United States
Environmental Protection
Agency

Policy , Planning,
And Evaluation
(2127)

EPA 230-R-95-007
September 1995

EPA

Integrating The Environment And The Economy: Proceedings Of June 1994 Association Of Environmental And Resource Economists Workshop

Integrating the Environment and the Economy: Sustainable Development and Economic/Ecological Modelling

1994 Association of Environmental and Resource Economists Workshop

Boulder, Colorado
June 5-6, 1994

PREFACE

The 1994 AERE Workshop was held June 5th and 6th in Boulder, Colorado. The topic was **Integrating the Environment and the Economy: Sustainable Development and Economic/Ecological Modelling.** Keynote addresses were given by John Hartwick of Queens University and Michael Toman from Resources for the Future. Michael's talk was entitled "Neoclassical Economics and Sustainability," and was based on papers by Michael; and Michael, John Pezzy and Jeffrey Krautkraemer. John spoke on "Sustainability and Constant Consumption Paths in Open Economies with Exhaustible Resources."

Session topics included Sustainability : Some Basics; Sustainability: Extensions and Issues; Issues in Environmental Accounting; and Economic/Ecological Modelling and Ecosystem Valuation.

There were almost ninety participants, and my perception is that most found the workshop either productive, enjoyable, or both. I both enjoyed it and learned a lot. The weather was great, the hotel nice, and the food good. The presentations were great. Those of you who were not there missed all of the site-specific amenities, but can still enjoy the papers. I recommend them.

The papers by Bishop and Woodward; and Hrubovack, LeBlanc, and Eakin are revisions of the manuscripts that were presented at the AERE Workshop. Due to copyright considerations, only abstracts are included for the following papers: Pezzey; Toman, Pezzey, and Krautkraemer; Gottfried, Wear, and Lee; Silvestre; and Albers.

Neither the conference nor this EPA volume would have been possible without generous sponsors. These include the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, the U.S. Department of Agriculture, and the University of Colorado. Thanks also goes to the AERE Workshop committee members, Betsy David, Anne Grambsch, Mary Jo Kealy, Bob Leeworthy, Michael LeBlanc, and Kathy Segerson. Great on-site help was provided by four Ph.D. students in the Economics Department at the University of Colorado. Kate Carson, Kathleen Greer, Amanda Lee, and Charles Rossmann; each is specializing in environmental economics.

Edward Morey

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Papers presented at the 1994 Workshop Conference

ENR 93-14 REV

NEOCLASSICAL ECONOMIC GROWTH THEORY AND "SUSTAINABILITY"

by

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October 1993, revised April 1994

This paper is forthcoming in the *Handbook of Enviromental Economics,* edited by Daniel Bromley and published by Blackwell. The authors are grateful to Geir Asheim, Edward Barbier, Richard Howarth, David Pearce and Tom Tietenberg for helpful advice during the preparation of this paper. The paper also benefited from the assistance of Mary Elizabeth Calhoon and Kay Murphy. Pezzey's research was supported by the UK Centre for Economics and Environmental Development and the Economic and Social Research Council.

ABSTRACT

NEOCLASSICAL ECONOMIC GROWTH THEORY AND "SUSTAINABILITY"

The issue of "sustainability" figures prominently in contemporary discussions of natural resource and environmental management and economic development. However, the concept is not easily defined and is interpreted differently by economists, ecologists, philosophers, and others. Even among economists there are significant differences of interpretation. Some treat sustainability as not much more than another way of espousing economic efficiency in the management of services derived from the natural endowment. Others claim that conventional economic efficiency criteria are inadequate for addressing sustainability concerns.

Our aims in this paper are to identify the issues that seem to be most salient in formal economic analysis of sustainability, and to review economic growth theory that bears on these issues. In the latter effort we focus mostly on literature within the methodological mainstream of neoclassical economics, though the studies do not always maintain all the common assumptions of neoclassical theory. We first draw together arguments from economics, ecology and philosophy to briefly describe what seem to be the most important issues m addressing sustainability. Armed with this characterization, we then review several categories of studies related to economic advance, natural resource use, and environmental preservation over time. We include both representative-agent models and overlapping-generations models in the review. The concluding section of the paper summarizes our discussion and offers an overall assessment of the literature.

Economics and "Sustainability": Balancing Trade-offs and Imperatives

Michael A. Toman

ABSTRACT. *The concept of "sustainability" has been increasingly invoked in scholarly and public policy debates. Discussion has been hampered, however, by uncertainty and lack of uniformity in the meaning of sustainability. This paper seeks to identify some common ground among economists, ecologists, and environmental ethicists. Two issues seem salient: requirements for intergenerational equity and the definition of "social capital" to be provided to future generations. A concept of "safe minimum standard," which has received at least some recognition in the ecology, philosophy, and economics literatures, may provide the beginnings of a common ground for debate about sustainability. (JEL* Q2)

I. INTRODUCTION

The concept that use of natural resources, environmental services, and ecological systems somehow should be "sustainable" has become one of the most widely invoked and debated ideas in the area of resource and environmental management. It was a basic theme in the 1992 "Earth Summit," the United Nations Conference on Environment and Development (UNCED), and in the World Bank's 1992 World Development Report on environment and development. It is an issue discussed not just in professional journals but also in newspaper articles and in basic textbooks (see, e.g., Pearce and Turner 1990 and Tietenberg 1992). It is a principle behind the founding of a professional organization, the International Society for Ecological Economics, many of whose members question the sufficiency or even the validity of conventional economic approaches to resource and environmental management problems.

Despite the frequency with which the term is invoked, the concept of sustainability y remains surprisingly ambiguous. It is clear from examining various usages of the term that writers have very different meanings in mind.[1] For example, the use of the term in the 1992 *World Development Report* seems to refer primarily to the application of existing neoclassical principles of efficient resource and environmental management in developing countries. This is very different than the ideas expressed by Herman Daly (see, e.g., Daly 1990, 1991), who argues that use ("throughput") of energy and materials must be sharply curtailed to avoid ecological catastrophe. Sustainability also is interpreted very differently by many economists, who see the natural environment as one of many fungible assets that can be deployed in satisfying human demands, and by many ecologists and ethicists, who express 'greater concern for both ecological integrity and the interests of future generations (compare Ehrlich 1989 and Solow 1993a, 1993b, for example).

The goal of this paper is to provide some vocabulary and grammar that may be useful for this ongoing debate among economists, ecologists, and ethicists. We begin, as do many others, with the statement about sustainability from the report of the "Brundt-

Senior Fellow, Resources for the Future.

Earlier versions of this paper were presented at, meetings of the International Society for Ecological Economics and the American Economic Association, and at seminars at the World Bank, the Agency for International Development, and the University of Maryland. I owe a large debt to Pierre Crosson, Bryan Norton, and John Pezzey, whose insights played a substantial role in clarifying my understanding of the issues raised in the paper. I also appreciate helpful conversations with Geir Asheim, Doug Bohi, Allen Kneese, and Jeff Krautkraemer, and perceptive comments by Tom Tietenberg, Scott Gordon, Tim Brennan, arid an anonymous referee on earlier drafts.

[1] See also Pezzey (1989) and Pearce, Markandya, and Barbier (1989), who catalogue scores of sometimes vague and conflicting sustainability definitions. Dixon and Fallen (1989) discuss how sustainability has been transformed from a condition on steady-state management of specific resources to an expression of broad ecological concerns.

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land Commission," the World Commission on Environment and Development (WCED). That report described 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). The threat to future generations perceived in the report arise from potentially large-scale and irreversible degradation of natural systems in the course of global economic development, particularly in poorer countries.

The Brundtland statement thus focuses attention on two issues that seem to be central themes in any conception of sustainability: the nature of the current generation's responsibility to future generations, and the degree of substitutability between "natural capital" and other forms of social capital-physical investment and investment in knowledge and institutions as embodied in human capital.[2] The next two sections of the paper examine alternative views on these two issues to show how they lead to different conceptions of sustainability. In the fourth section of the paper these alternative conceptions are related to each other through a "two-tier" model of resource management based on the idea of "safe minimum standard." The fifth and last section of the paper contains concluding remarks.

II. INTERGENERATIONAL FAIRNESS

There is an enormous literature, spanning over two millennia, on concepts of distributive justice including fairness across generations. Unfortunately, there is not yet a conception of distributive justice that commands wide intellectual support. Nevertheless, there are several points of view that have attracted considerable attention in discussions of sustainability.3 The discussion that follows emphasizes issues of intergenerational fairness even though these issues cannot be entirely divorced from the subject of the next section, substitution possibilities among components of society's wealth endowment.

One fundamental partitioning of justice concepts separates theories based on maximization of an independently defined good (teleological theories) from theories based more on innate rights and obligations (deontological theories). A further categorization can be made based on theories that emphasize the current generation and its immediate descendants-"presentist" theories-and theories that put greater emphasis on the "further future." Yet another distinction, particularly in nonpresentist theories of justice, concerns justice concepts that emphasize individuals and more "organicist" conceptions that put greater weight on community interests.

The typical criterion of discounted intertemporal welfare maximization in applied welfare economics occupies one point in the continuum of alternative justice conceptions. This criterion not only emphasizes preference satisfaction over rights; it also is highly presentist, since with *any* positive intergenerational discount rate the welfare of individuals living one generation in the future is scarcely relevant to current decision making. Many writers have suggested that the presentist focus of the present-value (PV) criterion implies an influence of the current generation over the circumstances of its more distant descendants that seems, at least intuitively, to be ethically questionable (Kneese and

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[2] In emphasizing these themes we are placing ourselves within the anthropocentric stream of debate about sustainability, in which the needs and wants of people are central, as opposed to an "eccentric" perspective that asserts the intrinsic worth of the natural environment. We also are sidestepping, without in any way minimizing, the issue of how the state of the environment may be connected to income distribution within generations-in particular, connections between poverty and environmental degradation. See Pearce, Barbier, and Markandya (1990) and World Bank (1992) for discussion of these issues. Finally, we consider sustainability primarily in the context of resource management to meet identified human needs; as opposed to the broader "co-evolutionary" perspective discussed in Norgaard (1988), which emphasizes the mutual interactions between social actions and goals.

[3] See Pearce and Turner (1990, chap. 15) for a compact summary; Pezzey (1992) provides a wide-ranging survey of motivations for considering sustainability.

Schulze 1985; Norton 1982, 1984, 1989; Parfit 1983b; Page 1977, 1983, 1988).

The debate over the ethical implications of the PV criterion is long-standing and involves a number of considerations that often seem to be misunderstood. One basic issue in this debate is the relationship between the PV criterion and the broader concept of intergenerational economic efficiency as defined by the Pareto criterion, which requires only that it be impossible to improve the welfare of members of one generation without reducing the welfare of members of some other generation. This notion of "no waste" seems desirable in any intergenerational welfare criterion, at least to those who give some weight to the importance of individual preference satisfaction. The difficulty with the PV criterion thus is not that it requires Pareto efficiency, but rather that it puts weight on the welfare of the current generation in the social welfare function that some regard as excessive.

As Page (1977, 1988) points out, there are infinitely many intergenerational social orderings consistent with the Pareto principle that allow for different sets of intergenerational welfare weights without the "dictatorship" of the current generation embodied in the present value criterion. A number of analysts have explored other social welfare criteria that preserve the Pareto principle without imposing the preferences of the current generation on future generations.[4]

This issue has been carefully considered in a series of papers by Howarth and Norgaard (see Howarth and Norgaard 1990, 1992, 1993 and Howarth 1991a, 1991b). Using an overlapping generations framework, they argue that the problem of intergenerational equity must be viewed as a problem of ethics that is distinct from economic efficiency in the Pareto sense. They further argue that the intergenerational equity problem should be approached as one that involves a fair distribution of property rights between current and future generations. This argument is a simple but powerful intergenerational extension of a standard result in welfare economics: "The choice of distribution of income is the same as the choice of an allocation of endowments, and this in turn is equivalent to choosing a particular welfare function" (Varian 1984, 209; see also Bromley 1989). In particular, Howarth and Norgaard show that while purely "egoistic" utility concerns will motivate some savings to benefit the (short-term) future (since people live more than one period and may also have concerns for their own immediate descendants), purely egoistic savings will not in general be adequate to optimize a social welfare function that includes more altruistic concerns (e.g., the well-being of the entire next generation or individuals further into the future), Howarth's and Norgaard's arguments also have important implications for analyses of environmental valuation, discount rates, and policy design (e.g., pollution taxation), since all of these ate affected by the income distribution.

Howarth and Norgaard do not investigate the range of intergenerational social welfare functions that might plausibly be invoked in connection with intergenerational equity. In their analysis they are concerned primarily with the egalitarian "maximin" criterion discussed below as an alternative to maximizing the present value of utility streams.[5] In addition, trying to achieve intergenerational equity solely through savings that transfer endowments across

[4] See in particular Page (1977), Pearce (1983), and Burton (1993) for discussions of intergenerational discounting. These analyses suggest that a positive discount rate to reflect the growth of the economy is compatible with a zero rate of pure time preference in the social welfare function on ethical grounds. The arguments in Sandler and Smith (1976, 1977, 1982), Bishop (1977), and Cabe (1982) indicate "that the assumption of a uniform discount rate may not be consistent with intertemporal Pareto efficiency, particularly with intertemporal public goods.

[5] Howarth (1992) derives this social welfare criterion from a more restricted maximin ethic between just parents and their children. He shows that if parental altruism extends only to the direct consumption of the next generation, there is no assurance that utility levels will be maintained or increase over time; but if the current generation is concerned about the capacity of its descendants to exercise their bequest motive as well, the result is concern about the equity of welfare across all generations.

generations may not always be effective. Randall and Farmer (1993) argue that when the two-generation analyses of Howarth and Norgaard are extended to a setting with three or more generations, a kind of Coasian result obtains: the ultimate equilibrium allocation is not that sensitive to the initial distribution of property rights. Randall and Farmer argue for an approach to sustainability based on preservation rules like the safe minimum standard discussed subsequently in this paper.

The problem of intergenerational equity has received considerable attention in the economics literature through the application of a Rawlsian (1971) "maximin" concept of intergenerational rights (see, e.g., Solow 1974, 1986 and Norton 1989, as well as the work by Howarth and Norgaard cited above). The Rawlsian approach has been criticized as posing too harsh a trade-off between equity and welfare maximization, since a strict application of the Rawlsian criterion leads to the outcome that all generations must be equally well (or badly) off-that is, there is no scope for the current generation to pursue improvements in future conditions. However, more recent analyses of the Rawlsian social welfare problem suggest that this trade-off need not be so harshly drawn. In particular, Asheim (1988, 1991) shows that when individual preferences include some altruistic concern for immediate descendants, but there is also a social agreement to follow a Rawlsian ethic involving concern for the indefinite future, it is possible within the context of social welfare maximization to have economic growth coupled with a requirement that future generations be no worse off than the present.

As Pezzey (1989, 1994a) points out, there are a number of alternatives to the maximin criterion for social welfare orderings that could be used to reflect intergenerational equity concerns. Pezzey (1994b) analyzes in some detail the implications of a criterion based on the maximization of the present value of per-capita utility subject to an ethical constraint that per-capita utility not decline over time. Like Asheim, Pezzey finds that this criterion allows for concern for future welfare without necessarily sacrificing all growth possibilities. A weaker version of this criterion would accord intergenerational equity (as indicated by nondeclining utility over time) some *finite* weight in the social welfare function, allowing for well-defined trade-offs between maximum present value and fairness (see, e.g., Broome 1992).

The discussion thus far has concerned mainly individualistic conceptions of what is good or right. Even the individualistic point of view gives rise to deep controversy. On the one hand, critics raise objections to the capacity of utilitarianism, or even the concept of human preferences, to adequately describe human interests (see, e.g.; Sen 1982; Parfit 1983b; Sagoff 1988; and Norton 1992).[6] Defenders of deontological theory, on the other hand, point out the difficulties in assigning rights to future generations (e.g., Broome 1991). Even those who do not necessarily espouse utilitarianism agree that there are some deep logical difficulties in assigning standing to "potential" future persons whose circumstances not only are largely unknown to the present generation but also are endogenous to the set of choices made by the current generation (see, e.g., Baier 1984; Barry 1977; Gelding 1972; Passmore 1974; and Parfit 1983a).

One approach to this problem has been the development of organicist arguments that invoke an obligation to the entire context of future human life-the species as a whole, and the ecological systems that surround it—rather than just to potential future individuals (see, e.g., Leopold 1949; Lovelock 1988; Callicott 1989; Norton

[6] Some critics argue that the conventional approach to specifying preference orderings in economics is deficient on both empirical and moral grounds, since it does not distinguish "lower" or "higher" impulses, or "self-interest" and "community-motivatd" interests. The solution, it is argued, is some hierarchical representation of preferences. However, Brennan (1989) argues that this approach does not really solve any problems associated with conventional preference reasoning in economics; and in particular, that moral deficiencies associated with the outcomes of economic logic should be directly confronted as such, rather than attempting to reframe that logic.

1982, 1986, 1989; Page 1983, 1991; Nash 1989; Weiss 1989). This "stewardship" perspective emphasizes the safeguarding of the large-scale ecological processes that support all facets of human life, from biological survival to cultural existence. The stewardship perspective does not deny the relevance of human preferences, but it asserts the existence of larger societal concerns that members of society will feel (in varying degrees) beyond individualistic preferences.

The organicist position raises the interesting and as-yet unanswered question of whether there are important social values that simply cannot be captured in an individualistic resource valuation, no matter how broad and sophisticated the valuation methods are. The difficulty in addressing this issue is that the two perspectives are based on different fundamental axioms. The organicist position seems to avoid some of the difficulties in extending individualistic fairness concepts to intergenerational circumstances. On the other hand, a nonindividualistic perspective is a two-edged sword in that many of humankind's most cherished economic, political, and other social institutions derive fundamentally from giving high respect to individual rights. Organicism without constraints leads to supremacy of the group over the individual, a form of social order that history shows to be very dangerous and destructive. The two-tier system described subsequently in the paper seeks to provide a venue for considering the balance between individual trade-offs and social imperatives.

III. RESOURCE SUBSTITUTABILITY

Assuming one accepts some obligation to consider the well-being of future generations, what bundles of social capital should succeeding generations make available to their descendants? The answer to this question depends critically on one's assumptions regarding the degree of substitutability between the services provided by natural capital (material resources, waste absorption, other ecological functions, aesthetic and cultural values) and other forms of capital (plant, equipment; knowledge, skills, social institutions).

One view, to which many economists would be inclined, is that all resources are relatively fungible sources of well-being. This view appears to be influenced heavily by a number of classic and more recent applications of aggregate growth models with natural resources. A number of familiar theorems come out of this literature. In the standard growth model without natural resource constraints, the modified Golden Rule indicates that per-capita consumption and utility will grow over time provided the economy is not already saturated with capital. Clearly, sustainability presents no challenge in this world, even with positive discounting of future utilities. The same outcome obtains with natural resources provided these resources are in some sense "augmentable"—capable of being renewed or of having damages offset by compensatory investments (for a recent exposition of this see van Geldrop and Withagen 1993). Even with exhaustible resources or some other irreversible degradation of the services provided by the natural environment (such as accumulative pollution), it is possible for consumption and welfare to grow if there is sufficient substitutability between natural resources and capital accumulation, or technical progress sufficient to offset the depletion/degradation of natural resource services (Dasgupta and Heal 1974; Solow 1974, 1986; Stiglitz 1974; Baumol 1986; Dasgupta and Mäler 1991; see also the surveys in Asheim 1989, Pezzey 1992, and Toman, Pezzey, and Krautkraemer forthcoming).

From this point of view, then, large-scale damages to ecosystems such as degradation of environmental quality, loss of species diversity, or destabilization from global warming are not intrinsically unacceptable. The question is whether compensatory investments for future generations in other forms of capital are feasible and are undertaken. This is the essence of the argument advanced by Solow (1986) and Mäler (1991), based on previous work by Hartwick (1977), that investments of resource rents in other forms of capital provide the means to sustain consumption possibilities over time. Investments in human knowledge, techniques of production and social organization are especially pertinent in humankind's efforts to outrace any increases in the scarcity of services provided by the natural environment.[7]

An alternative view, embraced by many ecologists and some economists, is that such compensatory investments often are infeasible as well as ethically indefensible. Physical laws are seen as limiting the extent to which other resources can be substituted for scarce natural resources or ecological degradation. In particular, physical capital cannot be substituted for scarce energy without limit because there are minimum energy requirements for accomplishing any transformation of matter. In addition, because matter is conserved, waste is an inherent part of any economic activity; and natural limits may constrain the capacity of the environment to process these wastes.[8] Healthy ecosystems, including those that provide genetic diversity in relatively unmanaged environments, offer resilience against unexpected changes that preserve options for future generations.[9] For natural life-support systems no practical substitutes are possible, and degradation may be irreversible. In such cases (and perhaps in others as well), compensation cannot be meaningfully specified.[10]

The question of physical scale is central to this debate. If substitutability is relatively easy, then the total scale of human activity relative to the natural environment is of limited significance relative to efficient use of resources and, depending on one's ethical perspective, the adequacy of society's total savings for the future. The notion of "carrying capacity," so often invoked in sustainability debates, then would be at most ephemeral and at worst meaningless outside its traditional ecological usage. Critics of this view turn the entire argument around by claiming that physical limits cannot be ignored and then putting much more emphasis on scale issues (see, e.g., Goodland, Daly, and El Serafy 1991 and Costanza 1991).

A related issue that sometimes is overlooked is the distinction between local and global impacts when considering substitution possibilities. Local resource depletion and ecological degradation, while often having serious consequences, may be more easily compensated for by trade, economic diversification, and migration than regional

[7] As pointed out recently by Asheim (1994) and Pezzey (1994b), Hartwick's reinvestment rule has been widely misinterpreted as an instant test of the future sustainability of an arbitrary economy. Although an economy with constant utility over time must satisfy the HartWick Rule (as Hartwick proved), observing that investment currently happens to be greater than or equal to the resource rent measured at market prices does not imply that at least the current level of utility can be maintained by imposing Hartwick's Rule from now onwards. The intuition behind this result is that an economy which is depleting its natural resources too fast for sustainability will drive resource prices and hence resource rents too low, and investment at such a level does not ensure sustainability. The correct indicator of permanent sustainability would be resource rents as measured by shadow prices which reflect the sustainability constraint (which includes the constraint of the current resource stock). This poses a challenge for those interested in developing empirical indicators of sustainable development.

[8] Concern over these issues its the economics literature has been expressed by Ayres and Kneese (1969), Kneese, Ayres, and d'Arge (1971), Ayres and Miller (1980), Perrings (1986), Anderson (1987), Barbier and Markandya (1990), Gross and Veendorp (1990), Victor (1991), Daly (1992), Townsend (1992), and Common and Perrings (1992); see also the survey in Toman, Pezzey and Krautkraemer (forthcoming).

[9] A related argument at the macro level is that environmental quality may complement capital growth as a source of economic progress, particularly for poorer countries (Pearce, Barbier, and Markandya 1990).

[10] The importance of the substitutability issue can be illustrated in connection with the debate over allocating responsibility for greenhouse gas control. If one accepts the view that investments in adaptation to climate change have limited scope for effectiveness, then the atmosphere's capacity to absorb greenhouse gases also is a depletable resource with limited substitution potential. In this case cumulative past greenhouse gas emissions can be a simple metric for assessing a fair distribution of control obligation: greater cumulative emissions by industrialized countries imply greater responsibility. However, if one sees the investment in economic productive capacity and thus in global adap tive capacity by industrial nations as having provided significant benefits that do compensate for depletion of the atmosphere's capacity for greenhouse gas absorption, then the responsibility of industrialized countries is less clear-cut.

or global adversities. On the other hand, trade distortions (e.g., discrimination against manufactured exports by developing countries) may limit national capacities to develop sustainably, and individual countries may appear to develop sustainably by "exporting" unsustainable resource use to other nations that supply materials.

The discussion in this section and the previous one suggests that, at the risk of some caricature, three alternative polar conceptions of sustainability can be identified:

1. *Neoclassical presentism*. This position does not place much emphasis on sustainability as an issue distinct from efficient resource use. The standard present value criterion is adopted for intergenerational welfare comparisons, and natural capital scarcity is assumed to be remediable (given appropriate price signals and incentives) through substitution and technical advance.
2. *Neoclassical egalitarianism*. This view is the same as (1) with respect to assumptions about managing natural capital scarcity, but it also maintains a concern about a potential shortfall in total savings for the future that is not encompassed in the present value criterion.
3. *Ecological organicism*. In contrast to (1) and (2), this view emphasizes limits on substitution between natural capital and other assets. Like (2), this view includes a concern for intergenerational fairness, but that concern is not entirely individualistic; it also encompasses concerns for ecological systems and the human species as a whole.[11]

To be sure, views on sustainability that are composites of these positions also can be defined. The model discussed in the next section allows for a continuum of views about intergenerational fairness and resource substitutability.

IV. AN EXTENDED "SAFE MINIMUM STANDARD"

In this section a simple conceptual framework is outlined that can be used in considering how individualistic resource trade-offs might be balanced against social imperatives for safeguarding against large-scale, irreversible degradation of natural capital. The framework is not intended to imply a specific decision rule. Instead, its purpose is to indicate the implications of different sustainability conceptions and to provide some common ground for consideration of differences in conceptions among economists, ecologists, and ethicists. In broad outline, the framework is a two-tier system in which standard economic trade-offs (market and nonmarket) guide resource assessment and management when the potential consequences are small and reversible, but these trade-offs increasingly are complemented or even superseded by socially determined limits for ecological preservation as the potential consequences become larger and more irreversible. The framework is an extension of the logic of safe minimum standard promulgated by Ciriacy-Wantrup (1952) and Bishop (1978). Variants of this two-tier approach have been suggested by a number of writers from different disciplines (see, e.g., Norton 1982, 1992; Page 1983, 1991; and Randall 1986).

To begin the discussion, suppose for simplicity that all potential human impacts on the natural environment can be characterized by their prospective "cost" and "irreversibility." Prospective cost can be interpreted in several ways. It can be thought of as an (individualistic) economic measure of expected opportunity cost, as an ecological measure of predicted physical impact, or as some hybrid of individualistic or organicist concerns including social values like political freedom and justice. The

[11] It would be possible to identify a fourth position, ecological presentism, but this view could be internally contradictory and in any event it seems to hold little interest.

framework does not require a particular definition of cost, though some precision on what is counted as a cost is needed in practice when interpreting alternative conceptions of the safe minimum standard.

Similarly, irreversibility can be seen in terms of an ecological assessment of system function or as an economic construct involving the feasibility of restorative or compensating investment. Economic irreversibility here is taken to be the same as nonsubstitutability. Of course, considerable uncertainty exists regarding both the cost and irreversibility of particular human impacts. This uncertainty is in fact central to the concept of safe minimum standard.

One question that needs to be addressed is why two metrics are needed for gauging impacts and determining social responses. Economists are accustomed to valuing consequences of irreversibility in an uncertain setting (see, e.g., Krutilla 1967; Krutilla and Fisher 1985; and Fisher and Hanemann 1987), so this dimension to some extent is redundant. Indeed, the prospective cost measure could be thought of as including premiums reflecting risks that can be monetized. The concept of systemic scale in ecological research also may forge links between the severity and irreversibility of impacts (Norton and Ulanowicz 1992). This research suggests that damages to ecological systems that are larger in spatial scale or higher up in the hierarchy of natural processes—more complex, consisting of more component subsystems—is both more harmful and harder to reverse because of the complexity and slower time of adaptation in these systems.

Nevertheless, there are reasons for distinguishing the metrics. Monetizing all irreversibility suggests that compensatory investment for any environmental degradation is feasible and ethical.[12] This seems debatable, as already noted. Analytically, it rules out by assumption the ecological organicist position on sustainability defined above. To avoid this, we must retain both the cost and irreversibility dimensions.

The cost and irreversibility dimensions can be brought together in a single "sample universe" as shown in Figure 1.[13] Individuals can, in this theory, locate different impacts on the natural environment (e.g., a 5-degree global mean temperature rise or a 50 percent loss of tropical forest) in the square, depending on their own assessments of cost and irreversibility. Because of uncertainties, these assessments will reflect subjective judgments including attitudes toward known or potential risks (in other words, the cost and irreversibility assessments generally will not reflect just subjective mean or median values). Individual judgments inherently will reflect not just factual information but also personal values about the nature of the obligation to future generations. A variety of social institutions, notably the political process, education, and mass communication, presumably generate some synthesis of individual impact assessments at the societal level. The synthesis is dynamic in that it reflects a variety of forms of social learning (e.g., improvements in production technique and social organization).

We can now combine this construct with an extension of the safe minimum standard logic to indicate how individualistic tradeoffs and social imperatives regarding the natural environment might be balanced. The safe minimum standard originally was developed in the context of individual species preservation (see Bishop 1978 and Ciriacy-Wantrup 1952). The logic in this setting is that standard benefit-cost comparisons may be inadequate if the long-term cost of species loss is highly uncertain (in the Knightian sense of having probabilities that are difficult to gauge) but possibly quite substantial. Proponents of a safe minimum standard argue that with low information but high potential asymmetry in the loss function, the evenhanded assessment of benefit-cost analysis should give way to a greater presumption in favor of species

[12] This discussion leaves aside important practical problems of measurement that arise in any approach to irreversibility.

[13] This diagrammatic approach was originally developed by Bryan Norton (see Norton 1992). The figure shown here is an adaptation of Norton's schema.

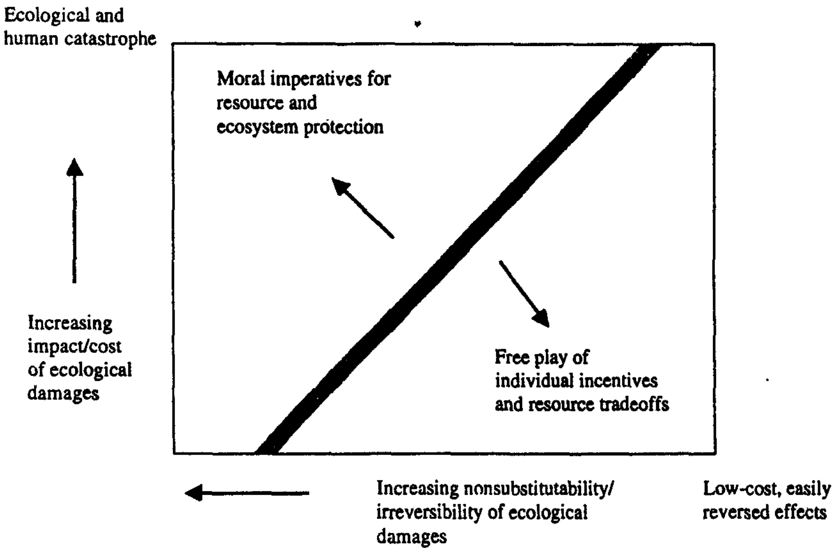

FIGURE 1

ILLUSTRATION OF THE SAFE MINIMUM STANDARD FOR BALANCING NATURAL RESOURCE TRADE-OFFS AND IMPERATIVES FOR PRESERVATION

preservation unless society judges that the cost of preservation is "intolerable."[14]

In Figure 1 we extend this logic to a continuum of potential impacts on the natural environment in the following way. First, impacts in the lower-right portion of the box involve both modest cost and a high degree of reversibility. In this area there is little threat of substantial lasting damage to the interests of future generations, and it is reasonable to rely upon individualistic valuations and trade-offs as reflected in benefit-cost analysis. Individual incentives for efficient resource use can be achieved through markets and incentive-based policies to correct "conventional" externalities.

Toward the upper-right comer of the box the costs become higher but still are relatively reversible. Here the primary concern in addition to efficient resource use might be to ensure that the current generation meets obligations to the future through general compensation for environmental degradation. On the other hand, impacts located toward the lower-left corner of the box are relatively irreversible but low in cost, so they presumably can be absorbed without too much detrimental effect on the future.

It is in considering impacts toward the upper-left comer of Figure 1 that the safe minimum standard assumes prominence. Here the long-term costs are likely to be high and substitution options likely to be low, making the impacts irreversible. Moreover, uncertainty is likely to be substantial since the impacts in question involve large-scale ecological systems and functions that remain poorly understood.

Under these conditions even individualistic, presentist valuations can provide a considerable impetus toward resource preservation. However, the logic of the safe minimum standard suggests that this impetus alone may not fully satisfy reasonable obligations to future generations, particularly when the negative effects involve

[14] See Bishop (1979) and Smith and Krutilla (1979) as well as Castle and Berrens (1993) for further discussion of the distinction between the safe minimum standard and benefit-cost analysis. This reasoning is another way of highlighting the need for considering cost and irreversibility as distinct metrics of impact.

large-scale ecological systems and long gestation periods. One can imagine that the closer one moves to the northwest comer of the box, the more entirely individualistic valuation ciriteria are supplemented by other expressions of community interest in the form of a priori social rules of a "constitutional" nature for preserving natural capital. This is illustrated by the fuzzy demarcation line in Figure 1. Such socially determined criteria could be changed if the members of society deem the cost of preserving natural capital to be excessive, but a higher burden of proof would be placed on arguments favoring acceptance of high-cost, irreversible impacts than on acceptance of smaller impacts.

As already noted, individual perceptions of natural impacts and thus individual assessments of where the fuzzy line should be located depend strongly on individual values and knowledge. Figure 1 can be used to illustrate the different positions on sustainability summarized in the previous section of the paper. Generally speaking, ecologists with a primary concern for natural function and resilience might be more inclined than economists to emphasize the irreversibility dimension and to draw a more vertical fuzzy line, limiting even lower-cost irreversible effects; economists with greater concern for cost and more confidence in substitutability might be more inclined toward a horizontal line. Neoclassical presentists might put little or no area to the northwest of the dividing line (or even dismiss the whole construct), while ecological organicists would take a contrary view. Neoclassical egalitarians might take a middle ground, drawing a close to horizontal line but placing more area above it to limit high-cost burdens on future generations.

It should be emphasized again that there is a distinct difference between the safe minimum standard approach and the standard prescriptions of resource and environmental economics, which involve getting accurate valuations of resources in benefit-cost assessments and using economic incentives to achieve efficient allocations of resources given these valuations. Whether a resource-protection criterion is established through application of the safe minimum standard concept or entirely by trade-offs through cost-benefit analyses, that criterion can be achieved cost-effectively by using economic incentives. However, for impacts on the natural environment that are uncertain but may be large and irreversible, the safe minimum standard posits an alternative to relying just on comparisons of expected economic benefits and costs for developing resource-protection criteria.[15] It places greater emphasis on scale issues involving potential damages to the natural system than on the sacrifices experienced from curbing ecological impacts, which are seen as likely to be smaller and more readily reversible. On the other hand, the arguments in this section do not require that either the safe minimum standard as a social decision rule, or individual preferences for environmental preservation, be rigidly hierarchical. The safe minimum standard can be seen as a social compact for expressing agreed-upon moral sentiments in the face of high ecological uncertainty and potential loss asymmetry, even with egoistic consumption, bequest, and time preferences that are entirely neoclassical.[16]

The arguments in this section are somewhat similar to those developed by Vatn and Bromley (1994) regarding environmental decision making and economic valuation. Briefly, these authors argue that large-scale environmental assets or risks are inherently difficult to value meaningfully in a conventional economic sense. This is not just because of limited information about these assets and risks, which causes individual preferences to be poorly defined, but also because large-scale environmental con-

[15] See also Pezzey (1989, 1994a), who shows with a simple example that efficient management of externalities over time may not generate sustainable welfare distributions.

[16] Tim Brennan suggests (in private communication) that the safe minimum standard also can be seen as a social decision strategy that economizes on costly information-gathering and enforcement activities relative to theoretically preferred marginal evaluations and policies.

siderations are bound up in social mores that condition individual preferences. Vatn and Bromley argue that people must be seen as dualistic, behaving as citizens as well as consumers, and that many social institutions for environmental management—including the norms surrounding government of the environment—must be seen as ways that societies have attempted to circumvent the informational and "contextual" problems surrounding individualistic valuation. This point of view justifies in particular the imposition of safe minimum standards determined through political discourse and other complex social processes.

V. CONCLUDING REMARKS

Sustainability ultimately is intimately wrapped up with human values and institutions, not just ecological functions. An entirely ecological definition of sustainability is inadequate; guidance for social decision making also is required. It must be recognized that human behavior and social decision processes are complex, just as ecological processes are. At the same time, economic analysis without adequate ecological underpinnings also can be misleading. The sustainability debate also should remind economists to carefully distinguish between efficient allocations of resources—the standard focus of economic theory-and socially optimal allocations that may reflect other intergenerational (as well as intragenerational) equity concerns:

The tension between ecological and economic perspectives on sustainability suggests several ways in which both economists and ecologists could adapt their research emphases and methodologies to make the best use of interdisciplinary contributions. For ecologists, the challenges include providing information on ecological conditions in a form that could be used in economic assessment.[17] Ecologists also must recognize the importance of human behavior, particularly behavior in response to economic incentives-a factor often given short shrift in ecological impact analyses. Economists for their part could expand analyses of resource values to consider the function and value of ecological systems as a whole, making greater use of ecological information in the process. Both methodological research and case studies are needed to synthesize ecological and economic perspectives. Research by economists and other social scientists (psychologists and anthropologists) also could help to improve understanding of how future generations might value different attributes of natural environments.

From the standpoint of economic theory, an important direction for further research is the consideration of how both physical limits and ethical' constraints on resource use may affect the time paths and shadow values of natural capital stocks, relative to the results found in standard theory. The literature on economic growth with natural resources is beginning to address these issues, and there is a lot of basic methodology that can be exploited for this purpose.[18]

One example is the work by Asheim (1988, 1991) and Pezzey (1989, 1994a, 1994b) alluded to earlier. Asheim shows that if we accept the idea of two-tiered social preferences, in which individuals have limited altruism for the next generation but also subscribe to a broader conception of intergenerational social justice, socially preferred outcomes can promote justice without sacrificing growth. In particular, this argument provides a more basic justification for the criterion of nondecreasing utility assumed in Pezzey's sustainability analysis.[19]

Another set of examples concerns the issue of resource substitution. A number of

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[17] Carpenter (1992) argues that the current state of biophysical measurement for assessing the sustainability of human impacts on ecological systems is too weak to effectively operationalize the concept of natural capital; only gross unsustainability can be detected.

[18] For further discussion see Toman, Pezzey, and Krautkraemer (forthcoming).

[19] Because of the obvious importance of uncertainty in dealing with long-term environmental change, for a complete analysis it is necessary to explicitly reflect this uncertainty in social welfare orderings. This issue is tackled in Asheim and Brekke (1993).

papers have explored the consequences for present-value-maximizing paths of including stocks in utility functions as a reflection of some sort of' "amenity" value (see, e.g., Krautkraemer 1985, 1988 and Tahvonen and Kuuluvainen 1993). In these analyses, preservation of some positive level of environmental attribute is not assured; achieving preservation in the steady state requires some combination of large initial capital accumulation and unbounded disutility from environmental degradation. Barbier and Markandya (1990), in particular, consider the consequences of requiring a threshold level of environmental preservation to stave off irreversible environmental disaster. Common and Perrings (1992) go further in discussing the basic differences between economic and ecological sustainability, and the difficulties in bringing these ideas together in a single model.

Despite its continued abuse as a buzzword in policy debates, the concept of sustainability is becoming better established as a consequence of studies in economics, ecology, philosophy, and other disciplines. With a better understanding of the interdisciplinary theoretical issues, and a better empirical understanding of both ecological conditions and social values, sustainability also can evolve to the point of offering more concrete guidance for social policy.

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Sustainability and Constant Consumption Paths in Open Economies with Exhaustible Resources

Abstract

We review some of the historical background to the capital theory approach to sustainability. We then turn to sustainability in a group of countries trading flows from an exhaustible resource. We derive an adjusted invest-resource-rents rule which leaves each country, in a group of trading countries, on a constant consumption path. Oil importers invest a fraction (greater than unity) of the rents ascribable to the current use of their own oil stocks and oil exporters invest a fraction (less than unity) of the rents ascribable to their current use of their own oil stocks. Each country's value of imports equals its value of exports. In a partial equilibrium model of a small open oil exporting country, we observe that the exact invest-resource-rents does leave the country's consumption constant over time.

(for AERE Conference, Boulder, Colorado, June 5, 1994)

* This paper was written while I was a visitor at the Center for Economic Studies, University of Munich. Thanks to them for hospitality and support and to Ray Rees for helpful discussions. The SSHRCC, Government of Canada, also provided support. Geir Asheim and Cees Withagen provided invaluable comments on an earlier draft. An earlier version was presented in seminars at the Universities of Munich and Tilburg.

Sustainability and Constant Consumption Paths in Open Economies with Exhaustible Resources

Introduction

Since there are at least three good surveys of theoretical aspects of sustainability (namely, Solow [1991], Hammond [1994], Pezzey and Toman [1994]) available, I will not attempt a cannibalized fourth. Instead I will make some brief general remarks about the background of theory of sustainability and then turn to an area of current research, namely open economy aspects of sustainability. With this approach I can still present the references to the literature which I know about, an invaluable part of a good survey, and also introduce a reader to the core of the theory because I need this material as the stalk to graft on my open economy analysis.

There are at least three distinct ideas tied up in the economic theory of sustainability which I am dealing with today. There is first the idea that if exhaustible resource stocks are depleted today in the course of producing final goods, one need not immediately contemplate a permanent shrinkage in future production possibilities because producible or machine capital can be "over-accumulated" in order to "compensate" for the current reduction in the stock of natural capital. This idea is mentioned in Pigou [1935] and in Hayek [1941; p.88]. An important variant of this idea is of "over-accumulating" knowledge capital in order to "balance-off" the current diminution of the stock of natural capital (Robson [1980]). More generally, technical progress may allow smaller and smaller flows from exhaustible resources to maintain say a non-shrinking set of production possibilities (as in for example Stiglitz [1974]). The second idea that comes to mind is that sustainability suggests non-shrinking production possibilities as time passes. A simple indicator of non-shrinking production possibilities is of course the observed aggregate consumption level not declining over time.[1] For the case of multiple consumption goods one turns to THE utility of the current consumption vector not declining over time. Rawls maximin criterion, a moral injunction, is a polar case in this line of thought. and in part inspired the classic Solow [1974] paper on sustainability. The injunction is of course: do for others who will . occupy period t+1 what we would have preferred back in t-1, what others who occupied period t-1 would do for us, the occupants of period t. The third idea involves linking the first two ideas together. The simplest variant is of course: consume at a level which results in no shrinking of one's "capital". For an individual, this is not too difficult to contemplate since everything can be measured in dollars but at the level of the nation satisfactory measures of what "capital" is being maintained intact are generally elusive. Hicks [1942] and Pigou [1941] debated aspects of the meaning of "maintaining capital intact". This was a final exchange in the long-running debate on the links between capital and national accounting, a debate in which Pigou and Hayek sparred "and Hicks assisted in clarifying matters. A primary legacy was Hicks' [1939; Chapt. 13] notion that INCOME be defined as POTENTIAL CONSUMPTION which if "withdrawn" from current production leaves capital intact.[2] In Solow [1974], the problem of measuring "capital intact" was reduced to, given oil stocks being run down in accord with the Hotelling efficiency condition, and given the level of consumption unchanging, how much K is currently needed to "support" this program, at least for another period. This is in fact one kind of <u>investment</u> balancing off

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[1] Asheim [1988] [1991] has axiomitized the concept of non-declining U(C) in an economy with exhaustible resources. There is no simple way to rank two distinct efficient candidate paths. See also Pezzey [1993].

[2] This leads to the idea that Net National Product be defined as some sort of "interest" on "national wealth" (Samuelson [1961], Weitzman [1976], Kemp and Long [1982], Lozada [1992], Asheim [1994] and Hartwick [1994]).

disinvestment in another stock. Dixit, Hammond, Hoel [1980] have labelled such paths as those with "zero net investment". Such paths are not in general those in which aggregate capital value (national wealth) are remaining constant because zero net investment is essentially changes in quantities of stocks at prevailing prices and changes in national wealth comprise both quantity changes and price changes - a chain rule calculation. The constant consumption model of Solow [1974] is of course a zero net investment model but it is not a constant wealth model. It is an increasing national wealth model. More on this below.[3]

When the stock of natural capital is regenerating itself as with say fish stocks, forest stocks, and environmental capital stocks, the notion of preserving capital intact is straightforward in the steady state. In fact, the term sustainable yield has been around in the economics of the fishery and forestry much longer than it has been in the discussion of how any economy is performing (as in, for example, the Brundtland Report). There remains however the question of what course of action to take along the approach to the steady state (the transient trajectory) with renewable resources in the economy. If one is wedded to a constant consumption path over ail time, then the investing of resource rents is the appropriate strategy off the steady state trajectory (Hartwick [1978], Becker [1982] Hamilton [1994]). This result contains the not-new suggestion that the exhaustible resource use problem is a special case of the renewable resource use problem in the sense that in the former, the economy has only a transient path to occupy. We now turn to some detailed analysis on constant consumption paths in open economies.

[3] I am indebted to Geir Asheim for clarifying this in conversation.

Open Economy Considerations

Consider splitting a closed economy with exhaustible resources, enjoying constant consumption over time, into two countries, one importing some oil (the exhaustible resource) from the other. We observe below that if each country saves exactly the resource rents ascribable to load resource stock flows, the importer's consumption level will be declining and the exporter's will be increasing (Asheim [1986]). We can describe this as the importer under-saving and the exporter over-saving relative to levels for constant consumption paths. Below, we characterize adjustment weights on each country's own resource rents which "neutralizes" the importer's under-saving and the exporter's over-saving. With "corrected" local savings levels, each country "ends up" on a constant consumption path, an intergenerational equity path (Solow [1974]).

The under and over saving takes the form of price changes on oil trade flows - opposite in sign but equal for each country. The adjustment weights on local own resource rents appear in offsets to these "capital gains" terms and one characterization is as an r percent rule on certain oil flows, not values. r is the rate of return, equal to the marginal product of capital in our model. We will work with an almost symmetric split of the one world into two countries. This makes the exposition straightforward and allows us to detour around special cases with corner solutions. The reader can easily develop the analysis for not nearly symmetric splits of the one world and for more than two countries. We comment on this in detail.

Under exact investment of resource rents, each country's change in consumption turns out to equal the exhaustible resource flow traded multiplied by its current price change. Thus the consumption shifts in each country can be interpreted as an adverse terms of trade shift for oil importers and a favorable terms of trade shift for oil exporters. This becomes clear when we set out a model of an oil exporting nation facing constant world prices and interest rates, at the end. No terms of trade effects or consumption “wedges” are observed under the exact invest resource rents strategy. Thus “over-saving” and “under-saving” under exact savings of own oil use rents in the two country model are a consequence of endogenous terms of trade shifts, induced, of course, via oil price changes. The oil price changes are a consequence of asset equilibrium in the market for oil stocks (Hotelling's Rule). Our partial equilibrium model at the end has constant world oil prices; the r percent changes in resource rents operate via endogenous extraction cost shifts.

The Model

We look first at the structure of a closed one world economy. It has $S(t)$ tons of say oil left at date t. $- S(t) = R(t)$ will be used in production of $Q(t)$ equal to $F(K(t), R(t))$ at date t. $K(t)$ is non-depreciating machine capital. $F(*)$ is homogeneous of degree 1 in inputs and $K(t)$ and $R(t)$ are smoothly substitutable. $F(*)$ is concave in its arguments. (Existence of constant consumption paths over infinite time requires $F(*)$ to be Cobb-Douglas (see Solow [1974], Dasgupta and Mitra [1983] and Hamilton [1993]).) Population N, constant, only consumes.[4] We postulate the savings-investment rule (invest resource rents):

$$\dot{K}(t) = \lambda(t)R(t)F_R(t) \tag{1}$$

where $\lambda(t)$ moves exogenously through time, say near unity. $F_R(t)$ is the derivative $\partial F(\ )/\partial R$. We

[4] This is not an issue with a Cobb-Douglas production function but otherwise, putting N, a constant in the production function can introduce complicated scale effects as the economy's level of aggregate output, $Q(t)$, changes over time.

also take dynamic efficiency in exhaustible resource use as given, that is (Hotelling r% Rule):

$$\frac{\dot{F}_R(t)}{F_R(t)} = F_K(t). \tag{2}$$

Current consumption C(t) is given by C(t) = F(*) - K. If one differentiates this expression with respect to time, and does the same for (1), and one uses (1) and (2), one obtains (see the Appendix):

$$\dot{C}(t) = \frac{\bullet}{(1-\lambda(t))R(t)} F_R(t). \tag{3}$$

The central case of investing exactly exhaustible resource rents (namely λ = 1) yields C = 0 Hartwick [1977]. See also **extensions**[5] in Dixit, Hammond, Hoel [1980] and cairns [1986].).

Consider the value of aggregate capital or national wealth W(t) in this economy at date t. We define W(t) = K(t) + $S(t)F_R(t)$. Observe that W(t) = $\dot{K}(t) + S(t)\dot{F}_R(t) + F_R(t)\dot{S}(t)$ **and** W(t) is the change in wealth (aggregate capital value) in the economy at date t. The following result can be derived. If the economy is efficient, has net investment zero, and has constant returns to scale in F(K,R) then

$$C + \dot{W}(t) = W(t)F_K(t)$$

or C + W(t) is the interest flow from current wealth W(t). The demonstration requires simple substitution, i.e. C = $F(\cdot)-\dot{K}$, $F(\cdot) = KF_K + RF_R$, $\dot{K} = RF_R$, **etc.** This result is quite Hicksian since the income flow on the left is interest on capital on the right. The "logic" of Hicks' position suggests that the left hand side is net national product in this economy. Asheim [1994] 1994a seems to espouse this view. W(t) includes capital gains $S(t)\dot{F}_R(t)$ on oil stocks and these terms

[5]These include extending consumption C to a vector in U(C). Then U(C) remains constant and extending our two capital goods K and S to many capital goods. The C=0 result was proved as an if and only if theorem. Our investing resource rents can be interpreted as aggregate or combined investment being zero. Another extension was to treat this combined investment as positive and constant.

have not been included in NNP in the modem stream of thought in national accounting, although some observers recommend land revaluations be placed in NNP (see Hartwick [1992] and references there). It turns out that these identical capital gains are in the WF_K term on the right. This suggests taht there is a more basic relation lying within ours above (it is $C - KF_K$) and that the claims for C + W(t), with its capital gains on current oil stocks, as the ‘formula” for NNP suspect. We end this discussion with the observation that W(t) above is not constant for the Solow [1974] constant consumption, zero net investment model. Thus maintaining capital value constant (capital “intact”?) is a separate matter from maintaining consumption constant over time or maintaining aggregate investment zero over time.

We now split the one world economy (λ = 1) into two price-taking, trading countries We set $K_1(t) = K_2(t)$, given $K_1(t) + K_2(t) = K(t)$ above. We set $N_1 = N_2$ with $N_1, + N_2 = N$, above. We make country 1 (C1) less endowed with oil stocks, that is $S_1(t) < S_2(t)$ with $S_1 + S_2 = S(t)$, above. We assume $S_1(t) \cong S_2(t)$ so that country 1 will import $\in(t)$ a small amount of R(t) at each date. Since $K_1 = K_2$, efficiency requires that $R_1(t) + \in(t) = R_2(t)$ where $R_i(t)$ is use of exhaustible resource from stock $S_i(t)$. World prices are given from the one large country scenario earlier.

(a) The oil importer (C1)

We have the output balance

$$C_1(t) = F(K_1(t), R_1(t) + \in(t)) - \dot{K}_1(t) - \in F_{R_1}(t) \qquad (4)$$

where $\in F_R(t)$ is payment for oil imports, $\in(t)$, and $K_1(t)$ is own investment in $K_1(t)$. In keeping with each country “covering off" the economic depreciation of its own oil stock $S_i(t)$, we have

$$K_1(t) = \lambda_1(t)\ R_1(t)\ F_R(t) \tag{5}$$

where $\lambda_1(t)$ is a fraction, endogenous and presumably near unity for $\in(t)$, small. Our task is to characterize $\lambda_1(t)$ since (5) represents the "adjusted" invest resource rents rule. We also have $\dot{F}_{R_1}/F_{R_1} = F_{K_1}$. These derivatives will be the spree as those in (2). If one differentiates (4) and (5) with respect to time and combines them, and uses (5) and (2), one obtains (see the procedure in the Appendix):

$$\dot{C}_1(t) = \frac{\bullet}{(1-\lambda_1(t))R_1(t)}\ F_R(t) - \in(t)\dot{F}_R(t). \tag{6}$$

It follows that $\dot{C}_1(t) = 0$ if

$$\frac{\dot{\Delta}_1(R_1)}{\in(t)} = F_K(t), \tag{7}$$

where $\dot{\Delta}_1(R_1) \equiv (1\ \overset{\bullet}{\overline{-\lambda_1)R_1(t)}}$. (Recall that $F_R/F_R = F_K$.) This condition for $C_1 = 0$ is an r percent rule in quantities, since $F_K(t)$ is the "rate of interest" here and $\in(t)$ and $(1-\lambda_1(t))$ $R_1(t)$ are quantities of oil. This r percent rule defines the time path of $\lambda_1(t)$ and when combined with (4) becomes the adjusted invest resource rents rule.[6] Observe that if $\lambda_1(t) = 1$, then we would have the unadjusted invest resource rents rule and (6) would become

$$\dot{C}_1 = -\in(t)\dot{F}_R(t).$$

This is a rendering of the result in Asheim [1986], namely, if country i invests its resource rents, its $C_i(t)$ will not be constant. In this case, importers C1's $C_1(t)$ is declining because it is "under-saving" in revering its own economic depreciation in its stock $S_1(t)$ and in paying for imports, $\in(t)$. Thus $\lambda_1(0)$ must be greater than 1 and decrease toward 1 as time passes.

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[6] Asheim [1986] and Asheim [1994a] contain expressions for country i's savings to cause C_i to remain constant. Their appearance and derivation are quite different from our adjusted resource rents expressions yielding $C_i = 0$.

Observe that $\in(t)F_R(t)$ is a quantity traded $\in(t)$ multiplied by a price change $F_R(t)$ and is thus a terms-of-trade effect. $\in(t)F_R(t)$ equals $\in(t)F_R(t)F_K(t)$. Hence the current decline of $C_1(t)$ from $C_1(0)$, given $\lambda_1(t)$ set at 1 is $\int_0^t \in(t)F_R(s)F_K(s)ds$ where $C_1(0)$ is a constant of integration. Since $\in(t) = -\dot{S}_\in(t)$ where $\dot{S}_\in(t)$ is the decline in C2's stock resulting from exporting $\in(t)$, we have[7]

$$C_1(0) - C_1(t) = -\int_0^t \dot{S}_\in(s)F_R(s)F_K(s)ds.$$

Wealth in C1 at date t is $W_1(t) = K_1(t) + S_1(t)F_R(t)$ and $W(t) = K_1(t) + S_1(t)F_R + S_1(t)F_R$. Given $C_1 = F(K_1,R_1) - K_1 - \in F_R, K_1, = \lambda_1 R_1 F_R$, constant returns to scale in $F(\cdot)$, and efficiency, one gets $C_1 + W_1(t) = W_1(t)F_K(t)$ or $C_1 + W(t)$ is interest on own wealth. This balance relation simplifes to $C_1 = K_1F_K + (1-\lambda_1(t))R_1F_R$. This contrasts with the closed economy analogue in which C equalled KF_K alone. Thus $(\lambda_1(t) - 1)R_1F_R$ is income "withdrawn" from K_1F_K to pay for the oil imports in C_1. The constant C_1 is less than interest on local K. The capital gains on oil stocks $S_1(t)F_R(t)$ in W_1 again cancel with such gains in $W_1(t)F_K$ and this suggests that $C_1 + W_1(t)$ is not a satisfactory "formula" for NNP in this economy. More on defining NNP below.

(b) The oil exporter (C2)

C2'S situation is the mirror image of that of the oil importer. Now C2's savings to replace her current oil use are $\lambda_2(t)R_2F_R(t)$, where $R_2(t)$ is current oil extracted in C2. $R_2(t)$ -

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[7] The term $-\int_0^t \dot{S}(s)F_R(s)ds$ figured prominently in Hartwick [1994]. It was a key measure of wealth. The analogous expression for machine capital was also prominent. See also Solow [1986]. Here we are dealing with a gap between two flows, $C_1(0)$ and Cl(t), not stocks. Hence the appearance of $F_K(s)$ under the integral.

$\in(t)$ is used in production in C2. Hence C2's replacement rule is

$$\dot{K}_2(t) = \lambda_2(t)R_2(t)F_R(t). \tag{8}$$

C2's value balance relation is

$$C_2(t) = F(K_2(t),R_2(t) - \in(t)) - \lambda_2(t)R_2(t)F_R(t) + \in(t)F_R(t). \tag{9}$$

We now differential (8) and (9) with respect to time, combine them, use (8) and (2) and obtain (see the procedure in the Appendix):

$$\dot{C}_2(t) = \frac{\bullet}{(1-\lambda_2(t))R_2(t)} F_R(t) + \in(t)\dot{F}_R(t). \tag{10}$$

This is the same as (6) with a sign change. (10) yields our principal savings rule result, now for C2, namely $C_2(t) = 0$ if

$$\frac{\dot{\Delta}_2(R_2)}{\in(t)} = F_K(t) \tag{11}$$

where $\dot{\Delta}_2(R_2) \equiv -\frac{\bullet}{(1-\lambda_2(t))R_2(t)}$. (11) characterizes the time path of $\lambda_2(t)$ in the investment rule in (8). The rule is the same as that for C1 in (7) except in our case $\lambda_2(t)$ will be less than unity, and will increase toward unity as time passes. ($\lambda_1(t)$ was above unity and declined toward unity as time passed.)

For $\lambda_2(t)$ set equal to 1.0, $C_2(t) > 0$ by current capital gains $\in(t)F_R(t)$. C2 is in fact over-saving relative to a constant consumption scenario, and for this case

$$\begin{aligned} C_2(t) - C_2(0) &= \int_0^t \in(s)\dot{F}_R(s)ds \\ &= -\int_0^t \dot{S}_{\in}(s)F_R(s)F_K(s)ds. \end{aligned}$$

Our crucial adjustment terms $\lambda_1(t)$ and $\lambda_2(t)$ are, in view of (7) and (11), not independent.

(7) and (11) imply

$$\dot{\Delta}_2(R_2) - \dot{\Delta}_1(R_1) = 0. \tag{12}$$

(12) indicates, roughly speaking, that for the case $\lambda_1 = \lambda_2 = 1$, C1's under-saving matches C2's over-saving. $\lambda_1(t)$ and $\lambda_2(t)$ ($\neq 1$) in (12) reflect this balancedness of the adjustments for over- and under-saving between our two countries. In fact $\lambda_1(t) - 1 = 1 - \lambda_2(t)$ because $k_1(t) + K_2(t) = K(t)$ where $k(t)$ is investment in the closed economy case and $R_1(t) + R_2(t) = R(t)$.

Again for C2's wealth defined in $W_2(t) = K_2(t) + S_2(t)F_R(t)$ we can obtain $C_2 + W_2(t) = W_2(t)F_R(t)$, i.e. the left hand side is interest on local wealth. Again capital gains on oil stocks cancel on both sides to leave $C_2(t) = K_2(t)F_K(t) + (1-\lambda_2(t))R_2(t)F_R(t)$. The oil exporter enjoys a constant level of consumption above the income from interest on $K_2(t)$ because it receives extra income from exporting oil. (Note that $(1-\lambda_2(t))$ is positive.)

Corner Solutions and More than Two Countries

We have characterized the savings-investment rule which yields constant consumption paths for our two-country, trading world with an essential exhaustible resource. It is an adjusted invest-resource-rents rule. Our framework was two almost identical countries. This made trade flows small so that neither country was specialized and the two country assumption allowed us to sign the oil flows from exporter to importer. Clearly no part of our calculations depended on our assumption of $K_1 = K_2$ and $S_1 \cong S_2$ with $S_1 < S_2$. Suppose, however, that C2 owned all the oil. In this case R_1F_R is zero and weigting this by λ_1 does not yield more saving. (An approach for this case is for C2 to have $\lambda_2(t) = 1$ and to transfer $\in(t)F_R(t)$ to C1 in order to have $C_1 = C_2 = 0$. This was proposed by Asheim [1986].) However, as long as own oil use

$R_1(t)$ is infinitesimally positive, $\lambda_1 R_1 F_R$ (= K_1) can be defied and our two-country results go through. (We require $C_1(t)$ and $\lambda_1(t)$ to remain positive.) Thus as long as each country holds' some positive stock $S_i(t)$ at t, our adjusted saving-investment rule is relevant. (We require that each country owns sufficient capital K to have income to pay for imports of oil in order to rule. out comer solutions.)

With say three countries, the pattern of oil flows in trade becomes more complicated. Suppose C1 is an oil importer and C2 and C3 are potential exporters, being equally 'over" endowed with oil stocks. Suppose $K_1(0) = K_2(0) = K_3(0)$. In this case C1 should import equal amounts from both C2 and C3. It is not complicated to use our above reasoning to obtain appropriate $\lambda_1(t)$, $\lambda_2(t)$ and $\lambda_3(t)$ for this case. Our $\lambda(t)$ adjustment factors "work" for the many-country case. Note, also, that standard national accounting procedures "work" for each country in the trading system. In particular the value of exports equals the value of imports for each country. Also domestic NNP in each nation equals consumption $C_i(t)$ plus domestically financed investment. That is, $C_i(t) + \lambda_i(t)R_i(t)F_R(t) + X_i(t) - M_i(t)$ is $NNP_i(t)$ for country i, where $\lambda_i(t)R_i(t)F_R(t)$ is investment in i generated from current domestic production, $X_i(t)$ is current exports and $M_i(t)$ is current imports. All components are denominated in the numeraire commodity price, namely final goods output $X_i(t) - M_i(t)$ equals zero in our framework. In the two country "example", $M_1(t)$ were oil imports and $F_1(\cdot) - C_1(t) - \lambda_1(t)R_1(t)F_R(t)$ were exports of the final good. This yields $NNP_1(t)$ in value-added in C1 as $F_1(\cdot) - M_1(t)$. Note that $F_1(K_1, R_1 + \in)$ here is gross of oil import flow $\in$. Hence $F_1(\cdot) - \in F_R(t)$ is C1's valued-added derived from domestic factors of production. Hence $F_1(\cdot) - M_1(t)$ is domestic valued-added and equals C1's NNP(t).

In C2, $NNP_2(t) = C_2(t) + \lambda_2(t)R_2(t)F_R(t) + X_2(t) - M_2(t)$. Given $C_2(t)$ in (9), it follows that $NNP_2(t) = F_2(K_2,R_2 - \in) + X_2 - M_2$ is value-added and $X_2-M_2 = 0$. In each country, the value" of exports equals the value of imports in "free trade". World NNP equals $NNP_1(t) + NNP_2(t)$ which in turn equals world value-added $F(K,R) \equiv F(K_1+K_2,\ R_1+R_2) = F_1(K_1,R_1+\in) + F_2(K_2,R_2 - \in)$.

An Oil Exporter Facing Constant Prices and Interest Rates

Our analysis above involved two country trade with endogenous prices, including the marginal product of capital, the interest rate. These prices were changing over time. Consider the case of a price-taking "oil republic" (OR) a country living off exports of oil. This is an autonomous problem. World oil prices will be constant at p per ton and the OR will have unchanging extraction costs. e(R) for R tons currently extracted from its stock, S(t). We assume $e(0) = 0$ and $e_R \equiv de/dR > 0$ and $e_{RR} \equiv d^2e/dR^2 > 0$. There is a constant population (say just consuming so that e(R) has no labor costs in it) and extraction is pursued to maximize discounted net profit. Hence

$$\frac{\dot{\overline{p-e_R(R)}}}{p-e_R(R)} = r \tag{13}$$

is satisfied (the Hotelling r% efficiency rule). r is the constant discount (interest) rate. We assume that the elders in this OR invest $R(t)\cdot[p-e_R(t)]$ abroad each period and live off current interest income rH(t) plus current producer surplus $L(t) = pR(t) - e(R(t)) - R(t)\cdot[p-e_R(t)]$. That is consumption

$$C(t) = rH(t) + L(t). \tag{14}$$

Since interest rH(t) is being drawn off wealth abroad period by period, we have

$H(t) = \int_0^t [p-e_R(s)]R(s)ds + H(0)$. Thus[8] $\dot{H}(t) = [p-e_R(t)]R(t)$. If one differentiates (14) with respect to time and uses (13) and $H = [p-e_R]R$, one obtains $\dot{C}(t) = 0$. Hence investing oil rents abroad and living off the current interest on such, plus current producer surplus, yields a constant consumption path.[9] When S(t) declines to zero at say T, there will be H(T) dollars invested abroad and C(T) will equal rH(T) which will be the same value as was being enjoyed up to T. Clearly this policy of efficiently extracting oil and accumulating rent, net of interest, abroad is a savings-consumption strategy identical with selling off S_0 at market price $V(S_0) = \int_0^T [pR^*(t) - e(R^*(t))]e^{-rt}dt$ at $t=0$ and setting $C(t) = rV(S_0)$. (*'s indicate optimal values.) This is true because there are no market imperfections or uncertainties in our set-up, and the problem is autonomous.

Our autonomous, constant price and interest rate model for a single oil exporter differs from that for exporter C2 in our two country model in the sense that oil prices heed by C2 varied over time and generated terms of trade changes in $\in(t)\dot{F}_R(t)$. We had to "neutralize" these capital gains enjoyed by C2 with an adjusted invest resource rents savings rule. The constant oil price p eliminated capital gains in our autonomous model of the OR. In both models agents were acting with perfect foresight so that they could anticipate price and interest rate changes and optimize appropriately.

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[8] H(t) is another instance of the index number mentioned in footnote 1. Clearly this index number is cumulative uncompounded or discounted rent. The lack of compounding occurs here because potential interest accumulation is "neutralized" by the period by period drawing. off of current interest on the capital value.

[9] This argument was set out in detail in Hartwick and Hageman [1993] but no formal demonstration of $\dot{C}(t) = 0$ was given.

Concluding Remarks

There are indeed subtleties in moving from a unitized world system to a system of' countries trading flows from their exhaustible resource stocks and each maintaining consumption constant over time. We derived the "wedges" that arise when our investment is financed in oil importing countries by own resource rents and derived adjustment weights for the own savings (resource rents). Oil importers should save more than resource rents ascribable to their own exhaustible resource flows and oil exporters should save less than resource rents ascribable to their own exhaustible resource case. Our subsequent model of a small open oil exporting nation, a PRICE-TAKER at a constant interest rate and commodity prices, revealed no "wedges" that were seen in the two country system with endogenous prices. Thus trade introduces subtleties to the derivation of constant consumption paths because prices are indeed moving over time and these price change effects show up as endogenous terms of trade effects. Relatively complicated savings-investment rules are needed in each country to neutralize these terms of trade effects on the simple invest-resource-rents rule, familiar for closed economies.

With our adjusted savings rule, we have been able to re-construct the closed economy set-up, given multiple countries in trade. This was our goal. We also noted that no new valuation issues were met and that traditional NNP measures "go through" in the open economy system. We were also able to relate constant consumption paths to interest-on-wealth expressions. These are compelling Hicksian notions of current national "income" being interest on national wealth. However constant consumption paths are not reflections of constant wealth paths. In no case was national wealth remaining constant over time.

Appendix: Derivation of Equation (3)

One differentiates $C(t) = F(K(t),R(t)) - K(t)$ to obtain

$$C = F_K K + F_R R - K(t) \tag{A1}$$

One differentiates equation (1) to obtain

$$\ddot{K}(t) = \lambda(t)R(t)\dot{F}_R(t) + \lambda(t)F_R(t)\dot{R}(t) + R(t)F_R(t)\dot{\lambda}(t). \tag{A2}$$

In A1, for F_K substitute $F_R(t)/F_R$ from (2) and $\lambda(t)R(t)F_R(t)$ for K. Also for K(t) in A1 substitute the expression in A2. A1 reduces to $C = \frac{\bullet}{(1-\lambda(t))R(t)} F_R(t)$, our expression in (3) in the text.

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THE OPTIMAL SUSTAINABLE DEPLETION OF NON-RENEWABLE RESOURCES

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Abstract. In a simple growth model based on capital accumulation, non-renewable resource depletion and constant technology, the maximum sustainable utility level is strictly less than net national welfare; and a growth path may be unsustainable, even though it has rising net wealth. PV-optimal sustainability ('opsustimality') is defined as maximising the present value of utility, subject to utility being non-declining forever. The opsustimal path will either have a finite phase of rising utility, and followed by a continuous transition to constant utility; or will always have constant utility. Only on the opsustimal path does non-declining net wealth always coincide with sustainability. Numerical simulations suggest that a rising opsustimal path has higher utility than the PV-optimal path at the same time. A consumption tax can achieve sustainability in a market economy only by approaching a 100% subsidy, and neither a resource depletion tax nor a resource stock subsidy can achieve sustainability.

This research was funded by award no. L320-27-3002 of the UK Economic and Social Research Council's Global Environmental Change programme. I particularly thank Mike Toman for helpful discussions at all stages of this paper, and I also thank Geir Asheim, Geoff Lewis, Malcolm Pemberton and David Ulph for many useful conversations and comments. The usual disclaimer applies.

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RETHINKING SUSTAINABILITY

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First version: September 1993

This version: May 1994

Comments welcome.

ABSTRACT

This paper argues that sustainability is an inappropriate guiding principle for the design of policy in a democratic setting. If policy is to be generally implementable then its design must be consistent with the social setting in which it is applied. In a democratic setting that permits individuals to act and vote in accordance with views of distributive Justice that are not necessarily consistent with sustainability, policy based on a sustainability criterion will not be generally implementable. The alternative conceptual framework I propose is based on three key elements: the relaxation of the distinction between ethics and preferences; the recasting of an intergenerational equity problem as an intragenerational allocation problem; and the requirement that Intergenerational resource allocations be intragenerationally efficient.

"The less you know about it, the better it sounds"

- Robert M. Solow (1991)

1. INTRODUCTION

This paper argues that sustainability is an inappropriate guiding principle for the design of policy in a democratic setting. This is not a fashionable stance to take. The tide of academic literature and political rhetoric seems to flow overwhelmingly in quite the opposite direction. Indeed, it is difficult to find a recent policy statement of any kind that does not make some reference to the term. The continuing absence of a clear definition of sustainability does not seem to detract from its political appeal. A cynic might even claim that the ambiguity of the notion is the main source of that appeal. It is not my intention in this paper to attempt to resolve that ambiguity by proposing yet another definition of sustainability. My primary purpose is to argue that an emphasis on sustainability in the design of policy in a democratic setting is misplaced.

The paper is organized as follows. In the next section I present a case against the imposition of a sustainability criterion. in the design of policy in a democratic setting. I then propose in section 3 an alternative approach to intergenerational resource allocation. I present a simple illustrative application of the proposed approach in section 4. Section 5 concludes the paper with a brief summary and some closing remarks.

2. RETHINKING SUSTAINABILITY

Sustainability as a societal goal is based on a particular ethical. stance. It rests on a view of distributive justice that gives at least some consideration to the well-being of future humans and/or other elements of the biosphere. Within that general class of ethical views there are many specific positions that are consistent with some notion of sustainability. They range from the purportedly non-anthropocentric view of the deep ecologists [Naess (1986)] to some form of (anthropocentric) egalitarianism embodied in a Rawlsian-type intergenerational social welfare function [Solow 1974]. It is not my intention to present a taxonomy of these ethical positions nor to debate their relative philosophical merits.[1] Nor do I intend to examine the nature of the link between an ethical stance and the definition of sustainability that it implies. I do not mean to imply that this is a topic unworthy of examination. Indeed, it is my impression that the clarity of the debate over competing definitions of sustainability could be enhanced if more attention was paid to the axiomatic derivation of a proposed definition from. the particular ethical position underlying it.[2] Consider for example the disagreement between those who define sustainability to mean the preservation of the "natural capital stock" [Pearce (1988), Costanza and Daly (1992)] and those who define it to mean the preservation of the "composite capacity to produce well-being" [Solow 1992]. This debate has sometimes confused two distinct Issues. The focus of the debate has been on the degree to which manufactured and human capital can physically substitute for natural capital in production. I believe this focus is misplaced. To the extent that there do exist at least some physical substitution possibilities, there remains the issue of whether or not it is ethically acceptable for the current generation to make those substitutions (perhaps irreversibly) without the consent of future generations. I believe this is the fundamental source of disagreement in this debate. It is a conflict of ethical positions. If one adopts an ethical position embodying an obligation to preserve for future generations the same *opportunities to choose* that were available to the current generation then one is obliged to make no irreversible substitutions. Whether or not such substitutions are physically possible is then irrelevant.[3]

Making the ethical positions that underlie various definitions of sustainability more explicit would help to clarify the differences between them but it would not necessarily lead to a convergence of those definitions. There is unlikely to arise a consensus about the precise meaning of sustainability until a consensus is reached about the meaning of distributive justice. No such consensus seems imminent. The main point I want to make in this paper is that the absence of a universally accepted notion of distributive justice has implications more fundamental than ambiguity in the precise meaning of sustainability. It raises the question of whether sustainability - no matter how it is defined - is an appropriate guiding principle for policy at all.

Disagreement over the meaning of distributive Justice can and does extend beyond the set of ethical positions that are consistent with some notion of sustainability. Some ethical positions. do not imply sustainability in any sense. Consider a deliberately extreme example. “It is perfectly just for my generation to consume the entire resources of the planet at the expense of future generations because we were here first”. I do not think there are many people who subscribe to this ethic (although I suspect there are some). The point is that this ethical position and many less extreme ethical positions are not consistent with sustainability. This means that the adoption of sustainability as a guiding principle for policy is restrictive. What is the basis for restricting the set of admissible ethics in this way? I submit that the restriction is an arbitrary one. This is not objectionable in itself. All guiding principles are fundamentally arbitrary. My objection to the restrictiveness of sustainability is based on more pragmatic grounds.

I begin with the assertion that any guiding principle for the design of policy should be consistent with the social setting in which it is to be applied. By consistent I mean here that the resource allocation implied by a policy prescription must be implementable given the social structure, in the sense that there cannot exist a constitutional mechanism by which the implementation of the allocation would be blocked. This is admittedly an arbitrary stance to take. It reflects my own view that policy should be designed with its eventual implementation squarely in mind. Not everyone may agree with this position but it seems sensible to me. My purpose is to examine what this criterion implies for the design of policy in matters of intergenerational resource allocation.

Whether or not a particular guiding principle is consistent with a given social structure will of course of depend on the nature of that structure. I will focus here on democratic structures, and do so at a fairly abstract level. I will assume a structure in which each agent is free to vote against a candidate allocation in favor of some alternative if they so wish. This is a reasonable approximation to a democratic system for the purposes of this paper. I should stress that it is not the purpose of this paper to advocate democracy over some other social structure. I focus on democracy only because it is the system currently in place in many countries.

If a guiding principle for policy is to be consistent with a democratic structure then it must be respectful of the voting rights of the members of that democracy. In the democracies with which I am familiar, voting rights are not restricted to those individuals who subscribe to an ethical position that is consistent with sustainability. Individuals are permitted to vote regardless of their ethical position, within certain limits. These limits are often enshrined in a constitution. For example, in Canada and the United States, a charter of rights and freedoms restricts the ability of the collective to violate what are deemed to be the rights of the individual. In Canada it is illegal to incite hatred of a particular social group. These restrictions reflect the fact that there are some ethical positions that these societies have deemed to be unacceptable.[4] Ethical positions that are inconsistent with some notion of sustainability may some day be included among them. Currently they are not. To impose sustainability as a guiding principle for resource allocation is to ignore in principle the voting rights of individuals who subscribe to those ethical positions. This creates the potential for the policies formulated under this guiding principle to be systematically unimplementable. This does not mean that democracy is necessarily inconsistent with sustainability. I have already noted that some notion of sustainability could possibly be enshrined in a constitution without necessarily rendering it undemocratic. Even without such a restriction, it is possible that all Individuals with voting rights might happen to subscribe to an ethical position that is consistent with sustainability. But to impose a guiding principle that does not conceptually admit a converse possibility fails my implementability criterion and is in my view inappropriate.

A conceptual framework for the analysis of intertemporal resource allocation issues must be able to accommodate conflict among individuals with voting rights if it is to be generally useful in the guidance of policy formulation. This rules out the imposition of sustainability as a guiding principle. More generally, it rules out the imposition of an intergenerational welfare function on a planning problem designed to guide policy. To do so implies that all of the agents in the modeled economy subscribe to the ethical position embodied in the welfare function. This is true regardless of whether or not the particular welfare function is consistent with sustainability. Such modeling exercises should be interpreted only as positive analyses of how an economy of agents with a common ethical position would optimally allocate resources across generations. They are inadequate for guiding policy in a realistic democratic setting because by construction they cannot in general admit differences in ethical positions.

I have argued that it is generally inappropriate to impose sustainability directly or to assume a particular intergenerational welfare function for the. purpose of guiding policy in a democracy. So how should one proceed? In the next section I propose one possible approach. I focus on the question of intergenerational equity rather than a more general consideration of distributive justice - that might Include, for example, the perceived rights of other sentient beings - only because this issue has received the most attention in the economics literature. The approach I propose could in principle be extended to encompass broader issues of distributive justice.

3. DEMOCRACY AND INTERNATIONAL RESOURCE ALLOCATION

There are three key elements of the conceptual framework I advocate for addressing issues of intergenerational resource allocation in a democratic setting. The first is the relaxation of the distinction between preferences and ethics (or "social **preferences").**[5] This distinction is sometimes used to justify the imposition of an intergenerational welfare function that applies positive weight to future generations in an economy in which agents have preferences defined only over their private consumption.[6] The welfare function is interpreted as a reflection of an ethical position that is conceptually distinct from preferences. This distinction may or may not be a philosophically interesting one; in any case it has little practical relevance in a democratic setting in which a vote motivated by preferences is treated equally alongside an observationally equivalent vote motivated by ethics. If a conceptual framework is to have practical relevance then it cannot rest on a distinction between ethics and preferences.

The second key element is the recasting of an intergenerational equity problem as an intragenerational allocation problem. The interests of future generations can be represented in a democratic setting only to the extent that current generation agents act as their advocates. This necessitates a focus on current generation agents. I have already argued that whether this advocacy is motivated by ethics or preferences is practically irrelevant. The important point to recognize is that this advocacy reflects some concern for the well-being of those future generations. The well-being of current generation agents can depend on the well-being of future generation agents just as surely as it depends on their own consumption. A transfer of consumption from the current generation to future generations can potentially make both generations better off. A conceptual framework that places exclusive focus on private consumption as the determinant of well-being is inappropriate. An equally important point to note is that current generation agents can differ in the degree to which they care about future generations. If these different agents are entitled to act and vote in a democratic setting then there can arise a conflict of interests among current generation agents. It is *this* conflict of interests that must be accommodated in a conceptual framework for addressing intergenerational resource allocation issues in a democratic setting. To frame these issues in terms of a conflict of interest *between* generations is not helpful for the purpose of guiding policy.

The third key element of the conceptual framework I advocate is a focus on intragenerational efficiency in the assessment of an intergenerational resource allocation. If each agent in the current generation is free to vote against a candidate intergenerational allocation in favor of some alternative, then implementability of the candidate allocation requires that it be efficient from the perspective of the current generation. If there exists an alternative allocation at which all current generation agents are better off than at the candidate allocation then the candidate allocation would be unanimously rejected in favor of the alternative. The candidate allocation cannot be implemented without a suspension of the democratic process. Intragenerational efficiency is a necessary condition for implementability in this setting.

It should be noted that intragenerational efficiency does not necessarily imply intergenerational efficiency. Suppose, for example; that current generation agents do not care at all about the well-being of future generation agents, and that there exist two allocations between which current generation agents are indifferent. If these two allocations have different implications for the well-being of future generations then imposing intragenerational efficiency alone will not guarantee intergenerational efficiency: the allocation In which the future generation is worse off will pass the intragenerational efficiency screen and could be chosen. But intergenerational efficiency is only a relevant criterion if the current generations deems it to be so, and it will be deemed so only if there are current generation agents who care about future generations. If there is at least one such agent then intergenerational efficiency is implied by intragenerational efficiency. Therefore, nothing meaningful is lost by focusing exclusively on intragenerational efficiency.

Intragenerational efficiency will generally not identify a unique social optimum. There will generally exist a continuum of efficient allocations from which one must be chosen according to some social choice rule. It should be stressed that there is nothing internally inconsistent about this. In a democratic setting the particular voting rule in place will determine which allocation is chosen and this voting rule is taken as given for the purpose of guiding implementable policy.

In the section following I present a simple illustrative example of the approach I have proposed. This example falls far short of a general formalization of the proposed approach but it does serve to demonstrate that resource allocation rules consistent with this approach can be very different from those implied by a sustainability criterion. A secondary purpose of the example is to highlight a potentially important reason why inefficiency can arise in intergenerational resource allocation, and that democratically consistent policy can play in a role in correcting it.

4. AN ILLUSTRATIVE EXAMPLE

Consider an economy with a sequence of identical generations each comprising n agents. Each agent in generation t has utility function $u(c_t, u_{t+1})$ defined over her own consumption c_t and the utility of her immediate heir u_{t+1}. This representation of Intergenerational altruism has been used extensively before in various contexts.[7] It reflects "non-paternalistic altruism" in the sense that utility is derived from the well-being of another person rather from their consumption. I assume a specific frictional form that is amenable to closed-form solution:

(1) $u_t = \log(c_t) + \beta u_{t+1}$

where $\beta \in [0,1)$ reflects the agent's degree of concern for the well-being of her heir. I assume initially that β is the same for all agents. It should be stressed that β does not represent the agent's private rate of time preference. (In an extended model of multiple-period lived agents a separate parameter for the rate of time preference would have to be introduced). Each generation presumes that the preferences of their heirs will be the same as their own.[8]

Consumption relies on a stream of benefits provided by natural capital, and this natural capital becomes depleted if over-exploited. The transition process for natural capital is given by

(2) $R_{t+1} = (R_t - C_t)(1+\delta)$

where R_t is the stock of natural capital in period t, C_t is aggregate consumption in period t, and δ is the rate of regeneration of natural capital. Sustainability requires that $R_{t+1} \geq R_t$, which in turn requires $C_t \leq \delta R_t/(1+\delta)$. This definition is a natural one in this setting and coincides both with a "preservation of the natural capital stock" requirement and a requirement to "preserve the composite capacity to produce well-being".

Efficiency with homogeneous agents

I begin the analysis by deriving the symmetric intragenerationally efficient consumption rule when all agents have the same β parameter. The planning problem is to choose the consumption path that maximizes the utility of a representative agent in the current generation (generation zero):

(3) $$\max_{c_0} \ \log(c_0) + \beta u_1$$

$$\text{s.t. } u_t = \log(c_t) + \beta u_{t+1} \quad \forall t$$

$$R_{t+1} = (R_t - nc_t)(1+\delta) \quad \forall t$$

$$R_0 \text{ given}$$

Recursive substitution for u_1 allows this to be reformulated as a standard infinite horizon dynamic programming problem:

(4) $$\max_{\{c_t\}} \ \Sigma_{t=0}^{\infty}\beta^t \log(c_t)$$

$$\text{s.t. } R_{t+1} = (R_t - nc_t)(1+\delta) \quad \forall t$$

$$R_0 \text{ given}$$

The corresponding Bellman equation is

(5) $$W(R_t) = \max_{c_t, R_{t+1}} \left\{ \log(c_t) + \beta W(R_{t+1}) \right\}$$

where W(R) is the (current value) value function. It is straightforward to solve this for the following aggregate consumption rule:

(6) $$C_t^* = R_t(1-\beta)$$

In comparison, the maximum sustainable level of aggregate consumption is

(7) $$\bar{C}_t = \delta R_t/(1+\delta)$$

It is clear from (6) and (7) that sustainability is consistent with efficiency if and only if $\beta \geq 1/(1+\delta)$. This means that the efficient path will be sustainable only if agents are sufficiently altruistic and the rate of natural capital regeneration is sufficiently high. If β and/or δ are too small then the stock of natural capital will be continually depleted and the consumption of future generations will tend towards zero. Policy intervention to ensure sustainability in this case would be inconsistent with a democratic setting. If $\beta<1/(1+\delta)$ then the agents in this economy would unanimously reject a (symmetric) sustainable consumption path over a (symmetric) unsustainable one if given the opportunity to vote. A policy that imposes sustainability in this economy could be implemented only if democracy is suspended.

Efficiency with heterogeneous agents

I now turn to a case with heterogeneous agents. Suppose there are two types of agents: strongly altruistic (type 1) agents with an altruism parameter β_1, and weakly altruistic (type 2) agents with an altruism parameter $\beta_2<\beta_1$. Let α denote the proportion of strongly altruistic agents. Agents of type j presume that their heirs will also be of type j. The intragenerational efficiency frontier for this economy can be derived from a planning problem in which the utility of a representative type 1 current generation agent is maximized subject to some lower bound on the utility of a representative type 2 current generation agent:

$$(8) \qquad \max_{c_0^1} \log(c_0^1) + \beta_1 u_1^1$$
$$\text{s.t. } u_t^j = \log(c_t^j) + \beta_1 u_{t+1}^j \quad \forall t$$
$$R_{t+1} = (R_t - \alpha n c_t^1 - (1-\alpha) n c_t^2)(1+\delta) \quad \forall t$$
$$u_0^2 = \bar{u}$$
$$R_0 \text{ given}$$

Recursive substitution for u_{t+1} allows this program to be reformulated as

$$(9) \qquad \max_{\{c_t^1\}} \Sigma_{t=0}^{\infty} \beta_1^t \log(c_t^1)$$
$$\text{s.t. } R_{t+1} = (R_t - \alpha n c_t^1 - (1-\alpha) n c_t^2)(1+\delta) \quad \forall t$$
$$\Sigma_{t=0}^{\infty} \beta_2^t \log(c_t^2) = \bar{u}$$
$$R_0 \text{ given}$$

The key to finding a solution to this program is to recognize that at the optimum the second constraint must be satisfied with minimal use of natural capital. The linearity of the transition equation in this example makes it straightforward to exploit this characteristic of the solution. The stock of natural capital at any point in time can be conceptually split into two separate stocks R_t^1 and R_t^2 such that $R_t=R_t^1+R_t^2$, where R_t^1 provides a consumption stream for type 1 agents and R_t^2 provides a consumption stream for type 2 agents. It is then possible to find the minimal value of R_0^2 needed to satisfy the second constraint as the solution to

(10) $$\bar{R}_0^2 = \min_{R_0^2}$$
$$\text{s.t. } \Sigma_{t=0}^{\infty}\beta_2^t\log(c_t^2) = \bar{u}$$
$$R_{t+1}^2 = (R_t^2 - n(1-\alpha)c_t^2)(1+\delta) \quad \forall t$$

This is just the dual of the standard dynamic programming problem described in (4). It solves for a consumption path given by

(11) $$c_t^2 = (1-\beta_2)R_t^2/n(1-\alpha)$$

Solution of the system then yields the following minimum value for R_0^2:

(12) $$\bar{R}_0^2 = \exp\left[(1-\beta_2)(\bar{u} - \theta)/\beta_2\right]$$

where $\theta = \Sigma_{t=0}^{\infty}\beta_2^t\log[(1-\beta_2)\beta_2^t(1+\delta)^t/n(1-\alpha)]$. The overall planning program can now be reformulated as

(13) $$\max_{\{c_t^1\}} \Sigma_{t=0}^{\infty}\beta_1^t\log(c_t^1)$$
$$\text{s.t. } R_{t+1}^1 = (R_t^1 - \alpha n c_t^1)(1+\delta) \quad \forall t$$
$$R_0^1 = R_0 - \exp\left[(1-\beta_2)(\bar{u} - \theta)/\beta_2\right]$$
$$R_0 \text{ given}$$

This is now a standard problem with solution

(14) $$c_t^1 = (1-\beta_1)R_t^1/n\alpha$$

Aggregate consumption for the current generation as a whole is given by

(15) $$C_0 = (1-\beta_1)[R_0-\bar{R}_0^2] + (1-\beta_2)\bar{R}_0^2$$

Whether or not this level of consumption is sustainable depends on δ, β_1 and β_2, and on $\bar{R}_0^2$. That is, the distribution of utility between strongly and weakly altruistic agents within the current generation, as reflected in $\bar{R}_0^2$, will generally be important in determining whether or not consumption is sustainable. In particular, sustainability is less likely if the utility distribution favors the weakly altruistic over the strongly altruistic. As noted earlier, the utility distribution that arises in this economy will depend on the particular voting rule in place. A natural distributional arrangement to consider is one that provides each group with control over a share of the natural capital stock proportional to its representation in the population. This implies current generation aggregate consumption equal to

$$C_0 = (1-\beta_1)\alpha R_0 + (1-\beta_2)(1-\alpha)R_0 \tag{16}$$

This consumption level is sustainable if and only if $[\alpha\beta_1+(1-\alpha)\beta_2]\geq 1/(1+\delta)$. That is, if enough agents care enough about their heirs then the efficient path based on proportional representation is sustainable. Otherwise it is not. An alternative distributional rule is to vest control of the entire natural capital stock in the hands of the group that constitutes a majority. The preferences of this group would then dictate the consumption levels for all agents in the economy. In this case the efficient path would be sustainable if $\beta_1\geq 1/(1+\delta)$ when $\alpha>1/2$, and if $\beta_2\geq 1/(1+\delta)$ when $\alpha<1/2$. Regardless of the particular distributional rule, it is clear that if the weakly altruistic group constitutes a large enough majority and if their altruism is sufficiently weak then the consumption path will not be sustainable.

Equilibrium with open access

The discussion so far has focused on efficient consumption paths. I have argued that efficiency is not necessarily compatible with sustainability and that policy intervention to ensure sustainability is generally not consistent with a democratic setting. This does not mean that there is no role for policy in directing intergenerational resource allocation. Much of the natural capital stock is characterized by open access. In some cases it is feasible to assign private property rights over natural capital (such as with some fish stocks and trees) but this is not always possible. In this section I derive the Nash equilibrium consumption path when there is open access to natural capital. I focus on the homogeneous agent case since it illustrates the consequences of open access most simply.

Each agent k in generation t perceives the following transition equation:

$$(17) \qquad R_{t+1} = (R_t - c_t^k - C_t^{-k})(1+\delta)$$

where C_t^{-k} is consumption by agents other than agent k in period t; it is taken as given by agent k since there is open access to the natural capital stock. I confine consideration to rational expectations equilibria. This means that each agent in the current generation correctly anticipates the equilibrium implications of her consumption decision for the utility of her heir and correctly anticipates that all of her descendants will do the same. The choice problem for agent k in period t can therefore be formulated as

$$(18) \qquad \max_{c_t^k} \log(c_t) + \beta\hat{u}_{t+1}$$

$$\text{s.t } R_{t+1} = (R_t - c_t^k - C_t^{-k})(1+\delta) \quad \forall t$$

$$\hat{u}_{t+1} = \Sigma_{i=1}^{\infty}\beta^i \log(\hat{c}_{t+i})$$

$$\hat{R}_{t+i} = (R_{t+i-1} - n\hat{c}_{t+i-1})(1+\delta) \quad \forall i\geq 2$$

where c_{t+i} is equilibrium per capita consumption in period t+i. This is not a standard dynamic programming problem. However, a solution can be found by positing a time-invariant equilibrium consumption rule of the form $\hat{c}_{t+i}=\alpha R_{t+i}$, and verifying that this in fact solves the program.[9] Solving the problem in this way and imposing symmetry yields the following equilibrium aggregate consumption path:

$$(19) \qquad \hat{C}_t = R_t n(1-\beta)/[\beta + (1-\beta)n]$$

Comparing this equilibrium path with the efficient path reveals that equilibrium consumption is too high in early generations. This inefficiency is due to the–open access to natural capital. Each individual in period t recognizes that the natural capital she leaves intact for her descendants will also be available for consumption by the descendants of her fellow citizens. She cannot protect the legacy she leaves. Recognition of this fact leads her to leave less than she otherwise would.[10] It should be noted that this result is sensitive to the form of the utility function. The inefficiency could in principle go the other way: the open access could induce an agent to consume less than is efficient in an attempt to compensate for the fact that the legacy she leaves for her heir may be depleted by others. The inefficiency of the Nash equilibrium implies a role for policy intervention. In this example policy intervention is needed to reduce the rate of consumption but it is conceivable that intervention in the opposite direction may be needed. In either case the appropriate role for policy in a democratic setting is to ensure efficiency rather than to impose sustainability.[11]

5. CONCLUSION

In this paper I have argued that sustainability is an inappropriate guiding principle for the design of policy In a democratic setting. If policy is to be generally implementable then its design must be consistent with the social setting in which it is applied. In a democratic setting that permits individuals to act and vote in accordance with views of distributive justice that are not necessarily consistent with sustainability, policy based on a sustainability criterion will not be generally implementable. The alternative conceptual framework I have proposed is based on three key elements: the relaxation of the distinction between ethics and preferences; the recasting of an intergenerational equity problem as an intragenerational allocation problem; and the requirement that intergenerational resource allocations be intragenerationally efficient.

To recognize that different individuals in a democracy can legitimately hold different and incompatible views on distributive justice is not to say that there is no place for continued debate about the meaning of distributive justice. Such debate is surely valuable. Economists can and should play an important role in that debate. But is it essential that economists carefully distinguish between their philosophizing about the meaning of distributive justice and the more mundane business of guiding implementable policy.

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ACKNOWLEDGEMENTS

I am grateful to Malcolm Rutherford and participants at the 1993 Meeting of the Canadian Resource and Environmental Economics Study Group for helpful comments and discussions.

NOTES

[1]Pearce and Turner (1990, Chapter 15) provide a concise review of some of the ethical views that are most commonly cited to motivate sustainability.

[2]See Chichilnisky (1993) for some recent work in this direction.

[3]As an aside, it seems to me that a requirement to preserve the same opportunities to choose is impossible to fulfill. The second law of thermodynamics renders it physically impossible to leave the planet exactly as we found it over a sufficiently short time interval. To the extent that the next generation follows the current generation instantaneously (there are a continuum of generations) then they cannot inherit exactly what the current generation inherited.

[4]This of course begs the question of how this unacceptability is decided upon. Important as this question is, It is not one on which I need comment here. My scope is more narrow. I am concerned only with the consistency of a guiding principle with the democratic constitution currently in place. The process by which that constitution is established or revised is not directly relevant to that issue.

[5]See Sen (1977) for a discussion of this distinction.

[6]See Howarth and Norgaard (1992) for an example of such a model.

[7]See Ray (1987) for a discussion of this representation.

[8]While I later allow agents to differ according to the size of their β, they could also conceivably differ in their beliefs about what future generation preferences will look like. It should in principle be possible to extend consideration to this issue within the same basic framework.

[9]See Levhari and Mirman (1980). It should be noted that this approach does not guarantee that the posited equilibrium is unique.

[10]Levhari and Mirman (1980) derive an exactly analogous result in the context of a fish war between two infinitely-lived national governments.

[11]Marglin (1963) identifies a different potential source of inefficiency in intergenerational resource allocation. In a model with paternalistic altruism Marglin shows that if the consumption level of the next generation as a group is a public good for current generation agents then there may be too little saving in the economy due to free-riding. The equilibrium discount rate will consequently be too high. This public good problem could co-exist with an open access problem.

An Efficiency Argument for Sustainable Use

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Working Paper Series No. 94-11
September 1994

This paper is available in *Property Relations, Incentives, and Welfare,* edited by John E. Roemer.

For USA only:
Published by St. Martin's Press, Incorporated

For the world excluding the USA:
Published by Macmillan Press, Ltd. (London)

ABSTRACT

"An efficiency argument for sustainable use."

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Sustainability is often viewed as a moral obligation to future generations. The paper adds an argument for sustainability that is entirely based on efficiency and is free from distributional considerations.

Many natural environments admit two uses: (i) a destructive use, where the environment is converted into a private good, used by (a fraction of) the present generation: and (ii) a nondestructive use. where the environment is maintained in its natural form: the environment is thus a public good, useful to both present and future generations. The nondestructive use can often be defended purely on efficiency grounds: this is made precise in a quasilinear model of a finite number of overlapping generations. Efficiency is there equivalent to the maximization of surplus, i.e., the maximization of the sum of the benefits over generations minus the sum of costs.

Two qualifications. First, large transfers of wealth from future to present generations must be physically possible Second, if individual discount the future, then efficiency requires the maximization, not of the sum of utilities, but of a discounted sum of utilities. Efficiency can dictate conservation in Society I and destruction in Society II for two societies that are identical except that individuals discount the future in Society. This is somewhat surprising in overlapping generation models.

JOURNAL OF ECONOMIC LITERATURE CLASSIFICATION NUMBERS:

D61, H41, H43, H82, Q20, Q23, Q26, Q30, Q38.

THE UNITED NATIONS
INTEGRATED ENVIRONMENTAL AND ECONOMIC ACCOUNTING SYSTEM: AN ENVIRONMENTAL ECONOMICS PERSPECTIVE

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Paper presented to the 1994 AERE Workshop "Integrating the Environment and the Economy: Sustainable Development and Economic/Ecological Modeling." June 6. Boulder, CO.

The views expressed in this paper are the authors' own and do not represent the official position of the Environmental Protection Agency.

Introduction

Conventional economic accounting, including accounts for assets, income and product as well as input-output accounts, is practiced by most nations of the world because it supports economic policy in several important ways. The national accounts provide measures of a nation's wealth, summary statistics regarding overall economic performance, and an instantaneous but static picture of the flows of economic activity. The description provided by the national accounts of the relationship between outputs of economic processes-the production of goods and services-and economic inputs supporting these processes is critical for economic analysis and policy. An understanding of these mechanisms is essential if the government wishes to influence economic activity predictably. Since their introduction over 50 years ago, the national economic accounts have evolved to respond to changes in the structure of the economy and the analytic and data needs of policy makers.

While there is widespread agreement that the standard national economic accounts provide invaluable information on economic activity, there is also recognition that the standard measures fail to capture other factors which influence social welfare, such as the quality and quantity of environmental resources and amenities. Changes in the environment and in natural resources have not been explicitly included in the economic accounts, principally because ways to measure these changes monetarily were not apparent and thus integrating them with other entries in the accounts was impossible. This neglect of environmental and natural resource activity impairs the functions of the national accounts. First, it fails to include a potentially important category of a nation's wealth and thus future production and consumption possibilities. Second, it provides an overly optimistic picture of economic perfomance in that it omits the effect of negative environmental externalities, such as pollution, on current well-being and the effect of natural resource degradation on future well-being. Finally, the ability to picture relationships between outputs and inputs is degraded since the environment and natural resources generate important input and output services that compete with and substitute for the monetized services that are covered in the conventional accounts.

Integrated environmental and economic accounting systems attempt to address these shortcomings of the national accounts. Three major objectives of the such integrated systems are to: 1) provide an accounting of the interaction of the economy and the natural environment, 2) address sustainable development concerns through proper accounting of both man-made and natural assets, and 3) develop environmentally adjusted measures of product (i.e., a "green" GDP) and income, which may inform on and serve as guidance toward sustainable development policies. The particular system proposed by the United Nations (System for Integrated Environmental and Economic Accounting or SEEA) is designed to expand upon and complement existing economic accounting systems (Systems of National Accounts or SNA) with regard to costing the use (depletion) of natural resources in production and to satisfy final demands, and recording net changes in environmental quality associated with production consumption, and natural events on the one hand and environmental protection and restoration on the other. Using the SNA as the basic framework for an integrated environmental and economic system is not meant to lead to an exclusively economic view of environmental concerns. Rather, it is intended to introduce environmental issues into mainstream economic analysis and policy making through the use of a common framework. Ultimately, the integrated system is intended to provide a suitable database for analyzing sustainable development policies and options.

It should be noted that extending the framework to incorporate environmental concerns is a separate issue from the failure of SNA-type aggregates (e.g., GDP) as welfare measures. Gross Domestic Product is a measure of the market value of economic production; modifyng it to reflect environmental issues will not make GDP a welfare measure. Further, the SEEA also excludes phenomena which take place entirely outside the economic system. For example, the generation of solid waste and gaseous emissions by natural sources and associated assimilation and transformation by ecosystem processes would not be included in the SEEA. Rather, the architects of the proposed system believe that such phenomena are better dealt with by complementary biophysical resource accounts, environmental statistics, and environmental monitoring systems with appropriate linkages to the SEEA. As a result, the SEEA is primarily concerned with the interactions between the environment and economic production, value added expenditures, and tangible wealth.

Over the past decade, a series of international workshops and meetings and a growing body of research and implementation efforts, culminated in the publication of a set of guidelines for integrated environmental and economic accounting (United Nations, 1993). With a few notable exceptions, environmental economists have not played a large role in the development of the accounting framework. Our purpose in this paper is to stimulate a discussion on integrated environmental and economic accounting within the environmental economics community and to challenge members to contribute to the implementation effort drawing on the analytical skills and insights gained from years of studying environmental issues. The first section discusses conceptual issues associated with implementing an integrated environmental and economic accounting system, paying particular attention to how standard welfare analysis concepts can be translated into the measures needed for an accounting effort. The basic structure of the SNA and the proposed extensions to reflect environmental concerns are summarized in the following sections. Results from a preliminary implementation of the SEEA for the U.S. are presented in the fourth section. Given the major omissions and measurement difficulties, these results should not be taken very seriously. Rather, they are intended to illustrate the types of protocols that are necessary for implementing the system, as well as possible adjustments to summary aggregate measures. Finally, summary conclusions and possible extensions are described in the last section.

Conceptual Issues in Implementing Integrated Environmental and Economic Accounting Systems

Conceptually, the natural environment can be viewed as an asset or reproducible capital good which provides a flow of goods and services to the economy over time. When economic use of the "output" of the natural environment results in a permanent or temporary reduction in the quantity of the asset this quantitative reduction is termed depletion. When use results in a reduction in the quality of the natural asset this use is termed degradation. Further, economic use of natural assets also results in feedback effects: depletion of natural resource stocks reduces future flows of goods and services from the environment, degradation due to the disposal of residuals results in costs imposed on third parties. In addition, firms and households may be required to make expenditures for pollution abatement and control. Obtaining a comprehensive picture of advantages and disadvantages of the economic use of the environment in production activities requires estimates of all of these items.

Constructing accounting entries which maintain comparability with the SNA requires the market prices or proxies of market prices, i.e., marginal values exclusive of consumer surplus, and associated quantities. Market values can be used for those natural assets which are connected with actual or potential market transactions, such as subsoil minerals and managed forests. However, environmental functions of these natural assets (e.g., habitat provision and CO_2 sequestration) are in most cases not reflected in the market value of the asset. Directly observable market values for environmental assets (e.g., air, undisturbed ecosystems) do not exist because there are no market mechanisms to convert the value of their generated services into observable market prices. One approach (Peskin, 1989) suggests treating environmental assets as if their services were in fact marketed. However, since it is necessary to record transactions from both "buyers'" and "sellers'" points of view, it raises questions regarding the service quantity to be valued (i.e., the current level of discharges into the environment or the current level of environmental services provided given existing environmental quality) and the appropriate valuation concept to be applied to this service quantity. The second issue arises, of course, because there are no market forces driving buyers' and sellers' marginal valuation to an equilibrium.

The standard macroeconomic analysis of externalities can be used to illustrate these issues. To simplify the discussion, we assume: 1) there are only two users of an environmental asset, 2) their uses of the asset are mutually conflicting and 3) there is an insufficient quantity of the asset to satisify both user's demands. For example, industry may seek to use the air or water to dispose of wastes, and households may seek to use the air or water to support certain levels of health or recreation. The more air or water is used to dispose of wastes the less it is able to support specified levels of health or recreation. Scarcity of the resource ensures nonzero marginal values. The traditional focus of welfare analysis on maximizing total net social benefits leads to a determination of optimal environmental asset use where marginal benefit equals marginal cost. The point we wish to make here is that, at any particular level of air or water quality, there are reciprocal benefits and costs for each user.

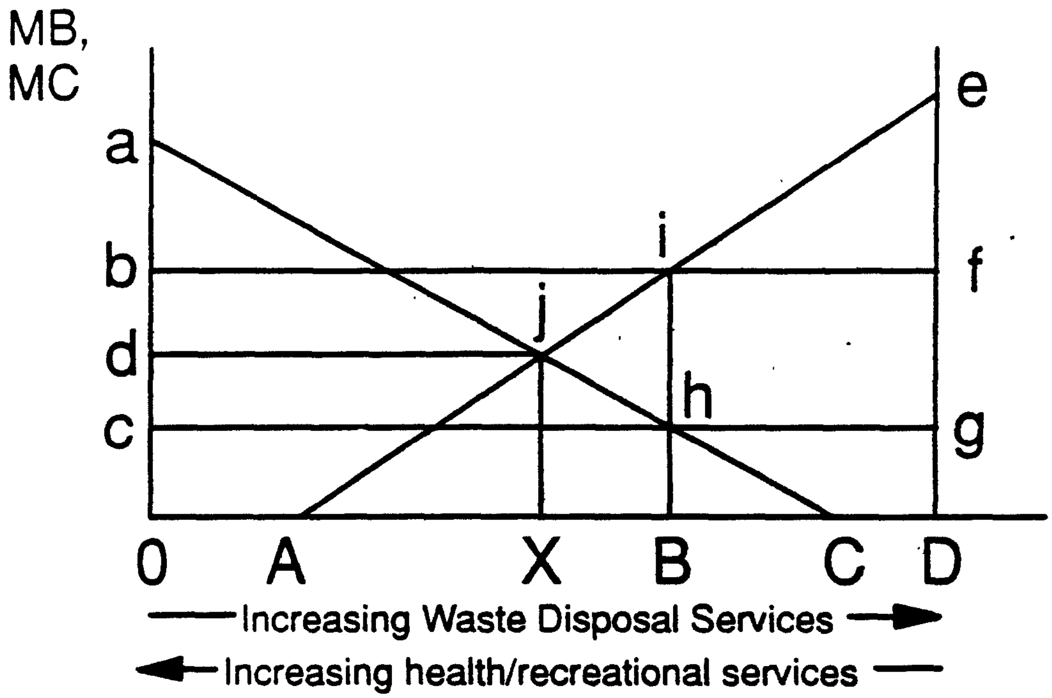
From industry's viewpoint there are costs which have already been incurred due to government regulations which restrict their access to the asset (i.e., environmental protection costs) and benefits associated with using the air or water to the current allowable level. This benefit could be viewed as a potential cost to industry, i.e., the potential costs of future air or water regulations if they further restrict industry's access beyond current levels. The first type of cost is recorded in the economic accounts, although their separate identification and reporting as distinct accounting entries is relatively recent,[1] while the second type of prospective cost is not included in the accounts. As noted in Peskin (1989), a complete accounting of all sources of income would include such costs since they measure the value of a nonmarketed factor input. In essence, industry is receiving a "subsidy" from the environment in the form of unpaid environmental waste disposal services.

For households, there are health and welfare "costs" (damages) or environmental repercussion coats associated with the current level of air and water quality, i.e., from being denied access to clean air and water. However, to the extent there has been some improvement in environmental quality due to abatement efforts, some of these damaging effects have already been avoided and benefits realized. Conventional accounts implicitly include damages which manifest themselves in markets (e.g., medical care expenditures) although they are not separately identified.

[1] Data on environmental protection expenditures has been collected since 1973. The Bureau of Economic Analysis has published a series of articles entitled "Pollution Abatement and Control Expenditures" in the *Survey of Current Business,* various issues.

Nonmarket service values of air and water, both potential and realized benefits (damages), are not accounted for in conventional accounts. Graphically, we can depict the situation as in Figure 1.

Figure 1.



Them is a total of 0D of the environmental asset. From the industry viewpoint curve aC represents the marginal benefits of being allowed access to the asset or the potential marginal costs if they are not allowed access to the asset. As drawn, industry would not use the entire asset (0D). From the household point of view, Ae represents the marginal benefits of being allowed access to the asset or the potential marginal "costs" (i.e., damages) if they are not allowed access to the asset As drawn industry could use 0A of the asset without causing any damage to households (i.e., them is a non-damaging threshold). We assume that government regulations allow 0B of the asset to be used by industry.

Associated with the current levels of asset use are two "prices": the marginal benefit/cost (b) for households and the marginal benefit/cost (c) for industry. Absent an equilibrating force such as a market, we would not expect in general for b = c. Using marginal values, we can define the following three areas:

- BDfi: The market valued benefits received by households from current policies (i.e., from denying access to industry)
- 0Bhc: The market valued benefits received by industry (or prospective future costs) from being allowed access to the asset.
- OBib: The market valued costs (damages) imposed on households.

The area BCh represents the actual pollution control costs incurred by industry, which are already recorded in GDP. These costs are to be separately elaborated in the SEEA, in aggregate and at the sector level. In extended versions of the SEEA, these costs are separated into external and internal environmental protection activities and a symmetric input-output table developed.

The SEEA captures the notion of competing uses of environmental assets by distinguishing the concepts of “costs caused”, i.e., costs associated with economic units actually causing or potentially causing environmental deterioration by their own activities, and “costs borne”, i.e., costs which are borne by economic units independent of whether they have actually caused or potentially caused environmental deterioration. In benefit-cost terms, costs caused would correspond to costs, costs borne would correspond to benefits. For example, consider a benefit-cost analysis of a proposed policy to reduce lead emissions to a specified non-damaging level. The analyst might estimate pollution abatement control costs which would fall on the industries emitting the lead and the benefits of expected improvements in human health and welfare which households would enjoy. For environmental accounting purposes, industry is *causing* environmental deterioration or a reduction in the service flow from the natural asset air. Households are *bearing* the repercussions associated with the degradation and presumably would be willing to pay (in terms of reduced consumption) to avoid this burden.

These two valuation concepts correspond to two possible approaches to environmental accounting: 1) accounts which describe the environmental impacts of economic activities, and 2) accounts which describe the condition of the natural environment and its effect on human health and welfare. The latter is a much more complex undertaking since it requires substantially more information (ecological processes, impacts on health, behavioral responses, etc.) which must take into account time and space dimensions. An additional complication is that costs borne will normally require some type of contingent valuation (CV) to estimate the value of adverse health and welfare effects associated with environmental degradation.

The preferred concepts in SEEA are oriented towards “costs caused”, i.e., SEEA focuses on which economic agents/activities are responsible (accountable) for deteriorating the natural environment. This focus is driven by both data availability and the relevance of accountability in integrated policies and stainable development management Recent attempts to implement the SEEA have focused on quantitative and qualitative asset use associated with economic production (0B), which is valued at cost (c). Thus, in the SEEA hypothetical (imputed) costs (0Bhc) play a prominent role. The cost of using the natural environment is extended to include costs that *would* have been incurred had the environment been used in such a way that its future use was unimpaired (i.e., the costs that would have been required to maintain natural capital intact). This approach parallels the treatment of man-made capital in the conventional accounts: consumption of fixed capital represents the monetary amount necessary to maintain the current level of man-made assets intact and thus allowing for sustainable fixture income flows. In addition capital consumption estimates the current costs of using fixed assets in production and could be interpreted as constituting a payment to the services of man-made capital.

Relatively little emphasis has been placed on the costs borne concept in the SEEA (area OBib in the diagram). As noted above, determining the impacts of a depleted and degraded natural environment will be a difficult undertaking. However, the SEEA recognizes that it is important to take into account the values accorded to the environment by those (industry and households) who bear the consequences of environmental degradation and depletion. For production activities, costs borne are to be estimated using actual or imputed market values. That is, the reduction in the market value of a natural asset due to quantitative depletion or qualitative degradation (which may be partly counterbalanced by restoration activities of the government) would be treated as a cost and integrated into the production accounts of the SEEA. For households, the SEEA acknowledges that a significant part of the valuation of repercussions associated with a deteriorated natural environment will require willingness to pay or CV methods.

Many accountants doubt whether it is possible to determine monetary values for preferences in the absence of markets (see Hueting, 1980, chap. 4.5), and remain skeptical about the feasibility of applying CV methods in a national accounting framework. The SEEA also expresses reservations about CV, stating "Use of the contingent valuation approach in environmental accounting is still in an exploratory stage. Further research and discussion are needed. The following proposals therefore provide only a generic framework for further experimentation with this valuation method and related accounting procedures" (UNSO, 1993). This reluctance on the part of accountants to use CV is not surprising given the focus of conventional economic accounting on production, transactions, and costs. Accountants would be the first to acknowledge that the accounts record market transactions, not values, and hence accounting aggregates are not measures of welfare.

In summary, both the costs caused and costs borne concepts involve actual costs, which are recorded in the SNA although not separately identified and imputed environmental costs, which are recorded as additional cost items in the SEEA. Nonmarket valuation approaches will be required to estimate imputed environmental costs although the costs borne concept would require additional, relatively more controversial, alternative valuation concepts such as CV. The SEEA recommends using maintenance costs to estimate costs caused since the data are more reliable and available and responsible economic agents are identified and held accountable. It is also similar to approaches followed for other non-marketed goods and services. For certain non-marketed goods and services (e.g., subsistence farming agricultural products, own-account production of housing services) conventional accounts base valuation on prices of similar products which are marketed (e.g., market prices of agricultural products, market housing rentals). However, where such market information is lacking, non-market goods and services are valued at cost (e.g., government services).

United Nations System of National Accounts (SNA)

The revised SNA constitutes Version I of the SEEA. The parts of the SNA that form the conceptual basis for the development of the SEEA are the supply and use table of produced goods and services and the non-financial asset accounts, which includes both produced (man-made and natural) and non-produced natural assets. These two segments of the SNA are described below.

Supply and Use accounts

The SNA supply and use accounts record production activities which took place during the accounting period. The total production by the economy, augmented by production from the rest of the world (i.e., imports) is then available to be used to satisfy intermediate and final demands. The supply and use accounts attempt to measure these transactions, recording them from both transactors' points of view. The supply-use accounting identity is:

$$(1)\ P - M = C_i + C + I + Ex$$

where P = production, M = imports, C_i = intermediate consumption, C = final consumption, I = gross capital formation (or Investment) and Ex = exports. A second identity defines gross product or value added (Y) as the difference between total production (P) and intermediate consumption (Ci):

$$(2)\qquad Y = P - Ci$$

When this income identity is substituted into (1), the familiar domestic-product identity emerges:

$$(3)\qquad Y = C + I + (EX - M)$$

Asset Accounts

The SNA asset accounts record all stocks and flows associated with changes in those stocks which are defined as part of the economy. Valuation is normally restricted to market values, although certain nonmarketed goods and services are included which are valued either on the basis of prices of similar products and services that are marketed (e.g., owner occupied housing) or at cost (e.g., government services). Relationships between the environment and the economy are viewed from an economic perspective only, i.e., the environment is viewed in terms of its use in economic production. However, a key criticism of conventional accounting is that the use of environment is not treated as a cost and so is not reflected in summary measures such as Net Domestic Product (NDP).

The SNA asset accounts categories include opening and closing stocks, capital formation, other changes in assets, and revaluation (holding gains/losses). These accounts explain changes between opening and closing stocks associated with flows during the accounting period. For both produced and nonproduced economic assets, the balances are defined as follows:

$$(4)\ K_1 = K_0 + I - Depr. + OC + Rev$$

where K_1 = closing stocks, K_0 = opening stocks, I = gross capital formation Depr. = consumption of fixed capital (or depreciation), OC = other changes in assets, and Rev = revaluation (i.e., holding gains or losses).

Certain elements of the capital formation account (i.e., gross fixed capital formation and consumption of fixed capital) intersect with the supply and use accounts described above. Gross capital formation refers generally to produced assets, although it also includes some additions to non-produced assets (e.g, reforestation). Gross capital formation is included in calculations of GDP as shown in equation (3). Subtracting consumption of fixed capital from both sides of equation (3) yields the net domestic product identity:

$$(5)\qquad Y_n = C + I_n + (Ex - M)$$

where Y_n = net product and I_n = I - depr. or net capital formation. Net domestic product may be considered a measure of Hicksian income (i.e., the maximum amount of income a nation can consume which will leave the nation as well off at the end of the period as it was at the beginning of the period). Hicksian income is thus “sustainable” and many argue that measures such as NDP represent a first step in developing sustainable development indicators. Consequently, many in the environmental policy community have focused on “greening” the NDP.

During the recent revisions to the SNA (United Nations, 1992) it was recognized that a more detailed description of assets was required. This was accomplished in part through the expansion of the asset boundary. In the revised SNA, the definition of assets was expanded to include all assets over which ownership rights can be enforced and which provide economic benefits to their owners. Conceptually, the asset boundary includes natural assets, both those which are owned and managed or cultivated directly by humans and those which are owned but not managed or cultivated. Within the revised SNA asset boundary, two types of nonfinancial assets can be distinguished: 1) produced assets and 2) non-produced assets. Produced assets may be man-made assets (e.g., buildings, equipment, inventories of harvested crops) or developed natural assets (e.g., cultivated biological assets such as livestock for breeding, fish stocks, orchards, and timber tracts). Non-produced natural assets include land, subsoil assets, uncultivated biological assets such as wild fish and forests, and water resources.

The other changes in assets account is particularly important for environmental analysis since it contains information on the impact of the environment on natural and other assets. This account contains economic appearance of non-produced assets (e.g., additions to proven oil reserves, additions to timber reserves through the logging of virgin forests), natural growth of uncultivated biological resources, and economic disappearance of non-produced assets (e.g., depletion of subsoil assets and forests, degradation of non-produced assets). However, these entries are not recorded as part of the production accounts and therefore do not affect the calculation of GDP or NDP. For example, if a site is degraded because it is used to dispose of solid waste, the market price of the natural asset (land) may reflect this degradation which would be recorded as other changes in assets. Essentially this reduction in the market price of the land is not considered a cost of production.

The use of the terms “economic appearance” and “economic disappearance”, especially with respect to non-produced assets, reveals one difficulty facing conventional national accountants. Natural resources “appear”, not as a result of economic activity but rather as a result of ecological processes. Consequently, they are considered “free gifts of nature”. Of course since they are “free" they are presumably available in unlimited quantities. Expenditures to develop these gifts (e.g., unproved mineral reserves can be developed into proved mineral reserves) are recorded as gross capital formation and the natural resource is considered a non-produced economic asset. What is not clear is how to record the additions to (appearance of) the natural resource stock itself. Similarly, these resources “disappear” as they are used up. Unlike appearance, however, disappearance is clearly tied to economic activity, which suggests that an entry to reflect this depletion should appear in the production accounts in a way that parallels depreciation of man-made capital. Initially, the U.S. national accounts did include such entries beginning in 1942. Dissatisfaction with this asymmetric treatment of natural resources (i.e., entries for depletion but no entries for additions), led to the removal of depletion from the national accounts in 1947.

A simplified SNA supply and use account with asset balances is depicted below based on these accounting identities and protocols.

SNA Supply and Use Accounts with Asset Balances for Economic Assets
(SEEA Version I)

				Economic Asset Balances	
Element	*Production*	*Rest of World*	*Final Consumption*	*Produced Assets*	*Nonproduced Assets*
Open Stocks				K_0.p	K_0.np
Economic Supply	P	M			
Economic uses	*Ci*	Ex	c	I.p	I.np
Gross Product	Y				
Capital consumption (Depreciation)	Depr.			Depr.	
Net Product/ Net Capital Formation	Yn			In	
Other Changes in Assets				OC.p	OC.np
Holding gains/losses				Rev.p	Rev.np
Closing Stocks				K_1.p	K_1.np

United Nations System for Integrated Environmental and Economic Accounting (SEEA)

In general, the SEEA advocates following principles and rules established for national economic accounting systems. For example, the SEEA observes the SNA'S production boundary, uses SNA methods of analyzing costs and outputs and incorporates the same accounting identities between supply and use of products and between value added and final demand. This allows the integration of environmental information into established economic accounting systems. The possibility of extending the framework to include environmental welfare effects (e.g., damages associated with the impairment of human, health, recreation, and other aesthetic values) is also acknowledged.

Distinguishing the boundary between economic and ecological systems is difficult and subject to a substantial amount of controversy. From an ecological point of view, the economy is part of nature; integrated accounting systems should thus determine ecologically sound balances between nature and human activities. From an anthropocentric (economic) point of view, the natural environment is considered only in terms of how it affects human beings, especially in the context of economic activities; integrated accounting systems should thus retard those natural functions which are exploited by human beings. The SEEA attempts to reflect a synthesis of the ecological and economic points of view. That is, the economy is not viewed solely as part of the environment and the environment is not viewed solely in terms of its economic usefulness. Several, often complementary, approaches to natural resource and environmental accounting are presented in the SEEA with the aim of developing compatible data sets which can be used to analyze environmental-economic relationships.

Finally, most accountants believe that it is important to make a distinction between accounting and analysis. In their view, the accounts should rely to the maximum extent possible on observed data and not on imputations or modeling. In many cases, modeled output is used to characterize the environment. This raises the question whether environmental modeling should be included in the accounts (i.e., considered as a generator of quantity and quality data for the accounts) or should such modeling be considered analysis which uses the data contained within the accounts. For example, the U.S. National Income and Product Accounts contain imputations (modeling) for the value of owner-occupied housing and the national accounts data is used in macroeconomic models of the U.S. economy (e.g., DRI, Wharton, Jorgenson-Wilcoxen, etc.).

Implementation of the SEEA

The SEEA is designed to be as comprehensive as the data will allow, while maintaining consistency within the system and close linkage with conventional national economic accounts. Given the lack of consensus on environmental accounting methods and data constraints, implementation of the SEEA requires a flexible, "building blocks" approach. Beginning with the revised SNA (Version I of the SEEA), four stages of implementation are described in the SEEA Handbook (UNSO, 1993). These are:

1. Reformatting and disaggregation of the SNA (Version II),
2. Physical accounting (Version III),
3. Imputed environmental costs, using alternative valuation methods (Versions IV. 1-3), and
4. Possible extensions (Versions V.1-6), including extending the production boundary to include household activities and environmental services produced by nature, and input-output analysis.

The fourth stage involves approaches which remain controversial and for which there is no general consensus on their feasibility and desirability. The SEEA handbook recognizes that they may become important for particular analyses and briefly covers these possible extensions to the SEEA. We do not discuss them further in this paper.

In Version II, environment-related monetary flows within the production and asset accounts are identified and further elaborated. The relevant portions of the supply and use tables of produced goods and services are disaggregation with respect. to the actual expenditures for: 1) prevention and restoration of negative environmental impacts associated with economic activities, as defined in the draft classification of environmental protection activities, and 2) for mitigating the repercussions associated with a degraded natural environment which encompasses avoidance activities (e.g., installation of water purifiers) and treatment of damages caused by environmental deterioration (e.g., purchase of additional health and cleaning services). Together the actual expenditures associated with environment-related activities are called actual environmental costs and comprise environmental protection costs and repercussion costs. All actual environmental costs are borne by the economic units financing the expenditures, although they may not have caused the environmental deterioration.

The SNA classification of non-financial assets is modified to more explicitly reflect natural assets. In particular, land is broken down to separately identify soil and air is introduced as an asset. although no monetary value is applied to it (i.e., it is to be used in physical accounting and in estimating imputed environmental cost. As noted above, within the SNA non-financial asset accounts. the other changes in assets is particularly important.

The data in other changes in assets are grouped into categories of depletion, degradation (as reflected in market values), other accumulation (additions to mineral reserves, natural growth of non-cultivated biota, etc.), and other volume changes (i.e., changes which are due to political, natural or other non-economic causes which affect the economic system). Thus Version II of the SEEA (shown below) will look much like the SNA presentation with additional entries detailing the environment-related information.

SEEA Version II. Supply and Use Accounts with Asset Balances for Economic Assets, Elaboration of Environmental Protection Costs, Environmental Repercussion Costs, and Elements of Changes in Other Assets

				Economic Asset Balances	
Element	*Production*	*ROW*	*Final Consumption*	*Produced Assets*	*Nonproduced Assets*
Open Stocks				K_0.p	K_0.np
Economic Supply Excluding EP, ER	P.ex.EP	M			
EP Activities	**P.EP**				
ER Activities	**P.ER**				
Economic uses Excluding EP,ER	*Ci.ex.EP-ER*	Ex	C.ex.EP-ER	I.p.ex.EP-ER	I.np
EP Expenditures	**Ci.EP**		**C.EP**	**I.p.EP**	
ER Expenditures	**Ci.ER**		**C.ER**	**I.p.ER**	
Capital consumption (Depreciation) Excluding EP,ER	Depr.ex.EP-ER			Depr.ex.EP-ER	
EP assets	**Depr.EP**			**Depr.EP**	
ER assets	**Depr.ER**			**Depr.ER**	
Net Product/Net Capital Formation	*Ynl*			*Inl*	
Other Accumulation					**OA.np**
Depletion					**Depl.np**
Degradation					**Degr.np**
Holding gains/losses				Rev.p	Rev.np
Closing Stocks				K_1.p	K_1.np

Version III focuses on a physical accounting of the environment. The SEEA physical accounts are based on the concepts of materials/energy balances and natural resource accounting. Materials/energy balances show the material input from the natural environment into the economy, the use and transformation of these inputs in economic activities, and their return to the environment. Natural resource accounts focus on natural resource stocks, such as biological, subsoil, and water assets, which are valuable from an economic point of view as well as changes in the quantitative and qualitative characteristics of those stocks. As noted previously, the SEEA does not attempt to provide information on the transformation processes which take place entirely within the natural environment. Nor does the SEEA provide a complete assessment of the transformation processes within the economy. Rather, the physical information in the SEEA is limited to recording flows from natural assets to the economy and residual flows back to the environment at an aggregate level.

An additional limitation is the lack of spatial detail in the SEEA natural asset accounts (i.e., the SEEA is intended to be a national system of accounts). Detailed regional-level accounts, based on various graphical information systems, are needed to adequately describe the natural environment. These regional accounts could be linked to the SEEA to provide a national picture, although it remains to be seen whether such aggregate accounts yield useful information for environmental policy purposes. Similarly, it would be desirable to describe the flows of natural resource inputs, products, and residuals in a detailed breakdown by type of input and output. Unfortunately, existing data on production and consumption activities is usually not sufficiently detailed to provide this information.

Flows of residuals (pollution) are recorded at the point in time they are generated by a particular economic activity. Similarly, the impact of these residuals on ambient conditions are shown only as environmental quality changes over the time period covered by the accounts. The impacts of many long-term environmental problems such as global climate change, stratospheric ozone depletion, and accumulation of toxics will thus be recorded when they occur. For example, the SEEA would show emissions of greenhouse gases which occurred in the last year, the impacts of climate change would not be recorded until they occurred, which may not happen for many years. The SEEA is not intended to record or predict future impacts and alone it will not be able to address many of the concerns surrounding sustainable development. Rather, the SEEA is designed to provide data to ecological-economic models which would capture the dynamics of environmental transformations.

Using materials/energy balances and natural resource accounts for the physical accounts of the SEEA does not mean that SNA concepts have to be modified. Linkages between the monetary data in the SNA and the physical data in the SNA can be accomplished by ensuring that corresponding items in the two systems can follow the same definitions and classifications. Alternatively, bridging matrices which applied compatible concepts at the interface between the SNA and the physical data in the SEEA could be used. This procedure would be necessary when there is no direct counterpart in the SNA for the physical data in the SEEA.

Presentation of environmental-economic interactions in only physical terms would severely limit the usefulness of the SEEA. If the SEEA is to truly integrate economic activities and environment effects, the relative importance of each needs to be determined and results aggregated, which in turn requires a common metric. Version IV of the SEEA introduces imputed environmental costs in order to provide a more comprehensive picture of environmental and economic interactions. Three different valuation methods are proposed:

1. Costs borne at market values by industry (Version IV.1),
2. Costs caused at maintenance costs (Version IV.2), and
3. Costs borne at market values by industry and at contingent values by households (Version IV.3)

Each approach involves imputing additional costs to economic activities, either through the rearrangement of existing information in the SNA (Version IV. 1) or by estimating costs using hypothetical control costs or other non-market (e.g, CV) methods. An additional asset category, non-produced environmental assets, is also appended to the Version I SEEA table.

Version IV.1. Imputed environmental costs at market values

This version of SEEA involves shifting the depletion and degradation items in the other changes in asset accounts into the production accounts. That is, the reduction in natural asset market values associated with depletion and degradation are treated as a cost. Corresponding positive cost items are imputed to the economic agents which cause the depletion and degradation and appear in the production column. In general it will be difficult to identify changes in market values of natural assets due to degradation. The accumulation items are shifted into the capital formation account and a parallel negative counterpart appears in non-produced environmental assets (OA.env). This element is intended to reflect the transfer of environmental assets and their services to economic activities. Two Environmentally adjusted net Domestic Product measures (EDP1) can be defined as follows:

$$\text{(6)}\quad \mathbf{EDP1 = C + (I}n\mathbf{ + OA.np - OA.env - Depl.np) + (Ex - M)}$$
$$\mathbf{= C + (I}n\mathbf{ - Depl.np) + (Ex - M)}$$

$$\text{(7)}\quad \mathbf{EDP2 = C + (I}n\mathbf{ + OA.np - OA.env - Depl.np - Depr.np) + (Ex - M)}$$
$$\mathbf{= C + (I}n\mathbf{ - Depl.np - Degr.np) + (Ex - M)}$$

Version IV.2 Imputed environmental costs at maintenance costs

Maintenance costs have been discussed in the context of costs caused above. The use of maintenance costs reflects a conservationist view toward the environment. Given the uncertainty with respect to long-term environmental problems and the potential for irreversible damage a high degree of risk aversion may be prudent. In this situation many have argued for, at a minimum, the maintenance of the current level of environmental quality. Maintenance mats are also closely related to sustainable development concepts, in that they measure the costs that would have been required to keep the natural environment intact during the accounting period. These costs are hypothetical since an actual use did take place which affected the environment. Of course, calculation of depreciation of freed assets is also hypothetical since it is not know whether actual investments will be made which will maintain the capital stock. Using the maintenance coat approach in combination with traditional depreciation measures allows for both the maintaining of income flows and preserving the natural environment intact.

Ideally determination of maintenance costs should be based on: 1) data which describes physical changes in the natural environment caused by economic activities, 2) analysis of ambient conditions to determine whether depletion or degradation is occurring,
3) determination_of non-damaging (sustainable) environmental quality levels (e.g., quantitative standards), 4) activities (e.g., discharge reductions) needed to meet these standards and 5) an estimate of the costs associated with these activities. Several types of actions aimed at preventing or restoring environmental deterioration could be undertaken.
Depletion of natural assets can result in a reduction in economic production. Reducing economic production or altering consumption patterns can reduce the generation of residuals. Changes in the composition of output, substitution of inputs, technological change and environmental protection activities can all prevent deterioration or restore the natural environment. Calculation methods will depend on the specific activity considered. For example, in the case of pollution, imputed environmental costs could be based on reductions in net value added or household consumption expenditures, substitution costs and environmental protection costs. Estimated degradation costs should be based on the most efficient methods for meeting environmental standards. One alternative for imputed depletion costs has been proposed by El Seraphy (1989), which allocates part of the operating surplus for alternative investment.

Imputed environmental costs are associated with the environmental media which directly receive the residuals generated by economic activities. The ultimate destination of these residuals is not taken into account. For example, acidic deposition and consequent damages to terrestrial and aquatic ecosystems due to the emissions of sulfur oxides into the atmosphere by electric utilities are not recorded. Similarly, unless transported by economic agents outside the territorial boundaries of the country, the transfer of residuals to another countries is not considered. In Version IV.2 of the SEEA, there are additional entries, particularly degradation of environmental assets.

Version IV.3 Imputed environmental costs at market and contingent values

The SEEA handbook raises several concerns regarding CV and its use in environmental accounting. The SEEA provides only a generic framework within which further research, discussion, and experimentation with CV and related accounting procedures are to be explored. While the SEEA does not emphasize the use CV, neither does it dismiss the technique outright.

The SEEA suggests that CV questions be posed in terms of specific consumption activities and expenditures that households would be willing to forego. The SEEA also notes that the number and order of environmental concerns raised may influence respondents willingness to reduce consumption. To deal with this problem, the SEEA recommends asking for total willingness to forego consumption as a first step and then ask for the proportion that respondents would allocate to alleviating specific environmental-concerns. Finally, households should be willing to reduce their consumption by at least actual repercussion costs, suggesting that CV studies should focus on respondents additional willingness to pay beyond the defensive expenditures they currently make. An alternative approach would be to present households with substitute consumption patterns and activities which are less environmentally damaging. Differences in expenditures associated with the offered change in activities could be used to represent the value of lost environmental quality.

Imputed repercussion costs, based on contingent values, are recorded as reduction in individual consumption and as additional costs of economic activities of households. An extended concept of household production, as discussed in Version V, would be needed to develop a comprehensive picture of the distribution of imputed repercussion costs. To avoid extending the production boundary of the SNA to include household production, a new row (Shift of environmental costs) is introduced and imputed repercussion costs are shifted from consumption to domestic production of industries. This shift allows the SEEA to fully account for the social cost of environmental degradation.

The table below is based on Version IV.2 and shows the types of changes that could be made to the basic SEEA. Corresponding entries in the additional column, Non-produced Environmental Assets (OA.env, Depl.env, Degr.env) and in the production and economic asset accounts can thus explicitly reflect interactions between environmental assets and economic activities. Corresponding definitions for EDP1 and EDP2 would be:

(8) EDP1 = C + (In - Depl.np - Depl.env) + (Ex - M)

(9) EDP2 " C + (In - Depl.np - Depl.env - Depr.np - Degr.env) + (Ex - M)

Pilot Implementation of SEEA for the U.S.

This section outlines the environmental components of the SEEA. These components can quickly add up to a dizzying array of rows and columns of data to any reader unfamiliar with the certain conventions of economic accounting in general and the specific organization of the SEEA. To make it easier to understand the final table that consolidates all of the major SEEA components achieved in this pilot implementation, the description in this section proceeds component by component, building up the table until all of the pieces are represented. Keeping this in mind may help the reader proceed through this demonstration more effectively. Before the final, consolidated table, four tables are presented. These tables focus on the following in turn: disaggregation of the accounts to show the role of environmental protection in the economy, adjustments to NDP to reflect the depletion of natural resources (EDP1), the linkage of EDP1 to asset balances for natural resources, and adjustments to NDP to integrate environmental degradation into the accounts (EDP2) and the linkage of EDP2 to balances for environmental assets.

Disaggregation of Economic Accounts

Information that is already in the accounts can provide insights into the role that the environment and environmental protection play in economic activity. For example, using input-output analysis and by isolating environmental protection expenditures currently undertaken by economic agents it is possible to illustrate the contributions of an environmental protection sector to each of the conventional macroeconomic aggregates.

In the shaded area of Exhibit A the contribution of such a instructed environmental protection industry to U.S. value-added (GDP) is indicated, from the work of Nestor and Pasurka (1994). Although the level of environmental protection effort by the U.S. has commonly been gauged by comparing environmental protection expenditures directly to GDP, such a comparison is misleading because the two measures are not on equivalent terms. Using the value-added estimate for the environmental protection is more appropriate. In 1987, the environmental protection sector's share of value-added was approximately 0.6% ($28 billion).

SEEA Version IV.2. Supply and Use Accounts with Asset Balances for Economic Assets, Environmental Protection, Contingent Valuation of the Repercussion Costs of Households and Capital Accumulation at Maintenance Values

Element	*Prod*	*ROW*	*Final cons*	*Economic Asset Balances*		*Non-produced Environmental Assets*
				Produced Assets	*Non-produced Assets*	
Open Stocks				$K_0.p$	$K_0.np$	
Economic Supply	P	M				
Economic uses	Ci	Ex	c	I.p	I.np	
Other accumulation					OA.np	OA.env
Capital consumption (Depreciation)	Depr.p			Depr.p		
Depletion	Depl.np Depl.env				Depl.np	Depl.env
Environmentally adjusted net product: EDP1	EDP1					
Degradation	Degr.np Degr.env				Degr.np	Degr.env
Environmentally adjusted net product: EDP2	EDP2					
Other Changes in Volume				OC.p	OC.np	OC.env
Holding gains/losses				Rev.P	Rev.np	
closing stocks				$K_1.p$	$K_1.np$	

Exhibit A.
Environmental Accounts for the United States, 1987
Environmental Protection Expenditures Separately Identified
($ Millions)

	Economic Activities				
				Economic	Assets
	Reduction	Rest of World	Final Consumption	Reduced Assets	Non-Prod. Assets
Opening Assets				$11,571,629	$479,025
Fixed Assets				$10,535,200	
Inventories				$1,030,700	.
Timber				$5,729	
Oil					$166,527
Natural Gas					$138,209
					$155,678
					$18,611
					K0.np.ec.h2o
Economic Supply	$8,042.812	$507,100			
Economic Uses	$3,502.812	$364,000	$3,933,800	$749,300	
Product GDP	$4,540,000	($143,100)	$3,933,800	$749,300	
Env. Protection	[28,172]				
Depreciation	$502,200			($502,200)	
Net Product: NDP	$4,037,800	($143,100)	$3,933,800	$247,100	

EDP1: Adjusting NDP to Reflect Natural Resource Depletion

EDP1 is a measure of NDP that has been adjusted for the depletion of marketed natural resources. In this pilot implementation for the U. S., the focus is on six natural resources. They are timber, oil, natural gas, coal, selected minerals, and water. These six were judged to be important because of their value or the sheer volume of their use in economic activities.

The shaded area of Exhibit B highlights the new components added to measure the depletion of these six natural resources and the resulting estimate of EDP1 in 1987. These figures show how natural resource adjustments in national economic accounting can present a more pessimistic view of the economy's performance. For the U.S., the revision is small, only 0.8%. Even though even a small difference in measures of output can accumulate to a large amount in absolute terms, this revision still appears to be minor. This finding is not surprising for the U.S. because of the diverse nature of the economy. Nonetheless, it has been argued that this revision results m a dramatic downward revision in the rate of return that can be derived from national economic accounts for the associated industries (Bureau of Economic Analysis 1994). This result may be informative for national economic policymakers but it probably is not new information for private investors in these industries who should already be aware that natural resource production or retraction depletes the assets of the industry. Given the results of this pilot case, it appears that including natural resource depletion in U.S. national economic accounts matters for keeping them as complete and comprehensive as possible even if the results do not appear to be significant. On this point, others

Exhibit B.
Environmental Accounts for the United States, 1987
Resource Depletion
($ Millions)

	Economic Activities		
	Production	Rest of World	Final Consumption
Opening Assets			
Fixed Assets			
Inventories			
Timber			
Oil			
Natural Gas			
Coal			
Minerals			
Water			
Economic Supply	$8,042,812	$507,100	
Economic Uses	$3,502,812	$364,000	$3,933,800
Product: GDP	$4,540,000	($143,100)	$3,933,800
Env. Protection	[28,172]		
Depreciation	$502,200		
Net Product: NDP	$4,037,800	($143,100)	$3,933,800
Environmental Uses			
Timber Harvests	$130		
Timber Net Growth	($159)		
Oil Extraction	$17,793		
Oil Discoveries			
Nat. Gas Extraction	$11,617		
Nat. Gas Discoveries			
Coal Mining	$532		
Coal Discoveries			
Mineral Extraction	$824		
Mineral Discoveries			
Water Extraction	$10,869		
Water Returned	($7,577)		
Net Product: EDP1	$4,004,071	($143,100)	$3,933,800

may disagree. Having the information publicly and widely available, as they would be if the SEEA were fully implemented, is consistent with an important function of the accounts - to provide access to a common set of data so that many users can evaluate them and draw their own conclusions.

Computation of EPD1

The computation of each of the depletion charges presented in Exhibit B is described briefly below. Greater-details are currently available only in an unpublished document (Abt Associates, 1994).[2] In all circumstances, a net price approach was applied to the change in the resource stock in question. This approach requires information on the opening and closing stocks of the resource. to infer physical depletion, and an estimate of the net price or its analogue. Each resource is considered in turn below.

The growing stock of timber for 1987 was interpolated from U.S. Forest Service inventories conducted in 1986 and 1991. Stocks grew from 756 billion cubic feet to 762 cubic feet. To value the stocks and harvests, information from competitively bid sales of U.S. Forest Service timber was used. These values exclude production costs and therefore were taken as estimates of net prices. The opening and closing stocks of timber were valued at $5.729 billion and $5.758 billion respective y. The increase in the stock, approximately $29 million, reflects the fact that net natural growth ($159 million) exceeded removals ($130 million) by this amount. The net differences is subtracted from NDP to calculate EDP1.

Information on crude oil and natural gas reserves and production were obtained from the U.S. Department of Energy's Energy Information Administration (EIA, 1988). The net prices of oil and gas were derived from estimates of "resource values," a net income concept, developed for 1981 by Stauffer and Lennox (1984).[3] A central assumption for this derivation was that resource values as a proportion of revenues were constant between 1981 and 1987. In the calculation of EDP1, only the depletion of oil and gas stocks is considered.[4] Based upon the net price method, oil extinction was valued at $17.8 billion and natural gas extraction at $11.6 billion. Together they account for 87% of the depletion that constitutes the difference between conventional NDP and EDP1.

Statistics on coal production and reserves were derived from EIA and U.S. Department of Commerce data (EIA, 1989; U.S. Department of Commerce, 1989). As was the case for oil and gas, only the extraction of coal figures in the calculation of a depletion charge against conventional NDP. In the absence of better information on production costs, an estimate of the resource value of coal in 1987 was calculated from industry accounting data. Net revenue for the coal industry was estimated by adding operating income and coal production taxes and subtracting income taxes from their sum. The resulting depletion charge for coal was $532 million.

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[2] The authors would like to acknowledge the capable assistance of Todd Aagaard in the compilation of the EDP1 data.

[3] Their estimate of resource value is the sum of lease and land acquisition of non-producing acreage, taxes other than income taxes, royalties, and windfall profits taxes.]

[4] As will be shown below, the SEEA treats discoveries in the asset balances, not in the measures of flow. The logic is that no production was involved since these are nonrenewable resources.

Statistics on production and reserves of more than eighty minerals are routinely collected by the Bureau of Mines (1988). Some production occurred for the majority of these minerals in 1987 but it was not possible to characterize the depletion of each one because of data constraints. For example, to preserve confidentiality, the Bureau of Mines did not release data on the domestic production of fourteen minerals. Furthermore, the Bureau estimated certain essential financial information only for selected minerals. For these minerals, Bureau of Mines' estimates of taxes and royalties per unit of minerals, averaged over facility lifetime with a 15% discount rate, were applied to the 1987 prices of the minerals to calculate their depletion charge. The resulting depletion charge for twelve minerals was $824 million.[5]

The U.S. Geological Survey (USGS) publishes estimates of water use every five years. For eight categories of users (domestic, commercial, irrigation, livestock, industrial, mining, and thermoelectric power), the USGS estimates total use and consumptive use. Consumptive use means that the water used dissipated, was incorporated into products or crops, consumed by humans or livestock, or otherwise removed (USGS, 1988). For this pilot study, the physical depletion of water was derived from net water use - the difference between water extinction (from surface or ground sources) and water returned. Data on water prices from the 120 largest metropolitan areas (Arthur Young & Company, 1988) and on government capital and operating and maintenance expenditures from the Department of Commerce (reported in EPA, 1990) were used to calculate net water prices. The average net. price of publicly-supplied water, weighted by categories of use, was $0.09 per 1000 gallons. The estimated depletion of water was $3 billion, reflecting the difference between water extraction ($10.9 billion) and water returned ($7.9 billion).

Linkage of EDP1 to Asset Balances

An important feature of SEEA is its characterization "of the contribution of the environment to economic activities. This contribution is depicted as a transfer from the environment to the economy. Natural resources that have not yet become "economic" (having a net price greater than zero) are defined as being environmental assets. Only once these natural resources are proven, which here is equated with being "discovered" do they become economic. At this point, they are transferred from the environmental asset balance to the economic asset balance. While conventional accounting would show a gain in wealth with the discovery of a natural resource- like oil, the SEEA does not. Because the discovery is treated as a transfer, overall wealth stays constant as long as none of the oil is depleted. For example, in 1987 the discoveries of oil were worth $20 billion. In Exhibit C, this discovery is shown as a deduction of oil from the environment asset balance and an increase in non-produced economic assets.

It has already been demonstrated that SEEA only the depletion' of oil and other non-producer natural resources is considered in adjusting NDP. The balance sheets for non-produced assets also incorporate this depletion. So, for example, the $17.8 billion depletion charge for oil that was included in the calculation of EDP 1 is also included in the asset balance for oil. Overall, in 1987, there was a growth in oil as an economic asset of $2.2 billion given discoveries and depletion of $20 billion and $17.8 billion respectively. Natural gas is shown in analogous terms, with a transfer from the environment of $8.4 billion. Natural gas, in contrast to oil, declined as an

[5] The twelve minerals were aluminum, asbestos, barite, copper, gold, lead, molybdenum, phosphate rock, potash, silver, sulfur, and zinc.

Exhibit C.
Environmental Accounts for the United States, 1987
Resource Depletion
($ Millions)

	Economic Activities					Environment
				Economic Assets		Non-Prod.
	Production	Rest of World	Final Consumption	Produced Assets	Non-Prod. Assets	Environment. Assets
Opening Assets				$11,571,629	$479,025	
Fixed Assets				$10,535,200		
Inventories				$1,030,700		
Timber				$5,729		
Oil					$166,527	
Natural Gas					$138,209	
Coal					$155,678	
Minerals					$18,611	
Water					K0.np.ec.h2o	
Economic Supply	$8,042,812	$507,100				
Economic Uses	$3,502,812	$364,000	$3,933,800	$749,300		
Product: GDP	$4,540,000	($143,100)	$3,933,800	$749,300		
Env. Protection	[28,172]					
Depreciation	$502,200			($502,200)		
Net Product: NDP	$4,037,800	($143,100)	$3,933,800	$247,100		
Environmental Uses						
Timber Harvests	$130			($130)		
Timber Net Growth	($159)			$159		
Oil Extraction	$17,793				($17,793)	
Oil Discoveries					$20,066	($20,066)
Nat. Gas Extraction	$11,617				($11,617)	
Nat. Gas Discoveries					$8,400	($8,400)
Coal Mining	$532				($532)	
Coal Discoveries					$0	$0
Mineral Extraction	$824				($824)	
Mineral Discoveries					$0	$0
Water Extraction	[illegible]				($10,869)	
Water Returned	[illegible]				$7,877	
Net Product: EDP1	[illegible]	($143,100)	$3,933,800	$247,129	$473,733	($28,466)

economic asset, by $3.2 billion. For coal and minerals no discoveries took place to of offset the depletion charges recorded in the calculation of EDP1.

The changes in water resources are characterized solely within the economic non-produced asset balances. This classification reflects the explicit judgement that water is a controlled resource rather than one that exists in the environment. This specification raises an important classification issue. To date, neither the applications of the SEEA nor the SEEA Handbook provides unambiguous guidance on how to classify a natural resource like water. The extent to which it exists in the economic or the environment realm is a question that environmental economics can aid national accountants in answering.

In closing this discussion of natural resource commodities, it is useful to emphasize that focusing on natural resource depletion provides an incomplete picture of the changing status of natural resource assets. This shortcoming applies as well to several past efforts to adjust GDP for natural resource_depletion. The calculation of EDP1 in SEEA does not complete the picture, since it ignores the discovery of non-produced natural assets (but not the production of natural resources like timber). Only in the SEEA asset balances, both economic and environmental, is there a complete picture of the overall change in wealth. In this respect, despite the classification issues raised earlier, the SEEA represents an improvement in the integration of economic and environmental perspectives for natural resource commodities.

Environmental Degradation, NDP Adjustments, and Asset Balances

In the larger scheme of things, the natural resource adjustments to NDP reflected in EDP1 were not that large. Environmental adjustments are more significant under this particular application of SEEA. EDP2, shown within the shaded area of Exhibit D, is the result of adjusting conventional NDP to reflect the costs of controlling residual pollution. The resulting estimate is $3.7 trillion, or 91% of conventional NDP. Since the unabated pollution is characterized as a loss of environmental assets, overall net capital formation is not only much smaller than under conventional economic accounting it is negative. This implies a decline in the overall capital (man-made and natural) of the U.S. There is a growth in produced assets of $247 billion a decline in economic non-produced assets of $5 billion, and a decline in environment non-produced assets of $328 billion summing to a decline of $86 billion. The decumulation of capital stock causes tremendous concern when ordinary capital is involved. If one accepts the definition of environmental assets as part of the capital stock from which we derive important goods and services, then this decumulation raises the possibility that something socially undesirable is occurring. Taking these estimates at face value, net manmade capital accumulation needed to be about 35% higher to avoid a loss in national wealth.

Calculation of EDP2

In this U.S. pilot study of SEEA the degradation of environmental resources is valued using a maintenance cost approach. For each of three environmental media (land, water, and air), the costs of controlling the existing level of pollution became the basis for adjusting NDP/EDP1 to derive EDP2. The level of assumed control is complete meaning that the aggregate maintenance costs presented here suggest the level of resources necessary to eliminate this pollution entirely.

This assumption may appear to be an extreme one. It does however illustrate the type of decision that anyone implementing this SEEA version has to make. The SEEA developers provide little definitive guidance on how to specify this parameter. In effect, it represents one's assumptions about the level of pollution with which no damages are associated. Environmental policymakers, much less national income accountants, would be hard pressed to make a clear decision, except possibly through the use of extensive modelling.

While the zero-pollution assumption may result in an unusually high estimate of the maintenance costs associated with the level of pollution in 1987, the estimated unit costs themselves tend to offset this tendency. For land and air pollution, unit costs were estimated using average costs of control experienced in the past. These costs would probably be lower than the marginal costs of controlling existing pollution. Water pollution may be the single but large exception. Unit costs of controlling conventional water pollutants were derived from recent surveys of wastewater