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EFFICIENCY AND SUSTAINABILITY IN IMPERFECT MARKET SYSTEMS

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Economists have thus far placed primary emphasis on market and market-like solutions to environmental problems. This is an outgrowth of mainstream theory, which implies that, under suitable conditions, markets improve economic efficiency. Much has been accomplished by application of the market-efficiency perspective. However, as the first major section of this paper shows, when time and future generations are explicitly considered, an important conclusion follows: an efficient economy is not necessarily a sustainable economy. Despite its accomplishments, an environmental economics that assumes efficiency to be the sole goal of environmental policy may not be adequate to assure that future generations will have economic opportunities comparable to those of the current generation. Environmental economics will need to look beyond simple efficiency prescriptions if it is to address issues of sustainability.

Theoretically speaking, efficient, sustainable economic paths could be achieved by reallocation of capital and environmental resource endowments across generations. However, for reasons discussed below, practical implementation of this prescription is not easy. The second major section of the paper focuses on practical steps to help assure that economies are not only more efficient but also more sustainable. A strategy for addressing biodiversity issues based on the concept of the safe minimum standard of conservation will illustrate the approach. Also, a tax on resource exploitation will be considered. Such a tax would promote sustainability by discouraging economically marginal uses of resources and providing money for activities that will improve the position of future generations. Research is needed to further explore how economic activities in both the private and public sectors can be circumscribed to enhance sustainability.

This paper is written for both economists and non-economists. The theoretical principles applied are well accepted within mainstream economics. Hence, a technical treatise is not required. Still, economists need this paper because not enough attention has been given to these principles as environmental economics has evolved. We have tried to keep the exposition as simple and free of jargon as possible. Those with more economic background will find what we have written more accessible, but those with modest training in microeconomics should be able to follow the gist of the message. We are particularly interested in reaching those who are ready to abandon economics as irrelevant or even inimical to sustainability. Perhaps a new economic paradigm is needed to address current environmental issues, but we are not convinced. This paper shows that the existing paradigm provides important practical insights.

THE QUEST FOR AN EFFICIENT ECONOMY

Efficiency and Markets

Economic efficiency requires complex incentives and countless signals to coordinate production and consumption activities. Markets are increasingly appreciated as having great potential for creating such incentives and conveying such signals. Not simply in the U.S., western Europe and Japan, but in eastern Europe, in nations of the former Soviet Union, in the developing countries, and even in countries like China that continue to identify themselves ideologically with communism, market mechanisms are being increasingly harnessed to promote economic efficiency.

The economic argument for efficiency is straightforward: if taking a given action will make one or more members of society better off, without leaving any other member of society worse off, then why not do it? In economic theory, efficiency would be achieved if it is impossible to reallocate natural, labor, or capital resources or intermediate or final goods and services so as to make at least one person better off without making someone else worse off.

Markets promote efficiency by providing opportunities for individuals to achieve mutually agreeable gains from trade. If two economic actors, Alpha and Beta, can both benefit from trade, then markets provide the opportunity for them to come together and realize those gains. Once all the Alphas and Betas in an economy have done so, then this should, under standard assumptions, lead to a state of the economy where all possible opportunities to improve the lot of some without harming others have been exploited. Thus do markets achieve efficiency, at least in theory.

However, it is fundamental to recognize also that any such efficient state of the economy is conditional. Under standard theoretical assumptions, an efficient state of the world is unique in the sense that market trade will lead inexorably toward a specific level of economic well being for each and every member of society. However, underlying any such unique state of the economy are the "initial endowments" that form its foundation. Each member of the economy holds some share of the total natural, labor, and capital resources of the economy with which to enter the market and trade so that an efficient final outcome is achieved. Given a different allocation of endowments, market trade will again achieve efficiency. However, in general, the end result will involve a different allocation of labor, capital, and natural resources to produce a different mix of goods and services which will be consumed in different quantities by different consumers.

Follow this same line of reasoning far enough, and the result, in theory, is an infinite number of efficient states of the economy, each of which would be achieved through market trade beginning from a different allocation of initial endowments. Furthermore, how well off any given individual is depends on his or her initial endowment. With a large endowment, an individual can enter the market and do quite well. With a small endowment, the same individual will be poor. Some allocations of endowments may lead to relative equality in economic circumstances of various members of society, while other allocations can lead to states of the world where the few are very rich and the many are very poor. Stated differently, so long as the assumptions of the theory are maintained, all the possible states of the world are equally efficient, but some of them might be deemed by a reasonable person as fair while others might be deemed very unfair.

Economists have been very reluctant to express views on fairness. Most would leave to politicians or philosophers the task of fairly allocating initial endowments. Economists, according to this view, are to take whatever allocation of endowments the political system divines. Their role is to determine when the assumptions underlying the market-efficiency argument are violated, causing markets to fail to achieve efficiency. Once market failures are identified, remedies are prescribed. Most of environmental economics as it stands today is oriented toward achieving efficiency when markets fail.

When Markets Fail

Environmental economists watch the world as it embraces market solutions to economic problems with mixed feelings. While acknowledging the power of the market to achieve some economic ends, they have devoted a great deal of effort to understanding the circumstances under which markets will fail. Market failure occurs when the signals that normally promote efficiency are short-circuited in ways that prevent the efficient state from being achieved. Market trade stalls before all possible opportunities to make some better off without harming others have been realized. Nowhere are prospects for market failure more apparent than in the environmental area.

Roughly speaking, three sources of market failures affect environmental resources. The first is environmental externalities. Quoting from the recent book by Bromley (1991, p.59, emphasis in original),

> In essence we are interested in instances where the actions of one party (Alpha) results in unwanted costs being visited on another party (Beta). In this context, social costs are those falling beyond the boundary of the decision-making unit that is responsible for those costs . . . This notion of costs going beyond the decision unit that creates them explains the origin of the term externalities. Alpha's factory or automobile or septic system or whatever reduces Beta's well-being by polluting her environment, yet this cost is not borne by Alpha and thus does not affect his decisions. Effective market links between the Alphas and Betas of the world do not exist for many environmental resources. The result is economically inefficient levels of pollution.

Second, markets fail to provide efficient quantities of a class of goods and services known as "public goods." For such goods and services, consumption of a unit by one individual does not diminish the quantity available to others by one full unit. Again, environmental examples are numerous. Alpha's enjoyment of a scenic vista, clean water at the beach, clean air in her city, and other such amenities does not diminish substantially the availability of those same resources for Beta.

A third source of market failure is lack of property rights in natural resources. Under open access, property rights do not exist to allow "resource users to act together and institute checks and balances, rules and sanctions, for their own interactions within a given environment" (Bromley, 1991, p.22). The result can be the free-for-alls that have resulted in depletion of many fisheries, grazing lands, petroleum resources, forests, and other resources. What one does not own, one cannot trade in markets and hence market linkages that could lead to efficient environmental resource use are lacking.

Economists tend to propose market or market-like solutions to problems involving externalities, public goods, and open access. Thus, transferability is viewed as essential to the promotion of efficiency by economists advocating "market solutions" to environmental problems. Transferable discharge permits are proposed for air and water pollution; transferable development rights are recommended to solve land-use problems; individual transferable catch quotas are advocated for depleted fisheries. Others recommend taxes on pollution and subsidies for pollution control or taxes on resources used to exploit open-access resources or on harvests from those resources as corrective measures. Such taxes and subsidies act as proxies for market prices in encouraging market-like solutions to environmental problems.

In other cases, rather than altering private sector incentives through transferable rights or taxes or subsidies, governments attempt to remedy market failures by directly managing resources. Here, economists advocate application of formal benefit-cost analysis. When governments choose from among alternatives for management of resources, there are inevitably winners and losers as various members of society compare their levels of well-being after the choice with their prior positions. The benefits of an alternative equal the maximum amount that winners could pay to see it implemented and still be no worse off than they would have been had it not been implemented. The costs are equal to the minimum amount required to fully compensate the losers such that they would be no worse off than they would have been had they maintained their prior positions. When benefits and costs are compared, the question is whether the willingness to pay of the winners exceeds the compensations required for the losers. If the value of the benefits of a project exceeds that of the costs, implementation of the project is efficient.

Market evidence provides valuable insights into benefits and costs, but such evidence may be lacking for many environmental assets affected by governmental management decisions. Here, economists employ non-market valuation techniques. They may apply the contingent valuation method, asking winners and losers about their values in surveys, or they may search for clues about values in travel expenditures, expenditures to avoid polluted resources, property values or elsewhere. Using market and non-market values in this way encourages governmental officials to manage public resources in ways that emulate what the private market would produce if market failure were not a problem.

However, decisions based on comparisons of benefits and costs emulate the results of market trading only up to a point. Unless market failures are present, under market trading only actions that are mutually agreeable to all those affected occur. In essence, under market trade, there are no losers.[1] Would-be losers can protect themselves by not trading. In the absence of market failures, market trades satisfy the full efficiency criterion: only those trades are completed that improve the well-being of at least one of the traders and leave no one else in society worse off. Benefit-cost analysis, on the other hand, does not satisfy the full efficiency criterion. The full criterion would be satisfied only if the winners were required to actually fully compensate the losers, thus erasing their potential losses, and this is

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[1] Of course, such statements are only fully valid in a theoretical world. In practice, market traders could be worse off through errors. The theoretical point is that real world traders are protected from becoming losers by having full discretion about whether or not to trade.

not required under benefit-cost analysis. The requirement that benefits exceed costs boils down to a requirement that it be possible for winners to compensate losers. Thus, the benefit-cost criterion requires only that it be possible to fulfill the full efficiency criterion, not that the full criterion be completely satisfied. Implicit in the benefit-cost criterion is the assumption that once the benefits and the costs are duly specified, the winners and losers must negotiate in the political arena as to the distribution of the now larger economic pie. If the losers are consistently absent from the political debate, however, their interests will be poorly represented. If the losers are yet to be born, it would not be surprising if their interests are not adequately protected by the political process today. To the extent that this is the case, benefit-cost analysis appears to have a built-in bias against future generations.

Let us try to summarize the point of all this. Mainstream economics argues that markets are, under suitable conditions, a very effective way to achieve economic efficiency. Environmental economists recognize that markets may fail to deliver this desired result in important cases and advocate measures to either establish markets that will remedy market failures or establish other market-like mechanisms to achieve the ideal market outcome. Benefit-cost analysis will lead to decisions that are "market-like" only up to a point, since actual compensation of potential losers is not required. This aspect of benefit-cost analysis tends to work against the interests of future generations when public decisions are made affecting their endowments.

Discussion

Before turning to the weaknesses of modern environmental economics, it is important to recognize its accomplishments. When the ideas we have just summarized began to gain momentum among academicians in the 1960s, they were viewed with a great deal of skepticism by environmentalists, policy makers, and industry. The result was systems of pollution control in various countries including the US based on regulations rather than economic incentives. As economists predicted, inefficiency was the result. For example, one estimate is that the annual costs to the United States of achieving current air quality goals is $10 billion higher than it needs to be (Howe, 1991). Stated differently, we in the US could have the same level of air quality we are currently enjoying plus $10 billion in other goods and service each year by using economic incentives rather than the current system of "command and control" regulations. Such numbers are hard to ignore and pollution control programs are beginning to use economic approaches to achieve environmental quality goals. For example, recent amendments to the US Clean Air Act authorize transferable sulphur dioxide emission allowances that will soon be bought and sold on the Chicago Board of Trade. The European Economic Community is considering a tax on fossil fuels to help control carbon emissions and air pollution.

Experience has been similar for open access resources, as fisheries management will illustrate. Emerging from long debates over the desirability and potential side effects of economic solutions, various fishery management programs the world over are implementing limited entry systems that approximate, at least to some degree, the economists' ideal.

Likewise, tools of benefit-cost analyses are now routinely applied in the environmental context. In particular, non-market valuation of environmental resources is receiving wider and wider attention. In the US, all the major federal resource management agencies, including EPA, the Forest Service, the Bureau of Land Management, the Forest Service, Army Corps of Engineers, the National Park Service, and others, have embraced non-market valuation in at least some applications. Though still being hotly debated, non-market valuation techniques are now also being applied in assessments of natural resource damages from releases of toxic substances and oil into the environment. Non-market valuation techniques are increasingly applied in other countries as well.

Thus, environmental economists can point to significant successes. Still, some of us within the ranks are uncomfortable about whether we economists have adequately come to grips with the environmental problems confronting the world today. Is the single-minded pursuit of efficient solutions really adequate to address the issues associated with global warming, worldwide erosion of soils, contamination of groundwater, losses of biological diversity, destruction of wetlands, overfishing, decertification, ozone depletion, rapid depletion of exhaustible resources, and other resource related problems? At this point opinions diverge. Some would pin their hopes on eradication of externalities, provision of public goods at efficient levels, and the establishment of fully functioning property rights systems. Others would tinker with the discount rate. Still others would hope that through more adequate non-market valuation techniques, we can better assess the nature of the tradeoffs between environment and economy. While all these directions are worthwhile, we will argue that all of them combined are inadequate to address the crux of the environmental problems confronting the world today.

The question we want to raise can be stated this way. Let us suppose that all externalities that can be economically eradicated are eradicated and that all public goods are provided at efficient levels. Let us suppose that all open access resources are managed efficiently. Let us suppose that all market and non-market values are measured accurately and that governmental resource managers are able to fully incorporate resulting benefits and costs into their decisions. Let us assume that through all these efforts a fully efficient economic state is achieved throughout the world. Would it then follow that the environmental resource issues confronting humankind at the end of the 20th century would be fully resolved? We would argue that the answer is no.

Stated most simply, at their crux, many environmental issues can be conceptualized as problems in the intergenerational allocation of endowments. The target of environmental economic analysis is an idealized, highly efficient, state of the economy, but as we have seen, there are an infinite number of such states of the economy, each associated with a different allocation of endowments. There are significant complexities to be addressed in extending this theory to an intertemporal, intergenerational world (see, for example, Page, 1977 and Howarth and Norgaard, 1990). However, the principles are ultimately the same. Given an infinite number of possible efficient states of the world, one is chosen, the one based on the existing allocation of endowments between generations. And, nowhere is it guaranteed that this particular efficient state is, to use the current buzz word, sustainable.

Sustainability is not an easy term for the economist to define with a great deal of rigor, but a rough and ready definition is possible. Following the arguments of Norgaard (1991) Figure 1 will help to illustrate what is involved. U_f on the vertical axis above the origin represents the per capita economic well-being of future generations, while U_c on the horizontal axis to the right of the origin represents the per capita well-being of the current generation. Each point in the graph's northeast quadrant represents a time path of per capita well-being composed of a level of per-capita well-being of the current generation, measured on the horizontal axis, and a level of per capita well-being of future generations, measured on the vertical. We assume, for the sake of argument, that levels of well-being are directly comparable within and across generations. The curve connecting points E and E' is the efficiency frontier. It represents the locus of points that are economically efficient. The other quadrants in the Figure help illustrate the derivation of EE' for a specific, highly simplified situation. In the case depicted, there is a single non-renewable resource. Thus, any quantity of the resource not used by the current generation is available for future generations as shown along the diagonal function with a slope of -1 in the southwest quadrant, which has resource use by current and future generations on the horizontal and vertical axes. These are measured as R_c and R_f, respectively. Labor and capital inputs are not explicitly shown. The curve in the southeast quadrant shows the level of per capita well-being that can be achieved by the current generation as a function of resource consumption. The comparable function for future generations is shown in the northwest quadrant. These functions show the maximum level of per capita well-being that each generation can achieve for any given level of resource consumption.[2] Notice that we assume that the resource is essential for achieving a positive level of well-being. In essence, we assume that basic subsistence can be satisfied without the resource. Subsistence forms the baseline where well-being equals zero. The resource is assumed essential to achieving levels of well-being above subsistence.

Assuming that both the present and future generations achieve efficiency by operating on their respective well-being functions, EE' can be traced out. If the current generation uses the entire stock, then its well-being is E' and future generations only achieve subsistence. On the other hand, total use by the future generation would lead to its achieving E, while the current generation achieves only subsistence. In between, both present and future generations achieve intermediate levels of well-being above subsistence. For example, if the current generation uses resources equal to point A, this will leave resources equal to B for the future generations. Per capital well-being is then equal for both generations at F.[3] If the current generation uses more than A, there will be so few resources left that future generations will not be as well off as they would have been at F, and obversely.

Sustainability would be simply defined in such a case. It would be achieved if the current generation uses no more than A of the resource. Then,

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[2] Of course, there would also be issues surrounding the intragenerational allocation of endowments to be considered in a full analysis. However, these issues are widely recognized, and we have abstracted from them here to focus attention on intergenerational issues.

[3] To get this result, it is necessary to assume that levels of well-being are comparable in cardinal terms across generations. Economists normally consider cardinal, comparable welfare measurement a very strong assumption, to be avoided if possible. Still, this assumption appears necessary if any progress is to be made on intergenerational issues. To deny interpersonal comparisons of utility would condemn economics to silence on intergenerational issues, except possibly for vague mumbling about the possibility of trade-offs.

future generations will be at least as well off as the present generation. Future generations can achieve at least well-being level F and possibly more if the current generation uses less than B.

The situation becomes slightly more complex if economic imperfections are admitted. Suppose that the current generation does not achieve efficiency, say because it has a market economy and market failures are allowed to persist. Then, it will enjoy some level of well-being below its well-being function. Suppose, as a specific case, that it uses D of the resource, but only achieves level C of well-being. Then, this will allow future generations to achieve only G at a maximum. They would have to be perfectly efficient to achieve G, and any imperfections that persist in their economies will lead to even lower levels of well-being than G. In a world with economic imperfections, it would not be satisfactory to define sustainability in terms of future generations being at least as well off as the current generation, as point G makes clear. At G, future generations are better off, but this is true only because the current generation used its resources so inefficiently. In essence, such a definition would penalize future generations for the inefficiencies of the current generation. Alternatively, in a world with such imperfections, sustainability would be achieved if future generations receive at least B units of the resource. This definition would allow them to achieve a level of well-being at least as large as the current generation, had the latter been perfectly efficient. Call the cross-hatched area in Figure 1 the region of sustainability. Under the definition of sustainability proposed here, an economy would be on a sustainable time path only if the current generation leaves sufficient resources to allow later generations to enter the region of sustainability.

Any tendency here to advocate sustainability as a policy goal will be viewed with unease by many economists because it runs against their strong propensity to avoid expressing views of what is fair and what is not. We will proceed based on the commonly held view among the general public that the current generation, in dealing with natural resources, should act as a trustee for future generations. The widespread interest that sustainability is generating among policy makers, environmental scientists, and the general public is reason enough to assume, for the remainder of this paper, that making the economy more sustainable as well as more efficient has policy relevance.

The next question is: how does society determine the intergenerational allocation of endowments that, in turn, determines the current position of the economy relative to the region of sustainability? In Figure 1, the issue is how does society choose whether current resource consumption falls short of or exceeds A. In the real world, choices affect future endowments of both renewable and non-renewable resources as well as capital in its various forms. Each generation certainly has its labor as part of its endowment. Each has the capital stock that it has inherited from the preceding generation. And, each inherits whatever non-renewable resources have not been used up in the past, plus remaining renewable resources in whatever condition they were left by previous generations.

It is hard to escape the feeling that future generations are in a vulnerable position here. Historically, resource depletion and degradation certainly occurred, but were limited because past generations, for the most part, lacked the technology, labor, and capital to exploit natural resources on a scale that is feasible today. We of the current generation are using non-renewable resources at an unparalleled rate. Furthermore, renewable resources are being exploited and degraded on a global scale. There can be little doubt that future generations will inherit a resource base that is much reduced and much degraded in many respects. The current generation tends to treat as its endowment virtually all the resources that it has the technological and economic means to exploit. Future generations get the left-overs, plus accumulated capital and their own labor. Sustainability, if it can be achieved at all, will depend on technological progress and capital accumulation.[4] Will technological progress and capital accumulation be sufficient to assure a sustainable economy?

Those who followed the Growth Debate of the 1970s no doubt find all this familiar. There, systems scientists and economists debated the prospects for further economic growth.[5] One can recast the conclusions of systems scientists into today's language by saying that they concluded that then-current economic trends were not sustainable. Economists responded by suggesting that the models developed by systems scientists were woefully inadequate in portraying the social processes that counterbalance resource depletion. Substitution of more abundant for less abundant resources, substitution of renewable for non-renewable resources, substitution of capital and labor for natural resources, and substitution of less resource-intensive for more resource-intensive goods and services were, according to the economists, quite capable of supporting further economic growth, particularly with technological progress to help find and exploit opportunities for substitution. It was these very processes that the systems models neglected. The Sustainability Debate of the 1990s has its own nuances, but it is fundamentally a continuation of the Growth Debate of the 1970s, which in turn can be traced back at least to Malthus.

We do not propose to resolve this debate in any definitive fashion. Rather, these are issues about which sensible, intelligent people ought to agree to disagree. Those who argue that the current economy is not sustainable ought to admit that they could be wrong. And, those who have more confidence in substitutability and technological progress should admit that

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4 It should be explicitly acknowledged that technological progress may counterbalance the effects of resource depletion and degradation in the past. For example, groundwater contamination could be outweighed by cheap technologies to remove contaminants. Still, it seems doubtful that technological progress can fully correct the impacts of past economic activities. Some past activities will have technically irreversible consequences. Even if, in the groundwater example, economically feasible technologies emerge to fully remove contaminants, uncontaminated water will still be more expensive as a result of the decisions made by past generations.

5 Relevant literature is summarized in Hartwick and Olewiler (1986), Chapter 6.

the economy could possibly be at a point like G in the graph. At Point G, as we have seen, the current generation uses so many resources that it is impossible for future generations to enter the region of sustainability. It is also inefficient. That is, it is located inside the efficiency frontier because the economy is imperfect. Market failures and inadequate responses to those failures on the part of government mean that we of the current generation are not on the efficiency frontier.

Admitting the possibility that the economy is at a point like G has two implications in the context of this paper. First, environmental economics as it has evolved since World War II is not adequate to address the issues arising in the Sustainability Debate. Market and market-like solutions to environmental problems may move the economy in an easterly direction toward the efficiency frontier. Such solutions will tend to benefit future generations somewhat by encouraging time paths to the northeast of the status quo, but they may not be sufficient to permit future generations to enter the region of sustainability.

Second, the possibility that the current economy is unsustainable tells us something about the directions that environmental economics needs to take in the future. Rather than continuing the seemingly endless and unresolvable debate about whether today's economy is sustainable, we ought to admit that no one knows for sure and begin to develop economic approaches to address this uncertainty. This means a shift in emphasis from the quest for an efficient economy toward an economy that is not only more efficient, but also more sustainable.

TOWARD A SUSTAINABLE ECONOMY

How would environmental economics be different if it were to take as its ideal an economy that is not only efficient, but also sustainable? To some extent, environmental economists would continue to pursue the same avenues of research that they are currently pursuing. Seeking market and market-like solutions to environmental externalities probably tends to promote sustainability by reinforcing the justification for policies that reduce pollution and other forms of resource degradation. As transferable permits are increasingly used to regulate pollution, the costs of meeting environmental quality goals will decline and this may make higher levels of environmental quality affordable. Non-market valuation tends to give environmental concerns economic clout in public decision making that they do not otherwise have. This tends to reduce rates of exhaustible resource exploitation, pollution, and renewable resource degradation. Economic approaches will tend to improve prospects for successfully controlling the tendency to overexploit resources that have historically been managed under open access. In all these ways, environmental economic analyses will facilitate pollution reductions and conservation of resources, potentially benefiting both present and future generations.[6] However, as we have seen, improving efficiency through such strategies may not be sufficient to achieve sustainability.

Further steps toward sustainability immediately encounter practical problems. If we knew for sure that the economy, on its current time path, is not capable of reaching the region of sustainability in Figure 1, theory would dictate that endowments be reallocated in the direction of future generations, but this is not an easy prescription to implement.

Reallocating endowments at a given point in time is easy to visualize. If a more egalitarian allocation is desired, capital and natural resource ownership could simply be reallocated from those who are relatively well off to those who are poor. Alternatively, income itself could be transferred from the rich to the poor.

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[6] Indicating that such steps would "potentially" benefit future generations involves a caveat of some importance. Strictly speaking, all that can be said with complete confidence is that future generations will receive a larger, higher quality environmental resource base. As will be emphasized more as this subsection develops, it is theoretically possible that future generations could be worse off despite have an enhanced resource base if pollution control and better natural resource management are so costly that they receive a much smaller stock of capital, broadly defined.

However, reallocation of endowments over time and between generations is not straightforward, even on the theoretical level. Simply reassigning natural resources to future generations could backfire. The endowment we of the current generation pass on to future generations contains much more than just natural resources. Future generations will also inherit the physical capital that has accumulated. Perhaps even more importantly, they will inherit human capital, composed of levels of learning and skills of the citizenry. They will also inherit all the science and technology accumulated over past centuries. They will inherit accumulated art, music, and literature, as well. Finally, they will inherit a set of social institutions, ways we humans have learned to organize ourselves to attain economic, social, and personal goals. Producing human and physical capital, science and technology, art, music, and literature, and even social institutions requires that we of the current generation use natural resources. In terms of the northeast quadrant of Figure 1, massive reallocations of natural resources from the present to future generations could move the intergenerational economy to the southwest, where both present and future generations are worse off. Such a time path hardly seems tenable because of the loss in efficiency and sustainability.

All this would not be a problem if we of the current generation had perfect foresight about the implications of "our" actions for "their" inheritance. In fact, "we" are quite ignorant about which resource uses will enhance "their" economic prospects and which will reduce "their" opportunities to achieve level of economic well-being comparable to ours.

An additional issue relates to what Bromley (1991) has referred to as the problem of "missing markets." As we have seen, much of the power underlying the reasoning in favor of markets comes from the argument that, once endowments are established, mutually agreeable trading among economic entities leads to an efficient outcome. Bromley (1991, p. 87) noted, ". . . The existence of a market still requires the willful coming together of two consenting agents to exchange for mutual gain." Except for concurrent generations, this "willful coming together" is impossible. Such markets are quite literally "missing."

Economists (e.g., Solow, 1974) have tended to believe that such face-to-face contacts between generations are not necessary to achieve efficiency because intervening markets will accomplish the same task. An example will illustrate how intervening markets work and why missing markets are important despite the possible existence of intervening markets.

Suppose that there is a grove of old-growth redwood trees that "we" of the generations living today could cut down and use for lumber now. Assume that "we" are willing to pay $10 million now, net of the costs of capital and labor required to deliver the resulting wood products to final consumers.[7] To keep the argument to its essentials, we will assume that there is perfect knowledge about the future. Looking into the future, suppose that, beginning 100 years from now, the grove of redwoods will become valuable as a recreation site to all succeeding generations. To simplify the problem, assume that the trees will have no uses, either as standing trees or lumber during the intervening 100 years. Also, again to simplify without losing essential elements, assume that once cleared, the land on which the trees stand will be worthless forever. Thus, society's choice is simply between lumber now and recreation beginning in Year 100. Assume that the social rate of discount is 2 percent.[8] Assume perfect capital markets so that all economic entities can borrow and lend at the 2 percent real rate. Other than the choice about what to do with the redwood grove, hold all else in this economy constant.

Whether efficiency can be attained through market trade, given that "we" and future generations cannot meet face-to-face, depends on two factors: the future value of the redwood grove in recreation and whether the grove is viewed as part of the endowment of the current generation or future

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[7] In technical terms, I am subtracting extraction costs, but <u>not</u> user costs, from gross willingness to pay.

[8] The real rate of interest on short term government bonds has averaged between 2 percent and 3 percent in recent decades.

generations. Consider two possible future values of the grove, capitalized back to Year 100, $50 million and $100 million. The present value now of $50 million to be received in Year 100 is $6.77 million. Since this is less than the $10 million that will be earned if the trees are cut, if future generations value the trees at only $50 million as of Year 100, a benefit-cost analysis would dictate cutting the trees now. On the other hand, if the trees will be worth $100 million in Year 100, the present value now is $13.53 million and preserving the trees for future generations has positive net benefits.

In two out of four possible cases, markets are not needed to achieve the efficient outcome. The most obvious case is where the grove will be worth only $50 million in the future and the grove is considered to be part of the endowment of the current generation. The efficient choice is to cut the trees and that is exactly what the owners will do. Likewise, if the grove will be worth $100 million and belongs to future generations, then preservation of the grove is achieved without market trade.

In a third case, intervening markets may fill the gap. This is the case where the trees are part of current generations' endowment and will eventually be worth $100 million. Perfect information does play a key role here. If members of the current generation correctly perceive the future value of preserving the grove, they will find it more valuable to hold it intact than cut it. Stated differently, the grove intact will appreciate at a rate faster than 2 percent, making holding it intact an attractive investment for intervening generations.

The missing-markets concept becomes relevant in the fourth case, where the grove belongs to future generations, but will be worth only $50 million in Year 100. Here, the efficient course would be to cut the grove and invest the proceeds for the eventual benefit of future generations, the rightful owners. If all the generations could meet to bargain, the exact investment would depend on the final bargain struck between the parties involved. The final bargain would involve a minimum investment of $6.77 million, since this is the minimum amount that could be invested now to fully compensate the owners. It could be as high as \$10 million, the maximum willingness to pay of the current generation. However, here there is no obvious market mechanism to fall back on. Intervening markets do not help. The result is likely to be an inefficient outcome. If the members of the current generation decide to ignore the property rights of future generations and cut the trees, they may not invest enough.[9] The result would then be an outcome that does not satisfy the efficiency criterion, since future generations will be worse off compared to the starting point where the trees were part of their endowment. On the other hand, if the current generation decides to honor the endowment of future generations and leave the trees intact, then the opportunity to achieve a superior outcome satisfying the efficiency criterion will have been lost. Both present and future generations could have been made better off through cutting the trees and investing a sufficient share of the proceeds, but no market is present to facilitate such an outcome. Intergenerational inefficiency results from this missing market.

Nor will public decisions based on benefit-cost analysis remedy the problem of missing markets. If the redwood forest is worth only \$6.77 in present-value terms today, then such an analysis would dictate cutting the trees. As noted previously, benefit-cost analysis only requires that the current generation be capable of compensating future generations. Since there is no requirement that future generations actually be compensated, even if the trees are part of their initial endowment, benefit-cost analysis would effectively void their rights. This is a manifestation of the bias against future generations inherent in benefit-cost analysis, as we saw in an earlier part of this paper.

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[9] The example is not rich enough to conclude how much would be invested. Suppose that the current generation invests 10 percent of its net benefits, or \$1 million, and agrees that this investment and reinvested proceeds will be accumulated until Year 100. Then, the total capital owned by future generations as of Year 100 will be \$7.39 million larger than it would have been otherwise and this will fall far short of the \$50 million worth of redwoods they would have had if the intervening generations had honored their property rights.

What are the practical implications of all this? As we have already noted, the current generation tends to act as if its endowment includes all natural resources that it has the technological and economic means to exploit. Missing markets will not impede efficiency under such a set of endowments. However, to the extent that it is desirable to assign resource endowments to future generations--to achieve sustainability or for some other reason--missing markets raise doubts about the ability of market trade to achieve intergenerationally efficient outcomes. If intervening generations honor the rights of future generations they may miss opportunities to use resources in ways that will benefit both themselves and future generations. To the extent that they exploit resources that ought to belong to later generations, missing markets mean that market incentives will be insufficient to protect the future interests of the owners except by accident. A more realistic example, involving, for instance, uncertainty and imperfect capital markets, will only multiply such concerns. And, because benefit-cost analysis does not require compensation of losers, it does not resolve this problem. Markets and benefit-cost analysis both tend to work against sustainability. They both tend to signal that resources should be used sooner rather than later, yet neither is capable of assuring that future generations receive other resources or additions to their non-resource endowments (capital, new technologies, art, etc.) to compensate them.

Thus, while it may be easy enough to say, in theory, that a sustainable, efficient economy can be achieved by reallocating endowments, how to implement this prescription is not at all clear. Our great ignorance about the future and missing markets means that we of the current generation simply do not know what sorts of reallocations would be called for. And, even if we could define appropriate reallocations of endowments, market mechanisms and benefit-cost analyses cannot be depended upon to achieve efficiency.

To the extent that sustainability is a goal, we will suggest two strategies for moving the economy in that direction. The first strategy involves policies to bound the day-to-day operations of the economy to enhance the natural resource endowments of future generations, but with an eye toward the economic implications of specific steps to implement such policies. The concept of the safe minimum standard of conservation for biodiversity will illustrate how such boundaries would work. A second step toward a more sustainable economy would involve taxing resource exploitative activities and using the money to increase the economic options open to future generations.

Bounding the Economy: The Safe Minimum Standard

Extinction of plants and animals is an economic issue because it narrows the biological diversity upon which current and future generations may depend for new resources to produce food, building materials, aesthetic enjoyment, energy, paper products, pharmaceuticals, transportation, recreation, and other desired commodities and services. As long as human-caused extinctions were rare, there was little need for concern. Biological diversity was a free gift of nature. At the end of the Twentieth Century, however, biological diversity can no longer be taken for granted. Thousands of species of plants and animals will be lost in the next few decades unless steps are taken to save them. The steps needed to conserve diversity require the commitment of scarce capital, labor, and natural resources. Thus, on the one hand, massive extinction of living organisms may limit future economic possibilities. In the terms developed here, extinctions threaten sustainability. On the other hand, reducing the rate at which biological diversity is eroding will involve economic costs to the current generation which could conceivably affect the non-environmental endowments of future generations.

One could address the problem of biodiversity erosion using benefit-cost analysis. For example, Smith and Krutilla (1979, p.371) advocate an approach involving ". . . a direct extension of the conventional criteria for optimal public investment to take account of the irreversibilities associated with actions involving natural environments [including actions affecting endangered species]." They pointed out later in the same paper (Smith and

Krutilla, 1979, p. 372) that, at the theoretical level, such a "model assumes that all benefits and costs have been fully described and that the nature of uncertainty has been enumerated." Carried to its logical extreme, this thinking leads to statements like that made by Brown and Swierzbinski (1989, p.91), ". . . not all species should be preserved; we should actively seek to preserve only those for which the expected net benefits of preservation are positive."

The problem with this approach, as we have seen in the present paper, is that preserving only those species with positive net benefits (i.e. only those species for which preservation is potentially efficient) may not be sufficient to assure a sustainable economy. The net benefits of preservation are measured given the present structure of endowments as interpreted by the current generation, which may place future generations in a very disadvantaged position. Furthermore, even if more biodiversity is added to the endowment of future generations, large numbers of species preservation programs may not pass a benefit-cost test. Nothing about the benefit-cost test would assure that future generations will receive full compensation commensurate with resulting losses from their endowment.

An alternative approach to endangered species policies is the safe minimum standard of conservation (here abbreviated SMS) as originally proposed by Ciriacy-Wantrup (1952) and further developed by Ciriacy-Wantrup and Phillips (1970), Bishop (1978, 1980) and Randall (1991). Adopting an SMS strategy as an objective of policy would mean avoiding extinction in day-to-day resource management decisions. Exceptions would occur only where it is explicitly decided that costs of avoiding extinction are intolerably large or other social objectives must take precedence.

Randall (1991, p. 16) has explained the idea this way:

> The SMS rule places biodiversity beyond the reach of routine trade-offs, where to give up ninety cents worth of biodiversity to gain a dollars worth of ground beef is to make a net gain. It also avoids claiming trump status for biodiversity, permitting some sacrifice of biodiversity in the face of intolerable costs. But it takes intolerable cost to justify relaxation of the SMS. The idea of intolerable costs invokes an extraordinary decision process that takes biodiversity

seriously by trying to distinguish costs that are intolerable from those that are merely substantial.

The SMS strategy does not involve a new economic paradigm. Ideally, the efficient, sustainable economy would be built on a suitable foundation involving appropriate intergenerational natural resource endowments and an optimal path of capital accumulation over time. Once such a new foundation was in place and market failures were eradicated, species could be saved or discarded through market trade and an efficient, sustainable economy attained, at least with respect to biodiversity. Because of ignorance about the future and missing markets, such an ideal is far from attainable.

The SMS should be thought of as a second-best, practical strategy to be implemented in lieu of the ideal. The goal of the SMS strategy is to increase the well-being of future generations by preserving some species that will prove useful and valuable in the future and that would otherwise have been lost. In the face of great ignorance about the future, it increases the options available to future generations. In lieu of compensation that may be unavailable to future generation because of missing markets and because benefit-cost tests make no provision for compensation, they will at least receive a larger resource endowment under the SMS strategy than they would have otherwise. The first-best solution to the problem, were it attainable, would involve an optimal mix of species and other resource and non-resource endowments for future generations. The SMS strategy pushes an economy in that direction by augmenting their endowment of biodiversity.

It seems highly unlikely that the first-best, ideal solution can be achieved through the SMS strategy. Since the SMS depends upon the current generation's judgement as to what represents "intolerable" costs, it is inevitable that either too many or too few species will be preserved under the SMS compared to the ideal. Because of ignorance about which species will ultimately prove valuable and which will not, to some extent, the wrong species will be saved. Some species that would have turned out to be of great value to future generations may be lost. Some species that will never be worth anything either directly or in terms of their contributions as parts of larger ecosystems may be saved. Furthermore, economic development opportunities that would have yielded positive net benefits to both present and future generation but that would have caused extinctions may be abandoned. The SMS strategy carries certain additional risks. Overly stringent application of it could make both present and future generations worse off, in effect moving the intergenerational economy to the southwest of the point it would otherwise have chosen in the northeast quadrant of Figure 1. And, there is also the risk that those who are worried about sustainability are wrong, in which case the SMS strategy might simply enrich future generations that would have been better off than the current generation anyway.

Note also the SMS would only be one of many objectives of policy. As Randall stated in the quotation just presented, the SMS would not have "trump status." Many worthwhile objectives must vie for economic attention and public resources, and preservation of biodiversity would not necessarily take precedence in all cases. Most societies have a policy objective of preventing murder, yet the resources devoted to this end are not sufficient to prevent all murders. Similarly, if the SMS were an objective of policy, this would not mean that all extinctions of plants and animals would be prevented. The SMS policy would help limit extinction of plants and animals to those that could be saved only by bearing unacceptably high costs or through unacceptable sacrifices in other social objectives.

Stated policies in the U.S. are consistent with the SMS strategy. Federal legislation, as surveyed by Harrington and Fisher (1982), clearly states that preservation of endangered species is an objective of public policy. Amendments to the Endangered Species Act, precipitated at least partially by the snail darter controversy, even incorporate Randall's "extraordinary decision process" by providing for a high level government committee (the so-called God Squad) to grant exemptions to the act where overriding economic or other concerns are deemed to be of greater importance.

This is certainly in keeping with the SMS concept.[10] Several states also have legislation declaring species preservation to be an important goal. Increasing numbers of other countries are adopting similar legislation. Many international treaties are consistent with the SMS strategy as well.

The real challenge appears to be in implementation. Again focusing specifically on the situation in the US, a recent report from the Office of Technology Assessment (U.S. Congress, 1987) repeatedly cites lack of funding as a major impediment to implementing biodiversity preservation programs. This brings us to our second suggested direction for research into mechanisms to achieve a more sustainable economy: the resource tax.

The Resource Tax

An economist must proceed carefully here. Governments face many demands on scarce resources and must set priorities. If they choose to place a low priority on funding to implement policies to support sustainability, who are we to object? The current generation is "in charge" and has the discretion, and indeed the responsibility, to review priorities from time to time and alter resource commitments accordingly.

Still, the fact that future generations are not here to represent themselves in the decision process raises questions about the appropriateness of annual budgeting for this purpose. When budgets are tight and real or perceived needs are many, might it be too easy to cut a part of the budget designed to benefit one of the least vociferous of all the interest groups? Might there be some sort of middle ground like the highway trust fund or social security, where priorities and progress toward stated goals can be monitored from time to time, but where the commitment would not be vulnerable on an annual basis?

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[10] This is not to endorse every decision made by such a body. The decision to grant an exemption for logging certain old-growth forests that serve as habitat for the spotted owl may be objectionable on purely efficiency grounds. See Hagen et al. (1992). Nevertheless, under the SMS approach, some such decision making body is required in principle.

The idea is simple enough in theory. Anyone extracting or otherwise using environmental and other natural resources would be assessed a tax based on the value of the resource impacts associated with use and the money would go into a trust fund. The trust fund would then be drawn upon to increase the options open to future generations to meet their wants and needs. Given what was said above, some of the money could be used to augment biological diversity preservation programs. Other money could go to address other long-run environmental issues. Still other funds could go to research to help us understand better how the global environment functions and to augment the technological options of future generations. The end result would be to increase the likelihood that the economy is on a sustainable path through greater assurance that the well-being of future generations is not being sacrificed through our actions.

The topic of the resource tax is a bit embarrassing to raise. It may sometimes seem that economists recommend new taxes to solve all problems and that governments just as regularly reject the idea, arguing that taxes are for raising revenues, not for implementing policies. Yet one more economist with another tax proposal is likely to elicit a jaded reaction. Still, the idea has special merit in the current context for two reasons. First, as we have already seen in the case of biological diversity preservation, to find adequate revenues in the context of annual budgeting to address intergenerational environmental issues may be problematical. Second, the tax would discourage economically marginal uses of natural resources, thus preserving more nonrenewable resources for future generations and reducing pressure on renewable resources as well, in a way that cuts back on those resource uses that are contributing the least to the economic well-being of the current generation.

At this stage, the resource tax is not a well-developed, implementable idea, even if politicians were willing. How might the tax rate be determined? Should it be varied from one resource using activity to another? What would be the implications for the economic well-being of the current generations of such a tax at various levels? Should non-renewable resource uses be taxed more heavily than renewable resource uses or vice versa? At this point, the resource tax is only a possible topic for research. However, if we of the current generation are serious about sustainability, it should receive a high priority.

SUMMARY

Non-economists are often skeptical about the applicability of economics to long-term environmental issues. Perhaps they sense intuitively what most economists have not yet recognized. Achieving the economist's perfectly efficient state, even if that were attainable, could lead to an unsustainable path for the economy. This is not a conclusion that follows from some new, as yet half-baked, theory of economics. Instead, it follows directly from the mainstream paradigm. Theoretically, there are an infinite number of efficient states and a large number of those states could involve actions in the near term that will leave later generations with much diminished economic opportunities compared to earlier generations. Efficiency does not guarantee sustainability. In an age of unprecedented rates of extraction of non-renewable resources, overexploitation of renewable resources, and degradation of the environment in countless ways, the possibility that the economy is on an unsustainable path deserves attention. Technological progress and substitution may be sufficient to counterbalance these trends and allow future generations to enjoy levels of well-being equal to or exceeding those that currently exists, but to take such solutions as a foregone conclusion hardly seems warranted. Prospects for the future remain uncertain.

The existing paradigm leads rather naturally to a conceptual definition of an efficient, sustainable economy. It also helps identify why the ideal is unattainable. We of the current generation are ignorant of the wants and needs of future generations. Missing markets mean that even if intergenerational endowments could be rearranged to attain the ideal, market trade might not succeed in reaching the ideal even if all conventional sources of market failure could be eradicated. Conventional benefit-cost analysis ignores whether compensation is actually paid. Its uncritical application in public resource management could lead to shortchanging of future generations, even if intergenerational endowments were set at ideal levels at the outset. In this way, basing public decisions on benefit-cost analyses alone would tend to work against sustainability.

Practical steps toward an efficient, sustainable economy would involve bounding day-to-day activities in both the private and public sectors. Where sustainability is not an issue, the day-to-day quest for efficiency, defined on the basis of the current allocation of endowments, could proceed. However, when such day-to-day activities affect sustainability--for example, by threatening to cause extinction of species--then extraordinary decision processes would be activated to more carefully consider alternatives.

The SMS strategy involves just such a decision process. Where a public or private action would affect species survival, the SMS would dictate forgoing that action unless the sacrifices from doing so are unacceptably large. The economist has two roles here. First, the economist needs to help the public and their governments recognize that extinction of species is an important economic issue. Second, the economist has the tools to measure the economic sacrifices associated with species preservation projects.

Research is badly needed to explore SMS-like approaches in such areas as global warming, deforestation, soil erosion, desertification, agricultural land preservation, groundwater deterioration, and acid deposition. A portfolio of policies to bound the quest for efficiency with regard to renewable resources is a promising possible route toward increasing the sustainability of the economy.

Other bounds on the quest for efficiency might be imposed through taxes levied on resource uses to discourage economically marginal activities. Such taxes would, in turn, raise money to pursue social progress in directions that would enhance sustainability. More research on such taxes would increase the saliency of environmental economics to the Sustainability Debate.

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REFERENCES

Bishop, Richard C. 1978. "Endangered Species and Uncertainty: The Economics of a Safe Minimum Standard." American Journal of Agricultural Economics 60:10-18.

Bishop, Richard C. 1980. "Endangered Species: An Economic Perspective." Transactions of the 45th North American Wildlife and Natural Resources Conference, pp. 208-218.

Bromley, Daniel W. 1991. Environment and Economy: Property Rights and Public Policy. Cambridge, Blackwell.

Brown, Gardner M. and Joseph Swierzbinski. 1989. "Optimal Genetic Resources in the Context of Asymmetric Public Goods." Environmental and Applied Welfare Economics, ed. V. Kerry Smith. Washington, D.C.: Resources for the Future.

Ciriacy-Wantrup, S. V. 1964. "The 'New' Competition for Land and Some Implications for Public Policy." Natural Resources Journal 4:252-67.

Ciriacy-Wantrup, S.V. 1952. Resource Conservation: Economics and Policies. Berkeley: University of California Press.

Ciriacy-Wantrup, S. V. 1961. "Water Quality, A Problem for the Economist." Journal of Farm Economics 18(5):1133-44.

Ciriacy-Wantrup, S.V. and William E. Phillips. 1970. "Conservation of California Tule Elk: A Socioeconomic Study of a Survival Problem." Biological Conservation 3(1):23-32

Hagen, Daniel A., James W. Vincent and Patrick G. Welle. 1992. "Benefits of Preserving Old-Growth Forests and the Spotted Owl." Contemporary Policy Issues 10(April):13-26.

Harrington, Winston and Anthony C. Fisher. 1982. "Endangered Species." in Current Issues in Natural Resources Policy. Paul R. Portney, ed., Washington, D.C.: Resources for the Future.

Hartwick, John M. and Nancy D. Olewiler. 1986. The Economics of Natural Resource Use. New York: Harper and Row, Publishers.

Howarth, Richard B. and Richard B. Norgaard. 1990. "Intergenerational Resource Rights, Efficiency, and Social Optimality." Land Economics 66(1):1-11.

Howe, Charles W. 1991. "An Evaluation of U.S. Air and Water Policies." Environment 33(7):10-15,34-36.

Norgaard Richard B. 1991. "Sustainability as Intergenerational Equity: The Challenge to Economic Thought and Practice." Working Paper, Office of the Chief Economist of the Asia Region, The World Bank.

Page, Talbot. 1977. Conservation and Economic Efficiency: An Approach to Materials Policy. Baltimore: Johns Hopkins University Press

Randall, Alan. 1991. "Thinking About the Value of Biodiversity." Unpublished paper, Department of Agricultural Economics and Rural Sociology, Ohio State University.

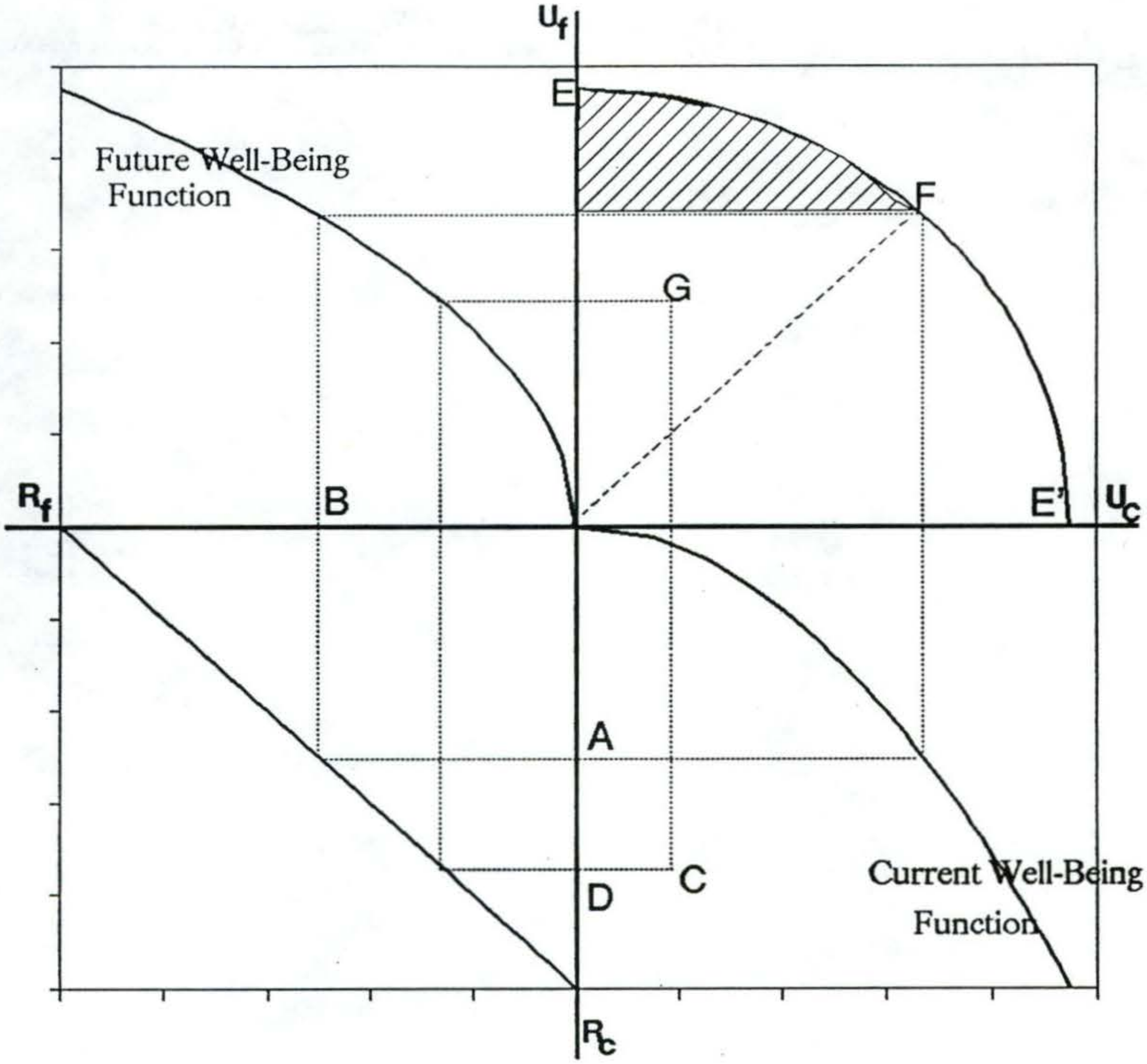
Ready, Richard C. and Richard C. Bishop. 1991. "Endangered Species and the Safe Minimum Standard." American Journal of Agricultural Economics 72(2):309-312.

Smith, V. Kerry and John V. Krutilla. 1979. "Endangered Species, Irreversibilities, and Uncertainty: A Comment." American Journal of Agricultural Economics 61(2):371-75.

Solow, Robert M. 1974. "The Economics of Resources or the Resources of Economics." American Economic Review 64(2):1-14.

U.S. Congress, Office of Technology Assessment, 1987. Technologies to Maintain Biological Diversity, OTA-F-330 (Washington, D.C.: U.S. Government Printing Office).

Figure 1



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