period that is indirectly related to sustainability and has taken on significance in the literature over time is by Krautkraemer (1985). Krautkraemer considers a generalization of the PV optimality problem studied by Dasgupta and Heal (1974), with an environmental disamenity related to cumulative resource use that has the economy generally use less than its entire resource stock.

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[7] Another interesting and relevant piece from roughly the same time is by Kemp and Van Long (1982).

Krautkraemer shows that depending on society's discount rate, the initial capital stock, and the nature of the disamenity, the economy may converge over time to a "clean" (low-resource-use) or "dirty" (high-resource-use) equilibrium. This generalization points to important issues to consider more generally in how growth might be managed sustainably, including both direct consumption and environmental values.[8]

Also of significance during the period were some developments in the philosophy of intergenerational equity, such as those put forward by Norton (1982), Page (1983), and Parfit (1983). Such papers paved the way for future debates about sustainability by underscoring the complex and sometimes problematic moral underpinnings of the PV criterion and drawing attention to other moral criteria (such as concepts of environmental justice and stewardship) that are important for intergenerational resource allocation.

1987–96: The Emergence of a Sustainability Literature

Verbal/Philosophical Analyses

We already mentioned the seminal influence of WCED's *Our Common Future*, published in 1987. In the mid-1980s, active discussion of sustainability concepts and criteria began in earnest in the economics literature as well. A notable early contribution was "The Concept of Sustainable Economic Development" (Barbier 1987). This highly cited paper contains questions, concepts, and language (terms such as "environmentally sustainable" and "natural capital") that have become an enduring part of the sustainability debate for developed as well as developing countries. Because it is presented with a purely verbal approach, the paper requires careful reading; even then it remains open to a wide range of interpretations.

Stress is placed on "the unique environmental, economic, and social features of sustainability …" (p. 101). Much emphasis is placed on the role of poverty: "Poor people often have no choice but to opt for immediate economic benefits at the expense of the long-run sustainability of their livelihoods" (p. 103). Concepts such as "environmentally sustainable strategies" and "socially and culturally sustainable development" are introduced, though not precisely defined (p. 102). Barbier (1987) presents an early illustration of the oft-repeated but sometimes ill-defined idea that environmental sustainability, economic sustainability, and social sustainability are separate but interlinked concepts.

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[8] One limitation of Krautkraemer's 1985 analysis is that it depends in certain important places on the assumption of a substitution elasticity between the resource and capital that is greater than 1, meaning the resource is inessential for production.

But Barbier also clearly states that "sustainable development involves a *process of trade-offs* among the various goals of [biological, economic, and social] systems" (emphasis in original).

A deluge of sustainability literature directed at broader audiences appeared from the late 1980s onwards. Much of it was not published in journals, and often it was as much aspirational as analytical. The most famous definition of "sustainable development" as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, 43) uses concepts of needs, or lack of compromise or tradeoff, that cannot be readily measured or expressed in the language of conventional economics. Publications by Pearce (1988), Daly and Cobb (1989), and Pearce and others (1989; a book whose publication produced tabloid headlines out of environmental economics – a rare case of immediate mass influence on the body politic!), as well as edited volumes by Collard and others (1988) and Costanza (1991), propelled the debate forward. However, many of these pieces served to identify conundrums as much as—or more than—resolve them. Among the first formal attempts during this time to analyze the new debate in terms of conventional economics were publications by Pezzey (1989/1992) in the field of growth theory (although this working paper is better known for its compilation of the dozens of sustainability definitions that had already piled up) and by Ahmad and others (1989) in the field of national accounts.

In "Toward Some Operational Principles of Sustainable Development," Daly (1990) highlights three intuitively appealing and memorable rules that are "obvious principles of sustainable development" (pp. 2, 4):

- Harvest rates should equal regeneration rates (sustained yield).
- Waste emission rates should equal the natural assimilative capacities of the ecosystems into which the wastes are emitted.
- Renewable energy sources should be exploited in a quasi-sustainable manner by limiting their rate of depletion to the rate of creation of substitutes for those renewable resources.

These rules encapsulate a kind of "folk wisdom" already reflected in Barbier (1987, 106). Daly's contribution, here and elsewhere, is as much his tireless promotion of these ideas as his care in analyzing them. To some extent Daly derives his ideas from two assumptions: that sustainability requires total (human-made plus natural) capital to be maintained intact (although we saw in our discussion of Solow 1986 that this may be neither necessary or sufficient), and that natural and human-made capital are complements rather than substitutes.

Daly thus was an important architect of the "strong sustainability" view that capital-resource substitutability is very limited, so the sustenance of specific resource sectors is very important. Unfortunately, although this verbal proof contains a grain of truth (derived from Georgescu-Roegen 1971), it assumes that "increased capital" always means more units of exactly the same physical technology (saws to cut timber, nets to catch fish), rather than allowing for changes in technology and the knowledge of how to use it. Short of some ultimate physical (thermodynamic) limits, the degree of long-term substitutability is an empirical question. As we noted earlier, empirical work on this issue has been limited. The tendency by partisans on both sides to refer to "obvious" propositions probably has not encouraged a much-needed empirical debate on substitutability.

"Sustainability: An Interdisciplinary Guide" (Pezzey 1992) is a long review article that (as the title suggests) includes not only economics but also material from disciplines such as anthropology, history, psychology, philosophy, and physics. The aim of the paper is to identify what can be said (and asked—the paper presents more questions than answers) about sustainability defined as "non-declining utility of a representative member of society for millennia into the future." Its main novelty is its stress on evolution: both the millennial evolution of "statically sustainable" societies (which use renewable resources and constant technology) versus "dynamically sustainable" ones (which use nonrenewable resources and changing technology), and the evolution of some "significant and durable influences" on the form and arguments of utility functions that must be taken into account in forming sustainability policies. In particular, Pezzey explores the implications of assuming that instantaneous utility depends on consumption changes and relative consumption as well on absolute consumption; thus, $U = U(C, \dot{C}, C/\overline{C})$ rather than just $U = U(C)$. Much of the apparent benefit of consumption growth then is canceled out by relative effects. Howarth (1996b) also addresses this issue, but other authors have not given it much attention.

"Economics and 'Sustainability:' Balancing Trade-offs and Imperatives" (Toman 1994) picks up on some of the sustainability themes in the environmental philosophy literature and examines how those themes relate to ideas in economics. As the title suggests, the dissonance in the two approaches to the subject stems from the difference between economists' strongly rooted belief in universal trade-offs (that is, there is a ceiling on willingness to pay for preservation of any natural resource), and philosophers' views about more universal moral rules (that is, societies do not use trade-off analysis to evaluate slavery; might not the same also be true in protecting ecological integrity?). Toman argues that one possible link between these disparate views might be found in an extension of the "safe minimum standard of preservation" idea developed by Ciriacy-Wantrup (1952) and Bishop (1978): Standard trade-off analyses apply when the magnitude and duration of risks are not very large, so moral stakes also are relatively low; however, ethical norms become increasingly important complements to trade-off analyses as the stakes rise (see also Norton 1992).

"'Sustainable Development': Is It a Useful Concept?" (Beckerman 1994) reminds everyone working away inside the new sustainability paradigm that many of those outside it remain fiercely critical of it. Beckerman assumes unlimited capital-resource substitutability, from which one can follow his logical argument that "'strong' sustainability, overriding all other considerations, is morally unacceptable as well as totally impractical." Given substitutability, the aim of sustaining a particular natural resource sector cannot be worth an unlimited sacrifice in terms of other economic assets, and insisting on such a sacrifice could arguably be immoral. Beckerman also criticizes the leaps frequently made by advocates from some analytical definition of sustainability (for example, constant consumption in Solow 1974) to sweeping moral injunctions for achieving sustainability thus defined.

However, Beckerman's argument that weak sustainability "offers nothing beyond traditional economic welfare maximization" is, we believe, incorrect.[9] In our analysis of Hartwick 1977, we show that weak sustainability in the form of constant consumption departs from PV maximization. The normative basis for weak or other sustainability criteria is open to debate, but sustainability analyses clearly are seeking notions of intergenerational equity that go well beyond the scope of conventional welfare economics.

Howarth (1995) develops the theme that moral obligations to future generations are distinct from altruistic individualistic preferences for the well-being of future generations. Using this rights-based framework, Howarth explores, among other topics, the often ill-defined "precautionary principle." Solow (1993), on the other hand, vigorously defends more conventional reasoning on sustainability. Solow argues in effect that if care is taken to internalize resource market inefficiencies and environmental externalities, and if society does not discount the future too much, then a sustainable allocation of resources—natural capital and otherwise—can result.[10]

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[9] Common (1996) offers similar, more extensive criticisms.

[10] Others that address this general set of issues include Page (1988, 1991), Howarth (1992), and Broome (1992), the latter a vigorous defender of utilitarian over rights-based moral principles. Norgaard (1988) brought to the fore the issue of a "co-evolutionary" relationship between human and ecological systems. Faucheux and Froger (1995) addressed the importance of addressing uncertainty and even ignorance in sustainability decisionmaking, underscoring the importance in their framework of "procedural" as well as "substantive" rationality. Ekins (1993) and Ayres (1996) produced wide-ranging general essays on both the equity and feasibility of sustainability as further responses to the "limits to growth" debate. A short essay by Arrow and others (1995), while fuzzy on many important details, brought together several themes and indicated that as a topic, sustainability had "arrived."

Analytical Papers Concerned with Sustainability, Efficiency, and Intergenerational Equity

"Intergenerational Resource Rights, Efficiency, and Social Optimality" (Howarth and Norgaard 1990) was seminal in showing that the classic welfare theory results regarding the effect of initial endowments on equity and efficiency readily translate from a static to an intergenerational context. Methodologically, this paper also brought the overlapping generations (OLG) analytical framework to the center of sustainability research. Different "endowments" of resource rights—in this case, a nonrenewable resource stock and labor—across two OLGs result in different distributions of wealth, all of them efficient but obviously different in their equity implications. There is no a priori way of saying which is "optimal."

Howarth and Norgaard extend their 1990 model to include many generations; capital accumulation; and in lieu of a nonrenewable resource input to production, an emissions output that accumulates and then causes an external cost of lost production, in "Environmental Valuation under Sustainable Development" (1992). Their key finding is that the path of consumption across time and the marginal valuation of the environmental externality (measured by the efficient emissions tax) depend on the distribution of wealth across generations (achieved by socially mandated income transfers from old to young). So, even in theory, there is no fixed notion of "correctly" valuing an environmental cost: The value varies with society's view of the future, whether expressed as a discount rate or some sustainability criterion. This point is relevant, for example, in valuing Pigouvian prices for greenhouse gas damages (see, for example, Woodward and Bishop 1995, 1997; Howarth 1996a, 1998).

Several other papers by Howarth, alone and with Norgaard, help to show the full analytical power of the OLG approach to sustainability. Howarth (1991a) first extends the results of Howarth and Norgaard (1990) to cover the case of many generations and to use labor and capital as inputs to production, then includes uncertain technical progress and showed how this makes the socially optimal transfers among generations risk-averse (Howarth 1991b). Howarth and Norgaard (1993) consider a range of intergenerational welfare functions and showed how, even if one generation cares about the next, transfers caused by private altruism may not maximize welfare. They also explore the relationship between intergenerational transfers and intergenerational discounting, noting that changes in discounting alter the intertemporal distribution of resources and thus also alter the rate of return on investment. It follows that concerns in policy debates about "excessive" long-term discounting can be reinterpreted as concerns about intergenerational resource allocation, without necessarily suggesting the need for massive intervention in capital markets to directly alter the discount rate.[11]

Asheim (1988, 1991, 1996a) explores the formal foundations of an ethics of sustainability, though the uncompromising rigor of the papers limits their readership to the technical, well-motivated few. In particular, Asheim (1991) shows how a particular definition of intergenerational justice is equivalent to a nondecreasing consumption constraint, like the kind of rising and then constant consumption path later highlighted by Pezzey (1994).[12]

One implication drawn from this analysis is that any assumption of conventional PV optimality effectively forecloses debate on intergenerational equity by giving all resource rights to the current generation. This observation is true to a degree, but it must not be overstated. The current generation cannot help existing earlier in time than its successors; this fact in and of itself does not create a moral obligation. Rather, any moral obligation must derive from other considerations. This matter is certainly not settled and may never be. In addition, the challenge to policymakers of finding conceivable political and legal institutions to give resource rights to people not yet born is a difficult one, to put it mildly.

Ecology–Environment Relationships

Another widely cited article written during this period is "Towards an Ecological Economics of Sustainability" (Common and Perrings 1992), which aims to show how the concept of ecological sustainability is very different from that of economic sustainability. The former involves resilience, conceived of as stability of the parameters defining an ecological–economic system.[13] In turn, these parameters include biological and engineering parameters in production functions, and psychological parameters in utility functions. The key conclusion is that economic efficiency is not necessary for ecological sustainability and, indeed, can conflict with it: "If existing preferences and technologies

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[11] Other important papers in this general area of literature included Burton's (1993) clarification of the distinction between intertemporal and intergenerational discounting and Mourmouras' (1993) OLG model of efficiency and equity.

[12] Other relevant literature includes an article by Collard (1994), who considered sustainability in the context of a societal aversion to income inequality. Hamilton (1995) clarified some technical relationships that may but do not always hold among sustainable development, a generalized Hartwick's rule, and PV optimality. Heyes and Liston-Heyes (1995) noted that a nondeclining utility constraint can cause a strictly Pareto-inferior consumption path to be chosen. However, this path can often be avoided by including the best available nondeclining path in the choice set.

[13] See the article by Perrings (1995) for further analysis of the relationship between resilience and sustainability.

are not ecologically sustainable, then consumer sovereignty implies system instability. … [A]n ecological economics of sustainability implies an approach that privileges the requirements of the system above those of the individual." This provocative paper is highly formal mathematically yet somewhat loose in conception, so it is difficult to read.

Several other studies consider how biophysical limits affect economic activity; Cleveland and Ruth (1997) provide a useful survey of much of this literature.[14] Several articles also have explored the "neo-Austrian" approach to investment, output, and the environment, which relies on an activity analysis with less substitutability between various factors of production (see Faber and others 1990 for an earlier example of this approach). Victor (1991) provided an early and frequently cited exposition of different sustainability concepts and their relationships to resource substitution possibilities.

The Beginnings of Empirical Sustainability Work

Despite a steady flow of work on the related topic of "green national accounting" (as in Repetto 1989), relatively little empirical work has been published on sustainability. No doubt this scarcity reflects in part the theoretical challenges discussed later. The first major paper was "Capital Theory and the Measurement of Sustainable Development: An Indicator of 'Weak' Sustainability" (Pearce and Atkinson 1993). The authors attempt to use data for 18 real economies (from the United States to Burkina Faso) to examine the "weak sustainability" of these economies in the sense of Hartwick (1990) and Victor (1991). In the notation of our Model (1), Pearce and Atkinson calculate the savings ratio $(\dot{K}/F)$, depreciation as a proportion of output ($\delta K/F$), and resource depletion rents as a similar proportion $([F_R(R-G(S))-\xi R]/F)$; the second and third values are subtracted from the first to arrive at a measure of overall sustainability.[15]

The economies of Japan and all the European countries in the sample were determined to be definitely sustainable, essentially because of high savings rates and low resource depletion rents (the latter perhaps because these countries have relatively few resources left to deplete). By contrast, the economies of all the African countries in the sample were judged to be definitely unsustainable, because of low savings rates and high depletion rents. The United States was labeled as marginally sustainable, only because its savings rate is much lower than that of Europe or Japan. Pearce and

[14] Several other articles in the same special issue of *Ecological Economics* will help the reader understand the dimensions of the debate that surround this subject.

[15] Pearce and others (1993, 43) present details about a similar calculation for the United Kingdom.

Atkinson (1993) thus focus useful empirical attention on savings-funded investment in human-made capital as well as natural resource depletion as an important determinant of sustainability, if one "believes" in the substitutability of the former for the latter.

However, there are at least two major flaws in Pearce and Atkinson's approach. First, technical progress, or what might be referred to as an increase in "knowledge capital," is ignored. Because of the absence of measures of technical progress, calculations based on current prices can unfortunately yield a false positive or a false negative message about an economy's sustainability. We return to this topic later in our discussion of the 1997 article by Weitzman.

Second, the implicit assumption is that observed prices used to estimate resource rents [F_R in Model (1)] can say something useful about sustainability. Both Asheim (1994) and Pezzey (1994) point out the flaw in this assumption. Asheim's presentation in "Net National Product as an Indicator of Sustainability" (1994) is technically difficult, but its intuitive message is simple. Because sustainability is a macroeconomic concept, shifting an economy from unsustainability to sustainability changes all its prices. Sustainability prices and sustainability itself are thus related in a circular fashion: Without sustainability prices, we cannot know whether the economy is currently sustainable; but without knowing whether the economy is currently sustainable, currently observed prices tell us nothing definite about sustainability. In particular, net national product (consumption plus the sum of investment minus depreciation for all asset types) equals the maximum sustainable level of consumption only if an economy is already on a constant consumption path.[16]

1997–2000: A Flourishing but Still Developing Literature

The last few years covered in this review can be conveniently demarcated by the publication of a special issue of the journal *Land Economics* devoted to sustainability issues (November 1997) as well as continued relevant journal publications elsewhere (notably, *Ecological Economics*) and a growing number of relevant books and conference proceedings.

Several these publications are useful extensions of previous work. Norton and Toman (1997) extend their analysis of "two-tier" decision frameworks for sustainability to develop a multicriteria model of environmental impact assessment. Farmer and Randall (1997, 1998) further formalize the notions of

[16] Asheim (1996b) showed how constant consumption rules in a world with different economies must include capital gains terms, and later focused on the differences between consumption-based and utility-based measures of net national product (NNP) and the role of technical progress (Asheim 1997). Both papers include explicit attention to the case of a nonconstant interest rate. Asheim (2000) provides a grand synthesis of relationships among sustainable income and three other income measures in a closed economy.

intergenerational transfer and the safe minimum standard. Howarth (1997) synthesizes ideas on the concept of "sustainability as opportunity." Faucheux and others (1997) offer a revealing simulation-based analysis of the limitations of weak sustainability indicators, using an OLG model derived from Howarth's work and building on the ideas of Asheim, Pezzey, and others. Stern (1997) neatly encapsulates the issues that arise in defining both individual preferences and (limited) production substitution possibilities. Portney and Weyant (1999) present a collection of essays on discounting and intergenerational equity with papers by several leading experts in the field (see also Weitzman 1998).[17]

Verbal/Philosophical Analyses

In "On the Problem of Achieving Efficiency and Equity, Intergenerationally," Page (1997) compares two approaches to the problem of achieving the socially chosen goals of intergenerational efficiency and intergenerational equity. In the first, standard benefit–cost analyses (that is, calculations of PV) are done first, and then intergenerational equity is considered separately. In the second, efficiency and equity considerations are integrated from the start. Page defines intergenerational equity in terms of Thomas Jefferson's principle of usufruct: If the resource base (including both natural resources and human-made capital) as a whole is kept intact over generational time, then each generation is treated equally.

Page then discusses the problems of sustaining the whole resource base that are posed by limits to substitutability and technical progress. In an application of David Hume's idea of the "circumstances of justice," he points out that sustainability may best provide guidance for decisions if the problems of maintaining the resource base in usufruct are neither impossibly difficult nor trivially easy. Page emphasizes that many social decisions are made neither in markets nor by marketlike benefit–cost criteria, but through legal and political institutions. As a society, we can choose to elevate sustainability to more of a "constitutional" principle; however, the dividing line between social decisions to be made using individualistic economic criteria and those using more collective mechanisms is not clearly marked.[18]

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[17] This period also saw the publication of an article in *Nature* (Costanza and others 1997) that ignited huge controversy about both the methods used to measure the value of ecosystem services and the underlying approach (for example, the attempt to value total services versus a change in the flow of services).

[18] Bromley (1998) is even more sharply critical of the reliance on market-based thinking; however, his arguments are couched in somewhat specialized philosophical language and contain some straw man criticisms of conventional economic reasoning.

One approach to resolving the tension between conventional economic criteria (benefit–cost analysis or, equivalently, PV maximization) and sustainability—firmly in the "traditional" sustainability camp and thus quite different from that put forth by Page (1997)—is suggested by Pezzey (1997) in "Sustainability Constraints versus 'Optimality' versus Intertemporal Concern, and Axioms versus Data." Pezzey defends the possible use of different variants of sustainability as a prior constraint on PV optimality. He argues that such a constraint is not self-contradictory, redundant, or inferior, contrary to the claims of Beckerman (1994) and Dasgupta (1995). In so doing, Pezzey questions the axiomatic foundation of PV maximization as set out by Koopmans in 1960. In particular, he challenges the validity of Koopmans' stationarity axiom, an axiom that Page (1997) also describes as having "strikingly unappealing normative properties."

Pezzey also suggests an alternative to sustainability constraints and to the tradition of analyzing constraints by appealing to "moral intuitions" when selecting from among conflicting axioms. He proposes an empirical approach that relies on psychological experiments on time preferences to extend the intertemporal welfare function in Model (1) to include a finite (and therefore not overriding) "value of sustainability" in some way (see also Pezzey 1992). This extension might involve replacing the instantaneous utility function with a more complex function that includes the individual's value of improvements in consumption. An important feature of this approach is that it may result in Pareto-inefficient consumption paths being preferred. The analytical implications remain untested so far, as does its practicality for an empirical approach to characterizing the value of sustainability.

Analytical Treatments of Sustainability, Efficiency, and Intergenerational Equity

A largely independent contribution to the "traditional" sustainability literature is "An Axiomatic Approach to Sustainable Development" (Chichilnisky 1996). Chichilnisky works in a discrete-time framework that can apply to either OLGs or non-OLGs and can allow for the functional form of instantaneous utility to vary from generation to generation.

Chichilnisky proposes two standard and two extra axioms that any intertemporal welfare function $W(.)$ that maps a utility stream $\{u_t\}$ to a real number should satisfy to be a "sustainable preference" ordering, that is, a function whose maximization provides an acceptable criterion for optimally sustainable development. First, $W(.)$ should be both "complete" (able to rank any two feasible utility streams) and "sensitive" (able to give higher rank to a stream that Pareto-dominates another stream). These axioms are satisfied by the PV criterion, but the extra two axioms that Chichilnisky adds are not: $W(.)$ should also satisfy both "no dictatorship of the present" (utility streams cannot be ranked only on the basis of a finite number of initial generations) and "no dictatorship of the future" [utility streams cannot be ranked if a finite, positive number of initial generations are ignored by *W*(.)].

Chichilnisky proves that the welfare function

$$W(\{u_t\}) = \sum_{t=1}^{\infty} \lambda_t u_t + \lim_{t\to\infty} u_t, \ \ \sum_{t=1}^{\infty} \lambda_t < \infty \tag{2}$$

where the positive discount factors (λ_t) need not be of negative exponential form, is indeed a sustainable preference. Several other well-known welfare measures then turn out not to be sustainable preferences: any sum of discounted utilities, Ramsey's criterion of minimizing the distance between $\{u_t\}$ and a "bliss" utility level, the overtaking criterion, long-run averages, Rawlsian rules, and a basic needs approach. Moreover, with the added restrictions that *W*(.) is continuous and independent, she proves that a sustainable *W*(.) must be of the form

$$W(\{u_t\}) = \sum_{t=1}^{\infty} \lambda_t u_t + \phi(\{u_t\}) \tag{3}$$

where $\phi(\{u_t\})$ is a "purely finitely additive measure," which is a generalization of the concept of giving weight to the welfare of far-distant generations.

Such a *W*(.) generates an allocation very different from that arising from maximizing the discounted sum of utilities. It remains to be seen whether this promising and rigorous development of sustainability theory will be more operational or more politically acceptable than any of the most frequently suggested options in current debates.

In "On Sustainability and Intergenerational Transfers with a Renewable Resource," Krautkraemer and Batina (1999) build on the OLG framework developed by Mourmouras (1993). They explore some issues of intergenerational equity in an economy that depends on a renewable resource with a strictly concave growth function and has a maximum sustainable stock (or carrying capacity) of S_M. They find that depending on parameters such as the resource payment's share of total output and the private utility discount factor (α and ϕ in our notation), the market equilibrium (if it exists—that is, if the resource is not exhausted or rendered extinct) could entail Pareto-inefficient overaccumulation of the resource, so that $S_\infty > S_M$ where S_∞ is the asymptotic resource stock. They also demonstrate that if there is initial overaccumulation of the resource [$S(0) > S_M$], then a nondeclining utility constraint produces a Pareto-inefficient path: A path of declining consumption can result in higher utility for all generations than a constant consumption path that maintains the less productive state of overaccumulation. This result is interesting mainly in illustrating the potential conflict between Pareto efficiency and sustainability criteria, and the fact that "the desirability of a particular social welfare criterion cannot be determined independently of its implications in different technological situations" (pp. 178, 180).

Empirical Sustainability Work

Weitzman (1997) covers both theory and empiricism in "Sustainability and Technical Progress." We include this article in this section rather than the previous one because we think its empirical result is just as important as its theoretical result.

Using a model with a linear utility function and a constant interest rate, Weitzman first generalizes his earlier result (Weitzman 1976) that on the PV-maximizing path, the annuity equivalent of the PV of consumption equals net national product (NNP), defined as current consumption plus aggregate stock changes (human made and natural) valued at PV-optimal prices. The 1997 extension shows that when the production possibilities set allows for exogenous technical progress over time (as measured by the "Solow residual" of neoclassical growth theory), the annuity equivalent of consumption will equal NNP adjusted by a multiplier that reflects in particular "… the pure effect of time alone on enhancement of productive capacity not otherwise attributable to capital accumulation" (p. 7).

Weitzman suggests a criterion for judging the sustainability of current consumption: It should be no more than its annuity equivalent, as adjusted for the impact of exogenous technical progress. As noted previously (Asheim 1994; Pezzey 1994), this criterion does not rule out the possibility of future declines in consumption. It is much more likely to be met if the upward adjustment to NNP from technical progress is much bigger than any possible downward adjustment from including resource depletion and environmental degradation as part of "green" national accounting.

Empirically, this result is just what Weitzman estimates (albeit crudely) for the U.S. economy. He concludes (p. 11) that while the total cost of environmental remediation and resource depletion for the United States is on the order of 2% of the gross national product (GNP), the "technological change premium" augments the GNP by about 40%. By Weitzman's definitions and calculations, therefore, the U.S. economy is very comfortably sustainable, and "sustainability would appear to depend more critically on future projections of the [technological progress] residual than on the typical corrections now being undertaken in the name of green accounting" (p. 12). Although the theoretical link between the national accounting measures and sustainability is problematic, Weitzman's provocative empirical results form an important challenge to those concerned about sustainability, one that cries out for further exploration and discussion. Some issues relevant to further evaluation include accounting for the endogenous accumulation of human and intellectual capital (which would reduce the estimate of exogenous productivity growth); refining the measures of environmental degradation, including global considerations; and accounting for how adverse impacts of U.S. economic activity might be enhanced by trade, if imports are far more resource-intensive than exports.

The last of these factors is not significant, according to calculations reported in "International Trade and the Sustainability Footprint: A Practical Criterion for Its Assessment," in which Proops and others (1999, 84) note that the carbon intensity of U.S. imports was actually lower than the carbon intensity of its exports. But the main focus of this article is to show that one way or another, trade in both resources and resource-intensive goods is certainly significant in real-world analyses of sustainability for most countries. We chose it rather than other conventional analyses (for example, Asheim 1996b; Vincent and others 1997)[19] to include in this review because it gives an analytically and empirically clear (though debatable) development of the idea of "exporting unsustainability" suggested by Pearce and others (1989, 45–47). This idea, which has since gained much currency in debates on trade and environment and "fair trade," states that rich, industrialized countries, which import large amounts of resources (or resource-intensive goods ultimately derived) from countries that are depleting their resources unsustainably, bear some responsibility for this unsustainability.

The set of disaggregated calculations for various countries from Proops and others centers on the difference between two key measures of sustainability. The first is *closed economy sustainability*, analogous to the measure used by Pearce and Atkinson (1993); its theoretical shortcomings mean that it can only be viewed as a rough guide. The second measure is *open economy sustainability*, which replaces calculations of the capital and resources used "by" an economy with the capital and resources used "for" or "attributable to" an economy. The latter parameters are calculated by matrix algebra derived from an input–output analysis of world trade flows.

The single most important empirical finding by Proops and his collaborators is that moving from the closed economy to the open economy dramatically increases the calculated sustainability of resource-based regions such as the Middle East, and reduces it for industrial regions such as western Europe and the United States (see Proops and others 1999, figures 5b and 6b). However, despite their contention that "industrialised countries appropriate the carrying capacity of other countries (e.g., by importing natural resources), therefore benefiting at the expense of their trading partners" (p. 77),

[19] Vincent and others (1997) empirically illustrate (for the case of Indonesia) how to calculate sustainable income in a way that accounts for the effects of capital gains in an open, resource-exporting economy. The need for such a calculation is underscored by the fact that resource prices have typically been flat or falling, not rising as in most theoretical models. A more radical view of trade and sustainability is expressed in Gowdy and McDaniel's (1999) case study of guano export from the Pacific Island of Nauru, even though the analysis is hampered by gaps in data.

Proops his collaborators draw no conclusions from their calculations for either national or international policymaking. Missing from their framework is a characterization of how and to what extent free trade is unfair and exploitative.

A fitting conclusion to our selection of papers, which highlights both what has been achieved and what remains unclear or unresolved, is "Measuring Sustainability: A Time Series of Alternative Indicators for Scotland" (Hanley and others 1999). Hanley and others heroically estimate and compare seven sustainability measures for Scotland during the period 1980–93. The measures are drawn from a wider set of 17 indicators, including both single and aggregate measures in economic, ecological/environmental, and sociopolitical categories. The latter two categories broadly match the "folk" idea (reflected in Barbier 1987) that economic, environmental, and social sustainability are three separate concepts. The indicators vary not only in their detailed definition but also in whether they include a clear test of sustainability versus unsustainability. Unlike in the analysis by Proops and others (1999), none of these categories makes any allowance for trade.

The two economic indicators of "weak sustainability"—green net national product (GNNP) as developed from Hartwick (1990) and genuine savings as developed from Pearce and Atkinson (1993)—yield somewhat surprisingly different results. GNNP shows Scotland to be increasingly sustainable over the period; genuine savings shows it to be unsustainable, but becoming less so. One reason for this discrepancy is that GNNP uses investment data, whereas genuine savings uses savings data that come from a different administrative source and may diverge widely from investment in a small open economy such as Scotland. The three ecological/environmental indicators of "strong sustainability" reveal Scotland to be either marginally sustainable with slight improvement, or marginally unsustainable with little change. The two sociopolitical indicators (Index of Sustainable Economic Welfare and the Genuine Progress Indicator) involve ad hoc adjustments of conventional GDP per capita aimed at finding a better measure of instantaneous utility, and have no direct connection with sustainability as intergenerational equity. The diversity of results from the various indicators and practical problems in their definition indicate how far we still have to go in developing reliable and widely accepted measures of sustainability.

Concluding Remarks

For all the legitimate criticism that can be leveled at the somewhat amorphous nature of sustainability, we believe some important basic lessons have emerged from the sustainability studies covered or referred to in this review.

First, there is no clear understanding of, let alone consensus around, what constitutes a sustainability objective or standard. It is clearly more than a simple PV criterion. But what it is, who decides what it is, and how that decision is made, continue to bedevil analysts of all stripes—just as similar questions about individual and social responsibility have been torments for millennia. We will not find answers to this question by resorting only to a priori philosophical constructs.

Second, efficiency and equity are different concepts, and economists need to maintain this distinction when analyzing issues related to long-term economic progress and the natural environment. In particular, values of long-term environmental costs and benefits ultimately depend on some implicit or explicit assumptions about the intergenerational distribution of income, hence about the current generation's obligations (if any) to future generations.

Third, economic analytical frameworks typically contain implicit as well as explicit presumptions about the prospects for both resource substitution and resource-augmenting technical innovation. These assumptions may or may not prove to be satisfactory, but the empirical foundation underneath them is not as strong as it could be.

Finally, and more generally, the dearth of empirical work on what sustainability might mean for environmental and economic valuations, and the continued lack of concrete understanding of what "sustainability policies" might entail in practice, indicate the scale of continued intellectual challenges in the field.

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