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

	Economic Activities			Economic Assets		Environment
	Production	Rest of World	Final Consumption	Produced Assets	Non-Prod. Assets	Non-Prod. 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	$10,869				($10,869)	
Water Returned	($7,877)				$7,877	
Net Product: EDP1	$4,004,071	($143,100)	$3,933,800	$247,129	$473,733	($28,466)
Environ. Degradation						
Land						
Soil Erosion	2891 * C[illegible]					2891 * C[illegible]
Hazardous Waste	$0					$0
Non-haz. Waste	[illegible]					($33,628)
Water						
Conventional	[illegible]					($229,976)
Toxic	$760 * C_{TOXIC}$					$-760 * C_{TOXIC}$
Air						
TSP (Stationary)	$3,963					($3,963)
SO_x (Stationary)	$5,112					($5,112)
NO_x (Stationary)	$875					($875)
VOC (Stationary)	$17,011					($17,011)
CO (Stationary)	$1,552					($1,552)
Pb (Stationary)	$1,077					($1,077)
TRANSPORT	$6,269					($6,269)
Net Product: EDP2	$3,704,629	($143,100)	$3,933,800	$247,129	$473,733	($327,908)

treatment costs by the National Research Council. These estimates approximate marginal costs better since they are based on current costs of constructing particular types of water treatment facilities.

Environmental damages were identified primarily through inventories of polluting residuals. An important consideration in constructing the SEEA system on a regular basis is the availability and reliability of these databases. Although most of the data were compiled from EPA data sources. there is still wide variability in the reliability and regularity in the collection of the source data. If a more routine implementation of the SEEA is envisioned, these data issues will need to be weighed in decisions about how the SEEA will be constructed and used.

The calculation of degradation costs for each of the three media are discussed briefly below.

Land

Three categories of degradation of land are considered: soil erosion, hazardous wastes, and "non-hazardous" wastes.

Estimates of soil erosion were derived from an inventory of rural lands by the Soil Conservation Service. No estimates of the maintenance costs were identified. For this mason, the entry is represented by the amount of soil erosion (million tons) times the hypothetical unit cost of mitigating the erosion.

Although this version of the SEEA does not permit its use, it was possible to derive an aggregate estimate of the off-site damages associated with soil erosion. This estimate was $14.3 billion, which indicates the amount that society would be willing to give up to control soil erosion. Under a different version of the SEEA that considers costs borne, this estimate could be used to adjust EDP2 by adjusting consumption in lieu of or in addition to production.

Hazardous wastes are for the purposes of this pilot study defined by federal regulations. Any wastes defined as hazardous must be managed in specific ways to protect the environment. Accordingly, it is assumed that hazardous wastes do not impose damage on the environment given the additional assumption of full compliance. Consequently, while the volume of hazardous wastes generated each year is very large (290 million tons in 1987), hazardous wastes do not affect the calculation of EDP2. The hazardous waste management expenditures are already reflected in the calculation of conventional GDP and NDP and in the estimate of value-added associated with the environmental protection industry highlighted above.

Just as hazardous wastes are defined by federal regulation by default so are non-hazardous wastes. These are wastes that do trot have to be managed according to federal hazardous waste regulations but which nonetheless may still pose a hazard or some other environmental impact. More than 8 billion tons of these wastes were generated, mostly from manufacturing. To estimate maintenance costs, it was assumed that the same level of care was necessary for these wastes as for hazardous wastes. To avoid any environmental impact, this assumption may not be too unreasonable since there are indivisibilities in the capital necessary to manage the wastes according to federal regulations (such as the requirement of liners in landfills). The actual unit costs applied to non-hazardous wastes reflects the incremental costs of going from the current level of expenditure on these wastes to what would be comparable for this volume of wastes if federal requirement were imposed. The resulting aggregate maintenance costs are $33.6 billion, accounting for about 10% of the adjustment for EDP2.

Water

Water pollution presented one of the most difficult challenges in calculating degradation. The difficulty stemmed primarily from the lack of reliable information on emissions of conventional or toxic pollutants. At the same time, the resulting estimate of aggregate maintenance costs were so large, accounting for 77% of the adjustment for EDP2. Together, these circumstances are cause for concern. Consequently this component of EDP2 should be viewed with considerable caution at this stage of development.

To construct a basic aggregate picture of the amount of conventional and toxic pollutants, it was necessary to use a variety of often irregular data sources. This approach posed significant obstacles to an independent verification of the estimated loadings. Ultimately, the physical measures of the majority of pollutants were not used directly (Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), nitrogen and toxics) in the estimation of maintenance costs. Only phosphorus emissions and their estimated control costs were used directly since their volume determined the number of facilities that needed to be constructed, assuming- that water pollution appears uniformly in the concentrations for which these facilities are designed.[6] Furthermore, given this same assumption for other pollutants, these same facilities would be sufficient in theory, to control BOD and 97% of nitrogen. TSS was so much larger in aggregate volume that this approach seemed inappropriate. As such, the estimated costs of $230 billion reflect the resources necessary to control phosphorus, BOD, and most of nitrogen under very special circumstances.

This approach to deriving a maintenance cost estimate is unsatisfactory because it applies a point-source means of control (wastewater treatment facilities) to a problem that sterns largely from non-point sources, which means that less costly ways to accomplish even a zero-pollution goal are likely. Ironically, this approach is also unsatisfactory because it may not satisfy the SEEA criterion of estimating the costs to reduce emissions to. a non-polluting level since TSS would not be eliminated. In this respect, the maintenance cost estimates may be too low. In practice, then, the implementation of SEEA with respect to water degradation had severe limitations in this U.S. application.

Nonetheless there may be some value in the experience. If even just a portion of the $230 billion degradation estimate proves realistic, then at least given a maintenance cost perspective, water degradation is likely to carry great weight within an SEEA system. For environmental economists, this may be a frightening prospect because it only reflects the cost side of the issue. Frightening, that is, unless the as yet unknown estimated damages are least equally large.

Air

Environmental degradation from air pollution may be the most straightforward of all the ones considered. EPA routinely collects or estimates statistics on the emissions of certain key pollutants. This SEEA example focuses on TSP, SOx, NOx, VOCs, carbon monoxide (CO), and lead (Pb). Toxic air pollutants represent a more recently considered phenomenon and are less well-tabulated.

[6] The estimates of control costs per facility were obtained from the National Research Council (1993).

Unit costs were estimated using information from published EPA documents, a not-so-small indication that this information could be compiled on a routine basis to support the implementation of environmental accounts. The unit costs were derived by dividing the aggregate air pollution control expenditures in 1987 by the estimated emissions reduction attributable to these expenditures. For stationary sources, it was possible to use pollutant-specific expenditures in 1987, based on U.S. EPA (1990), as well as pollutant-specific reductions (U.S. EPA, 1989). Because joint control of pollutants is more common with mobile sources, pollutant-specific expenditures were not available. As a result, the total mobile source expenditures for air pollution control were divided by the sum of all mobile source pollutants (by weight). In Exhibit D, the row labeled TRANSPORT provides the relevant maintenance costs for mobile sources. Together, the stationary and mobile source pollutants account for approximately 10% of the EDP2 adjustment.

Environmental Degradation: Conclusion

In sum, the exercise of implementing the SEEA maintenance cost concept of degradation revealed several types of problems that should be considered more carefully before the results can be taken seriously - for the light they shed on economic-environmental interactions much less for any bearing they may have on economic or environmental policy. Nonetheless, these results do not detract completely from the general impression drawn from this exercise that environmental degradation poses a serious matter to be addressed by economic accounting. Even discounting the degradation results by an order of magnitude (to $30 billion), they still appear to be substantial, at least relative to the depletion estimates ($34 billion) and to current efforts to control pollution (measured by value-added of $28 billion from the environmental protection industry).

Exhibit E presents the complete, consolidated table of SEEA results from this pilot U.S. study. Nothing significant has been added. The final components which have been added are the revaluation rows, for which no data are provided, and the closing asset balances, which summarize changes presented in earlier discussions of asset changes. Note that no entries are provided in the closing balances or the opening balances of environment non-produced assets. The SEEA only calls for measuring changes in these assets not their total values. Omitting total values seems to be more of a concession to the substantial obstacles posed by estimation than a conclusion about the validity of the concept. The difficulty may not stem so much from the challenge of making a physical inventory of the environment. That is indeed possible for certain facets, such as the extent of old “growth forests. Instead a substantial part of difficulty comes from the challenge of valuation which as this application has shown, is already very hard when only marginal changes are involved.

Consolidated SEEA Results for the U.S.

Exhibit F presents several key statistics from this pilot SEEA application, some of which have already been cited above. At a glance, this presentation highlights two environmental phenomena that are worth further inquiry. One is that environmental depletion adjustments to NDP stand out far more than natural resource depletion adjustments. The second phenomenon is the apparent indication that in 1987, the U.S. appeared to be living beyond its means. There is an apparent decumulation of wealth as indicated by negative net capital formation as well as by the fact that the final consumption exceeds EDP2. If the current implementation were more than a pilot effort and if the economic accounts truly encompassed all capital, this particular finding could point to unsustainable tendencies in U.S. economic activities. As it is, this statistical result merely suggests that there may be tendencies that are worth worry about and investigating further.

Exhibit E.

Environmental Accounts for the United States 1987

Resource Depletion and Environmental Degradation

($ Millions)

	Economic Activities			Economic Assets		Environment
	Production	Rest of World	Final Consumption	Produced Assets	Non-Prod. Assets	Non-Prod. Environment. Assets
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Timber				$5,729		
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Natural Gas					$138,209	
Coal					$155,678	
Minerals					$18,611	
Water					K0.np.ea.h2o	
Economic Supply	$8,042,812	$507,100				
Economic Uses	$3,502,812	$364,000	$3,933,800	$749,300		
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Timber Net Growth	($159)			$159		
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Oil Discoveries					$20,066	($20,066)
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CO (Stationary)	$1,552					($1,552)
Pb (Stationary)	$1,077					($1,077)
TRANSPORT	$6,269					($6,269)
Net Product: EDP2	$3,704,629	($143,100)	$3,933,800	$247,129	$473,733	($327,908)
Revaluation						
Prod. Assets				Rev.p.ea		
Timber				$0		
Oil					$0	
Natural Gas					$0	
Coal					$0	
Minerals					$0	
Water					Rev.np.ea.h2o	
Closing Assets				$12,239,158	$473,733	
Fixed Assets				$11,143,400		
Inventories				$1,090,000		
Timber				$5,758		
Oil					$168,800	
Natural Gas					$134,992	
Coal					$155,146	
Minerals					$17,787	
Water					K1.np.ea.h2o	

Exhibit F
Comparison of Indicators Based on Conventional and on Environmental Measures

	Conventional Accounts	EDP1 (% of Conventional)	EDP2 (% of Conventional)
NDP	$4,037.8 billion	$4,004.1 billion (99.2%)	$3,704.6 billion (91 .7%)
Net Capital Formation	$247.1 billion	$213.3 billion	-$86.1
Net Capital Formation, as % of NDP or EDP	6.1%	5.3%	-2.3%
Consumption, as % of NDP or EDP	97%	98%	106%

Conclusions

We return to the three objectives of the SEEA stated at the outset of this paper to determine whether implementation of the SEEA is appropriate and useful for the U.S. They 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 manmade and natural assets, and 3) develop environmentally adjusted measures of GDP to serve as a guide toward sustainable development. Since it seems reasonable to assume that these objectives are ones generally shared by our society, we review each as the means of answering this question.

The SEEA does provide a means for better accounting of the interaction of the economy and the natural environment, in at least two special ways. First, SEEA is far more complete in showing ways that the economy can infringe on the environment and how the environment contributes to the economy than the SNA ever was. When one starts with an accounting system that is so thoroughly oriented to market transactions and production it is quite an achievement to flesh out a system that maintains consistency with economic accounting while incorporating the environment. Through the progression of various versions of SEEA, it is possible to see, as shown in the paper, the concepts of environmental depletion and degradation transformed from alien concepts that are almost completely excluded or ignored in conventional accounting to ones that are full-fledged elements of an accounting framework that actually uses non-market values. Whether national accountants ever go that far may depend on how much environmental economists get involved in the process, an issue to which we return below.

The second special way that SEEA provides a better means for depicting environment-economic interactions is its recognition of natural capital as a legitimate component of a nation's asset balances. Although this step is a long way from making it possible to track the sustainability of a nation's wealth. it is a necessary step. Until natural capital is scrutinized in tandem with manmade capital, economic accounting will be biased against the preservation of natural capital, While the pilot study in this paper has demonstrated in a limited way the magnitude of the difficulties in reliably implementing a system of manmade and natural capital accounting, these difficulties do not remove the appeal of putting natural and manmade capital on even terms.

This point relates to the second objective of SEEA. Whether better natural capital accounting can help address sustainable development concerns will depend on how well natural capital is actually understood. Consequently, whether SEEA is right for the U.S. does not depend solely on the structure of SEEA itself. SEEA depends critically on the information which it incorporates. It should be emphasized that SEEA incorporates the environment less than it opens up the accounting system to better information on linkages between the economy and the environment. In many ways, SEEA can be seen as a user of environment-economic information rather than as a generator. For example, the maintenance cost approach demonstrated in this paper depends on judgments of the non-damaging levels of pollution. National accountants cannot be the arbiters of such choices. Instead environmental economist, public health specialists, ecologists, and others could be. This circumstance presents an opportunity for environmental economists. SEEA is like an empty vessel. It is good enough to use a lot of information that has not yet been fully developed. Any improvements in understanding the relationships between the environment and the economy can be incorporated in the SEEA system.

Promising as such developments seem to be, the number of unanswered questions about the relationship between the environment and the economy is very large. This predicament brings us to the third objective of SEEA - to develop environmentally adjusted measures of GDP as guidance for sustainable development. If the characterizations of natural capital and of environmental goods and services are still so limited how good can any resulting "green GDP" measures be that incorporate them? We suspect that they may indeed be inadequate but, in the face of GDP measures which turn an even blinder eye to the environment, we also suspect that improved knowledge lies in the direction of environmental accounting and not toward past conventions.

References

Abt Associates Inc. 1994. Environmental and Natural Resource Accounting: A Compendium of U.S. Estimates Based on the U.N. SEEA. Draft report for the U.S. Environmental Protection Agency prepared under contract with IEc Incorporated. March 3.

Arthur Young & Co. 1988. 1988 National water and wastewater rate survey. Arthur Young National Environmental Consulting Group: New York, New York.

Bureau of Economic Analysis. 1994. Accounting for Mineral Resources: Issues and BEA's Initial Estimates. Survey of Current Business. April.

Bureau of Mines. 1988. Mineral commodities summaries 1988. U.S. Department of the Interior, Bureau of Mines.

EIA. 1989. Estimation of U.S. coal reserves by coal type. U.S. Department of Energy, Energy Information Administration Publication No. EIA-0529. October.

EIA. 1988. U.S. crude oil, natural gas, and natural gas liquids reserves, 1987 annual report. U.S. Department of Energy, Energy Information Administration.

Nestor, D. V. and C. A. Pasurka. 1994. Environment-Economic Accounting and Indicators of the importance of Environmental Protection Activities. Revised paper presented to the 1993 Annual Meeting of the Southern Economic Association. March.

NRC. 1993. Managing Wastewater In Coastal Urban Areas. Committee on Wastewater Management for Coastal Urban Areas, Water Science and Technology Board, Commission on Engineering and Technical Systems, National Research Council. National Academy Press: Washington, D.C.

Stauffer, T.R. and F.H. Lennox 1984. Accounting for "Wasting Assets": Income Measurement for Oil and Mineral-Exporting Rentier States. OPEC Fund for International Development Vienna, Austria.

U.S. Dept. of Commerce. 1989. National energy accounts. U.S. Department of Commerce, Office of Business Analysis, Catalog No. OBA-NEA-08. March.

U.S. EPA. 1990. Environmental investments: the cost of a clean environment. U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, Publication No. EPA-230-11-90-083 November.

U.S. EPA. 1989. National Air Pollutant Emission Estimates: 1940-1987. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Publication No. EPA-450/4-88-022. March.

USGS. 1988. Estimated use of water in the United States in 1985. U.S. Department of the Interior, Geological Survey, Circular No. 1004.

Intergenerational Welfare Economics and Environmental Policy

by

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Paper Presented at the Association of Environmental and
Resource Economists Workshop,
"Integrating the Environment and the Economy: Sustainable
Development and Economic/Ecological Modeling,"

Boulder, Colorado, May 5-6, 1994.

Intergenerational Welfare Economics and Environmental Policy[1]

by

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The central "story" of environmental economics is now well established. Market economies do not, through the unaided guidance of the invisible hand, achieve economic efficiency in the allocation of many environmental resources. Causes of market failures include externalities, the public good characteristics of some environmental services, and property rights problems such as open access. Much has been accomplished by prescribing policies to reduce market failures. Nevertheless, one must ask whether market-failure based approaches adequately capture the full extent of the environmental issues facing the world today. Are global warming, worldwide erosion of soils, contamination of groundwater, losses of biological diversity, destruction of wetlands, overfishing, ozone depletion, rapid exhaustion of nonrenewable resources, and other such issues only of economic interest when they result from market failures? In this paper, we argue that defining environmental problems and their solutions within the market-efficiency framework misses the crux of many of today's environmental problems. A more complete environmental economics would be based on the dual goals of efficiency and sustainability.

We define an economy as sustainable if each successive generation has per capita economic opportunities at least as large as those enjoyed by earlier generations. By focusing on "opportunities" rather than "welfare" or "income," this definition places conditions upon initial endowments that each

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generation should receive. Endowments are broadly defined to include not only natural resources but also the capital, infrastructure, technology, knowledge and institutions that today's generation will pass onto its children.

In the first major section of this paper, we discuss the implications for welfare economics of including sustainability as well as efficiency. To accomplish this, three intergenerational theoretical models are developed. Following Page (1977), the first two are dubbed the “Hardtack World” and the “Corn World.” In the Hardtack World, a finite number of generations divide a single, non-renewable resource. In the Corn World, an unlimited number of generations exploit a renewable resource. Finally, we add a world with capital. The problem there is like the hardtack problem but capital formation (and hence technological progress) are possible. Here, output is produced using a non-renewable resource and capital. The output in each period can either be consumed or invested. Accumulated capital is productive in later periods and can be substituted, up to a point at least for diminished stocks of the resource as time progresses.

Though these cases are abstract and highly stylized, they serve to illustrate how a basic result of welfare theory carries over to the intergenerational world. Based on the familiar Edgeworth box diagrams, any Pareto efficient state of the economy rests on a foundation of initial endowments held by economic actors. However, as is well known, an infinite number of Pareto efficient states are possible, each based on a different allocation of initial endowments. While the Edgeworth box itself must be discarded in favor of a more dynamic representation of the economy, this basic conclusion carries over to a world with time and more than one generation. The result is an infinite number of possible efficient time paths for an economy, each depending on a different intergenerational allocation of endowments. In each of the cases we consider, there are many efficient time paths. Along any of these, it is impossible to make members of one generation better off without harming members of another. An important conclusion follows: While there are an infinite number of possible Pareto-efficient time paths, only a subset of those efficient paths are also sustainable. Achieving efficiency does not guarantee sustainability. Rather, if society wishes to be both efficient and sustainable, the quest for economic efficiency must be carried out within what we shall term “sustainability constraints.”

We then discuss how the principles of sustainability might be applied in a real world context. First, we address the basic question of whether sustainability should be a goal of economic analysis or not. Given the great public interest in sustainability and global environmental issues, it is our conclusion that economists would be remiss if we left such an important issue aside. A number of important complications arise in putting sustainability concepts to work. Most of all, the uncertainty associated with long-term environmental and economic issues makes determining if a particular path is truly sustainable difficult if not impossible. Uncertainty, even ignorance, of the long-term ramifications of our actions, make planning for efficiency and sustainability a very inexact task. Faced with this uncertainty, we discuss two policy options designed to push the economy towards both sustainability and efficiency.

EFFICIENCY AND SUSTAINABILITY IN THEORY

In this section we develop three simple models to discuss the fundamental issues of incorporating sustainability into the framework of welfare economics. We will demonstrate the importance of establishing constraints on the economy if society is to ensure that sustainability is achieved. While the framework presented here is far from general, we believe that extensions of the model can be developed to form policies for real economies that have a multitude of endowments and outputs. We start, however, with the most simple case.

The Hardtack World[3]

What we need to explore the welfare economics of intergenerational resource use is the dynamic analogue of an Edgeworth box diagram. Our simplest model elaborates a bit on an argument of Norgaard (1991). Figure 1 illustrates the principles involved. In order to focus on very fundamental issues, this figure takes the simplest possible intergenerational case: an economic universe consisting of only two non-overlapping generations with equal populations that exploit a single, non-renewable resource. It is as if "society" for purposes of welfare analysis consists of two separate groups of people who will be

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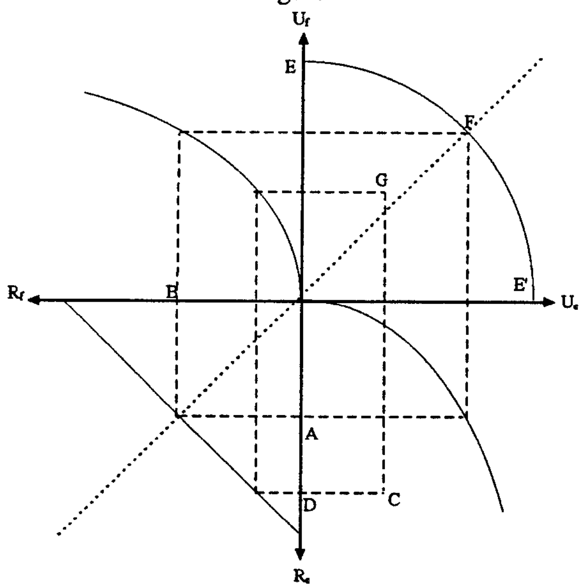
[3] This section draws heavily on Richard C. Bishop and Richard T. Woodward, "Efficiency and Sustainability in Imperfect Market Systems," Oregon State University, Graduate Faculty in Economics, Public Lecture Series, Forthcoming.

marooned on a desert island during non-overlapping time periods and only the first generation will have provisions, composed of a fixed supply of hardtack. The first group must decide how much hardtack to eat and how much to leave for the second group. We assume that capital per se does not exist and that there is no technological progress.

Figure 1



The per capita utility of the future generation, U_f, is measured by the vertical axis above the origin. Likewise the current generation's utility, U_c, is measured along on the horizontal axis to the right of the origin. Positive utility is assumed to be possible only when resources are consumed in positive quantities. Each point in the graph's northeast quadrant, then, represents a time path of per capita utility and points along the curve connecting points E and E' thus represents the efficiency frontier for this very simple world.[4]

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[4] We assume that the we assume that levels of utility are directly comparable across generations and that wealth within each generation is distributed according to that generation's social preferences. Obviously we are suppressing very important issues here, not the least of which is that Arrow (1963) has shown that a social ordering which adheres to a few simple rules is impossible.

The other quadrants in the figure help illustrate the derivation of EE'. The allocation of the resource between the generations is depicted in the southwest quadrant by the constraint with a slope of -1 to reflect its nonrenewable nature. From a slightly different perspective, the constraint pictured in the southwest quadrant shows the alternative time paths for intergenerational resource endowments. The curves in the southeast and northwest quadrants show the maximum levels of per capita utility that can be achieved by the current generation and the future generation, respectively, as a function of resource consumption. The intragenerational utility functions are assumed to be monotonically increasing in consumption and concave.

The point in the north-east quadrant that is actually reached depends upon two factors: the efficiency with which each generation uses the resource, and the distribution of the resource between the two generations. For example, if the current generation uses resources at point A, where the available resource is divided equally, and both generations behave efficiently, then per capita utility is F for both generations. If the current generation uses more than A, there will be so little of the resource left that the future generation will not be able to achieve a per capita utility level equal to that available to the current generation.

Sustainability can be simply defined in the fully efficient case. It would be achieved if the future generation achieves a level of per capita utility at least equal to that of the current generation. This criterion is met here if the current generation uses no more than A of the resource, so that the per capita resource stock available to the future generation is at least as great as that used by the current generation. In a fully efficient economy, therefore, sustainability can be defined either in terms of the distribution of endowments or in terms of outcomes.

The situation becomes slightly more complex if the possibility of intragenerational inefficiency is 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 per capita utility below its utility frontier. Suppose, as a specific case, that it uses D of the resource, but only achieves level C of per capita utility. This would allow the future generation to achieve only G at a maximum. Since, at G, the future generation's well-being exceeds that of the present, should we say that the current generation acted in a manner consistent with sustainability? Surely the answer must be "no." As point G makes clear, in a world with economic imperfections, it is not satisfactory to define sustainability in terms of levels of utility. While at G the future generation achieves a higher level of utility than the current generation, this is true only because of the inefficiencies of the current generation. We see in this simple example the importance of defining sustainability in terms of endowments, in this case the initial division of the resource stock. Our simple economy will be sustainable only if resource consumption by the current generation is less than or equal to A.

Interestingly, our analysis indicates that efficiency and sustainability need not be conflicting goals. We have demonstrated in the case of two generations and one-dimensional endowments that a subset of the infinite number of efficient paths is also sustainable. The dual goals of efficiency and sustainability could be pursued by treating sustainability as a constraint. A society holding both goals would constrain itself to considering only those efficient paths that are also sustainable. In the simple world of Figure 1, the sustainability constraint can be simply stated.

$$\text{Sustainability constraint} \quad R_c \leq \frac{S_0}{2}$$

where S_0 is the initial level of the resource. It is straightforward to extend this model to an economy with n generations. In this case the sustainability constraint for generation g would be given by

$$\text{Sustainability Constraint:} \quad R_g \leq \frac{S_g}{n-g+1}$$

Even with a large number of generations, it is possible to seek a path that is both efficient and sustainable. While we must examine this conclusion in more complex models, there is no obvious reason to believe this basic principle would not apply there as well.[5]

[5] We should candidly admit right here near the beginning that this issue has not been thoroughly explored in a rigorous fashion. Howarth and Norgaard (1990) and Howarth (1991) have made important beginnings. Their basic approach, however, is to assume a social welfare function and then investigate its implications for resource endowments. From our perspective, the dynamic equivalent of an Edgeworth box would be more useful in defining necessary and sufficient conditions for an efficient and sustainable equilibrium. Considerable progress has been made on growth models with overlapping generations (see, for example, Fisher 1992) but to our knowledge such models have yet to included natural resources.

Of course, the Hardtack World has tremendous limitations. It is not fully satisfactory as a model of sustainability for many reasons, not the least of which is its rather dim view of long run prospects. So long as the only resource is non-renewable and capital accumulation and technological progress are ruled out by assumption, sustainability over the indefinite future is infeasible. As the number of generations increases without limit the sustainability constraint will approach a restriction that none of the resource be used. Once a renewable resource is introduced, however, this difficulty disappears. Thus, we move from the Hardtack World to the Corn World.

Efficiency and Sustainability in the Corn World

Let us again consider an economy of non-overlapping generations, Instead of bringing a box of hardtack like in the preceding model, the resource is a renewable resource, say corn, where the g^{th} generation inherits an initial endowment of seed totaling S_g. The initial endowment of corn can either be consumed or planted. We presume growth rates are constant for each seed planted so that technology is constant returns to scale. Each pound of corn will result in a harvest of 1 + r units of corn at the end of a growing season. We shall assume that each generation lives for one growing season so that the corn available at the end of the growing season becomes the inheritance of the next generation. To be efficient all the corn available to each generation g, must either be planted or consumed, none can be lost. To be sustainable, each generation must plant enough corn, measured as I_g, so as to satisfy

$$\text{Sustainability constraint} \quad I_g \geq \frac{S_g}{1+r}$$

If this constraint is just satisfied, each generation will inherit an endowment of at least S_g so that the opportunities available to the next generation are identical to generation g. If generation g satisfies the sustainability constraint and is also fully efficient, they will be able to consume

$$C_g = \frac{rS_g}{1+r}.$$

Notice that economic growth is possible in the corn economy. Earlier generations could plant more than the minimum required by the sustainability constraint and enhance consumption possibilities for later generations. Later generations could in turn ratchet up the sustainability constraint from the initial level.

This is, of course, a much brighter world than the hardtack world provided that the initial endowment of corn is adequate. An indefinite number of generations could be supported at the minimal level set when the first generation arrives or at some higher level if the growth occurs. Furthermore, the corn world is easily interpreted within a welfare theoretical framework. An infinite number of Pareto efficient time paths exist. The only requirement is for Pareto efficiency is the one that has already been stated: each generation must either consume or plant all the corn at its disposal. Then, it would be impossible to reallocate corn among the generations to make members of one generation better off without simultaneously making some members of another generation worse off. Some of these time paths would be heavily skewed in favor of consumption by earlier generations; others would be more egalitarian; and still others would be skewed in favor of consumption by later generations. Still others might have rising and falling consumption across the generations. By adopting a sustainability goal, society chooses to limit itself to the subset of efficient paths that satisfy the sustainability constraint.

Before we begin to try to ferret out conclusions for policy from all this, one more world will be visited. It is like the hardtack world in that it depends to some extent on a non-renewable resource, but investment in productive capital will be possible.

Sustainability in an Economy with Resources and Capital

In the corn and hardtack economies discussed above, the endowment of each generation was limited to a single resource. We now consider the meaning of sustainability in economies with a two-dimensional endowment, consisting of a resource component, S, and a capital component, K. Some extensions to higher dimensions will be suggested but not fully developed. The basic idea, however, remains the same whether we are considering a one-dimensional or an n-dimensional endowment. The sustainability constraint will restrict economic activities to ensure non-decreasing economic opportunities.

In production each generation g uses up part of its stock of resources, R_g, leaving the next generation with $S_{g+1} = S_g - R_g$. The resources are used as inputs into a general production function $f(K_g, R_g)$ which is increasing and concave in both terms. The total output, $f(K_g, R_g)$, is either invested in capital, I_g, or a consumed, C_g, so that $K_{g+1} = K_g + [f(K_g R_g) - C_g]$. The capital stock is presumed to not depreciate and, once created, cannot be consumed but only used as an input into the production process. The population is again assumed to be constant, generations do not overlap and the total number of generations is finite. The implications for an economy with an infinite number of generations will be discussed below.

Since each generation's welfare is solely a function of consumption, generation g is acting sustainably if, after producing and consuming, it leaves an endowment of capital and resources sufficient for all succeeding generations to consume at the level that generation g could have consumed by being both efficient and sustainable. As an intermediate step, we define the sustainability set, $O_g(C_0)$, as the set of all endowment pairs, (K_g,S_g), which are sufficient to allow generations g, g+1,...,T to consume at least C_0. This set can be expressed in symbols as

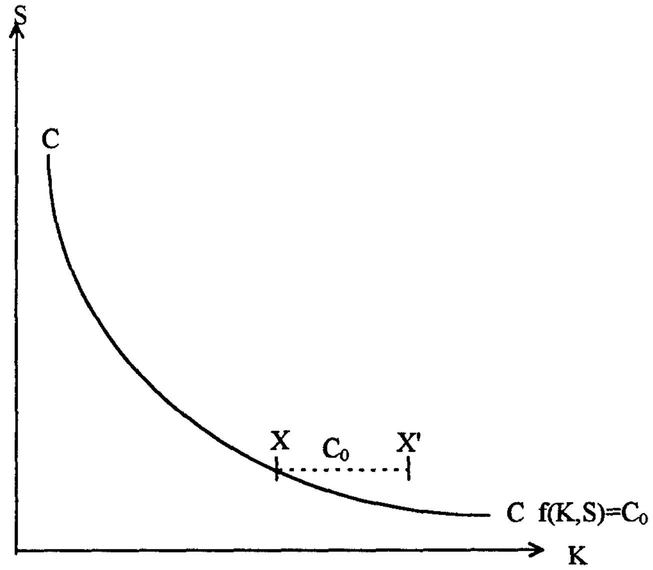
$$O_g(C_0) = \{(K_g,S_g) : \exists R_g>0: K_g + f(K_g,R_g)-C_0=K_{g+1}, S_g-R_g=S_{g+1}, (K_{g+1}, S_{g+1})\in O_{g+1}(C_0)\}.$$

The frontier of this set is the sustainability constraint, $\overline{O}_g(C_0)$. There exists a maximum level of sustainable consumption C^*, which is the greatest level of sustainable consumption given the available resources. The actual endowment of the g^{th} generation (K_g,S_g), lies on the sustainability constraint associated with C^*, $\overline{O}_g(C^*)$.

Derivation of a two dimensional sustainability constraint

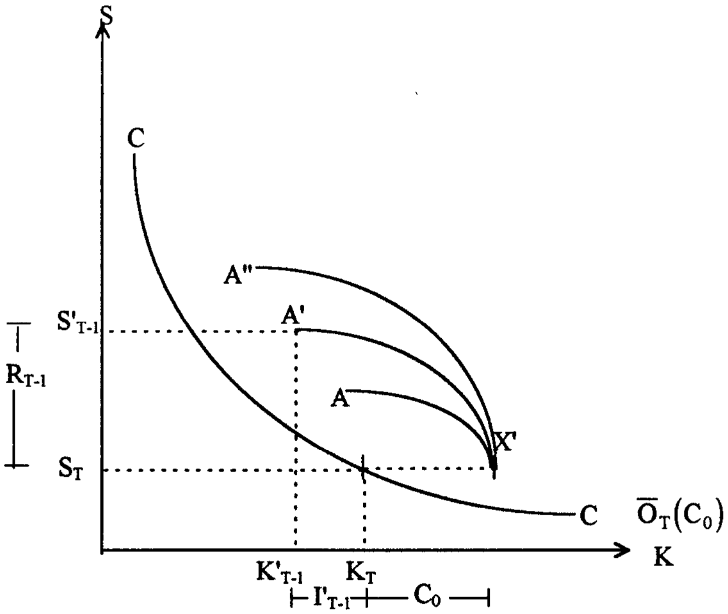
The sustainability constraint in the capital-resource economy is derived using backward induction. Consider the last generation in a T generation world. The last generation will, presumably, use up all remaining resources and not invest in capital so that, if they are efficienct, $C_T=f(K_T,S_T)$. The last generation's sustainability constraint associated with a consumption level C_0 is the set of all capital-resource endowments that will allow it to exactly produce C_0. This constraint, CC in Figure 2, is simply an isoquant. If the endowment pair inherited by generation T lies anywhere above CC, then it will have more than enough total resources to produce C_0. If it receives an endowment that falls below the constraint, then it will not be able to produce C_0.

FIGURE 2



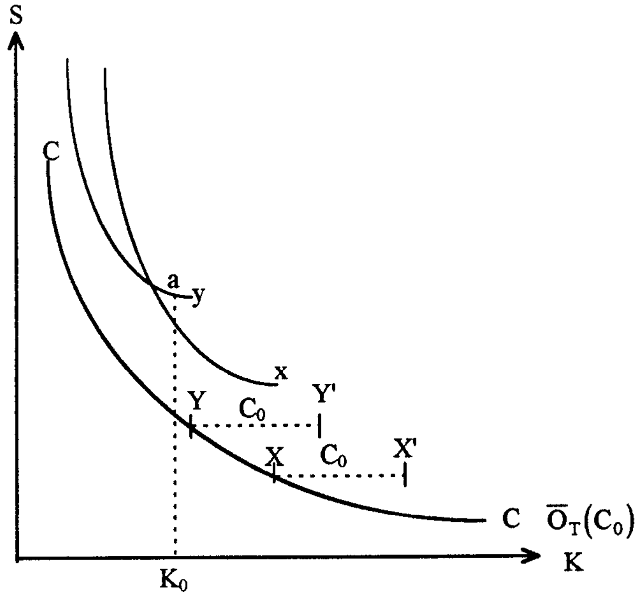
The next step is to derive the sustainability constraint for the second to last generation. Consider a point on CC, say X in Figure 2. If generation T is going to receive the endowment X, then generation T-1 will have to produce a level of output such that it is able to consume C_0 and still leave generation T at X. Since output, prior to choosing a level of consumption, can be used either for capital formation or consumption, generation T-1 must have an endowment sufficiently large to reach X' in Figure 2.

Figure 3



In Figure 3 three possible endowments A, A' and A" are indicated, all of which would be sufficient to allow generation T-1 to reach X'. Take point A', for example, where generation T-1's endowment is (K'_{T-1}, S'_{T-1}). By using R_{T-1} of the resource, and taking advantage of its endowment of capital, K'_{T-1}, generation T-1 could produce a total output of $I_{T-1}+C_0$. The curve connecting A' and X' is a production possibility frontier indicating the total output that can be produced at different levels of resource use. The production frontier is concave because as more resource stock is used up (movement vertically downward), the marginal increase in output declines. To reach X' from A, generation T-1 would have to use R_{T-1}. Because additional capital increases the marginal productivity of the resource, endowments with more capital stock, like A, would require less resource use to reach X'. Endowments with less capital stock, like A", would require more resource use to reach X'.

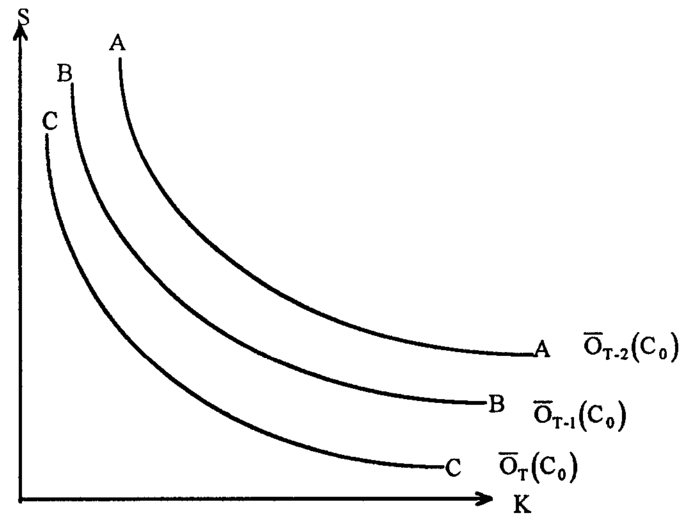
Figure 4



For each point like X, on the T^{th} generation's sustainability constraint, therefore, there are a multitude of possible endowments for the preceding generation that would allow it to consume C_0 and still leave generation T at X. By joining all the feasible endowments associated with X, we obtain a locus of points labeled with a small x in Figure 4. We then repeat the same operation for another point, Y, and obtain another locus, y in Figure 4. All the points on each of these two loci indicate endowments that would allow sustainable consumption of C_0 by generation T-1.

Consider two points along the feasible set of points x and y at a given level of capital K_0. Since either of these two points lead to the same level of consumption in generation T, the upper point, on they locus, indicated with an a is more than sustainable. That is, if the endowment inherited by generation T-1 were at a, then generation T-1 could produce enough to pass on a sustainable endowment to generation T and consume more than C_0. Hence point a lies above $\overline{O}_{T-1}(C_0)$. If we derived loci of sustainable endowments similar to x and y for every point on CC, the outer envelope of these curves would be the sustainability constraint for the $T\text{-}1^{th}$ generation $\overline{O}_{T-1}(C_0)$.

Figure 5



The resulting sustainability constraint for generation T-1 can then be traced out and would take a form like BB in Figure 5. Following the same procedure, the sustainability constraint for generation T-2 could also be traced out and would look something like AA. Repeating this process over and over again, the sustainability constraint of the g^{th} generation, $\overline{O}_g(C_0)$, is found. This locus would be the set of minimum endowments that generation g would need in order to consume C_0 and still leave an endowment of capital and resources so that generation g+1 and all following generations can also consume C_0.

Once $\overline{O}_g(C_0)$ is found, we can compare the actual endowment, (K_g,S_g), with the sustainability constraint. If we find that the g^{th} generation's endowment lies above $\overline{O}_g(C_0)$, then a C_0 is not optimal, a higher level of consumption could be sustainably consumed. If we find that the actual endowment lies below $\overline{O}_g(C_0)$, then C_0 is not sustainable and a lower level of consumption must be considered. In an iterative fashion it would be possible to determine the level of consumption C^* such that the g^{th} generation's endowment lies on $\overline{O}_g(C^*)$.

Extensions and generalizations of the multi-dimensional sustainability constraint

A number of extensions of the above analysis are worth pointing out. First, we can make some inferences about the economy as we relax the assumptions of finite generations. Much like the hardtack world above, the world that we have been discussing here may not allow sustainable positive levels of consumption if the number of generations is infinite. One way to state this is that for any positive level of consumption C_0, any finite endowment (K, S) will become unsustainable (fall below the sustainability constraint) in some finite number of generations, T^*. If, for example, the production function $f(\cdot)$ is CES with an elasticity of substitution less than one[6], then the average product of a unit of resource is bounded from above, making it impossible infinitely sustain a positive level of output (Dasgupta and Heal, 1979).

If the resource is more like that of the corn economy, such that if there is any positive resource stock $\underline{S}$, a level of resource $\underline{R}($ $\underline{S}$ can be used without diminishing the resource endowment of the following generation, then sustainability can be achieved even with an infinite number of generations. In this case the sustainability constraint associated with any finite level of consumption will converge to a single locus so that $\overline{O}_g(C_0) = \overline{O}_{g+k}(C_0) = \overline{O}(C_0)$ for all finite k.[7] This capital-corn economy simplifies the analysis in many ways since if generation g can determine the sustainability constraint on which its endowment lies, it can determine whether its actions are sustainable by evaluating if the endowment it passes onto generation g+1 lies on the same constraint. This property is used to analyze indicators of sustainability in Appendix A.

While we have considered only a two-dimensional endowment, the endowment vector could in principle be extended to a third or higher order vector. The number of calculations involved in

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[6] A constant elasticity of substitution (CES) production function in K and R is of the form

$$f(K,R) = \left[\alpha_1 K^{(\sigma-1)/\sigma} + \alpha_2 R^{(\sigma-1)/\sigma} + (1-\alpha_1-\alpha_2)\right]^{\sigma/(\sigma-1)}$$
$$\alpha_1, \alpha_2, 1-\alpha_1-\alpha_2 > 0 \text{ and } \sigma > 0, \sigma \neq 1.$$

where σ is the elasticity of substitution between K and R If $\sigma = 1$, and $\alpha_1 + \alpha_2 = 1$, then $f(K,R)$ is Cobb-Douglas

[7] This can be seen by noting that if the g^{th} generation inherits (S_g, K), then passing on the same endowment to the next generation would clearly be sustainable, though this might not be optimal. Nonetheless, for any $\underline{R}>0$ and $\underline{C}>0$, there is a level of capital, $\underline{K}$ such that $f(\underline{K},\underline{R})=\underline{C}$. So, for all resource levels S that yield a positive recharge, R, we know that there is a capital level sufficiently high to support any consumption level without diminishing the resource stock. Hence, there is an upper bound on the sustainability constraint, composed of levels of K and S which can produce C_0 without diminishing the resource stock. Because this upper bound to the sustainability constraint exists, it must be the case that a single constraint exists at or below this upper bound.

calculating such a frontier, however grows exponentially. Hence, the properties of the n-dimensional sustainability constraint are not explored in this paper.

SUSTAINABILITY IN PRACTICE: FROM THEORY TO POLICY

There are several lessons from the above theoretical models that we will draw on to discuss the implications of sustainability for economic policy. First and foremost, in each of the models we showed that to ensure that sustainability is achieved, policy makers must consider the joint objectives of economic efficiency and sustainability. This may at first appear to be an obvious extension of the Second Welfare Theorem, and in a sense it is. Yet, when we consider intertemporal problems, as some examples below will show, very often economists voice only efficiency concerns when sustainability seems to be the central issue.

Secondly, we find that substitution and replenishment are both sources of sustainability in the long run. In the corn economy, sustainability required that each generation consumed no more than the recharge to the resource stock. In the capital-resource economy sustainability could be achieved if attention is given to the degree to which substitution is possible given the economy's productive capacity. Here too, however, sustainability will not be guaranteed unless the economy operates within the bounds defined by the sustainability constraint.

Finally, up to a point, sustainability can be achieved through substitution. As we see in the capital-resource economy in which substitutability is possible, sustainability does not require that the resource endowment passed from one generation to another be constant. Unless a particular resource is both essential and non-renewable, a policy that leads to the reduction of that resource is not necessarily unsustainable. However, unless specific measures are taken to increase other dimensions of the endowment vector, policies that have the effect of diminishing the resources being passed on to future generations will threaten sustainability. Here we see that our uncertainty makes defining policies that pursue both sustainability and efficiency particular troubling. Accurate knowledge of the sustainability constraint is never available. One policy intended to move the economy towards sustainability despite our enormous uncertainty is discussed below. We turn now, however, to a more fundamental question.

Should Sustainability Be An Economic Goal?

Advocating sustainability as a policy goal will be viewed with uneasiness by many economists because of their strong propensity to avoid expressing views on what is fair and what is not. 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 economies sustainable is a worthy policy goal. We propose to conduct an economic discussion on a "what if" basis: What if sustainability were a goal of economic policy? What would the implications be for environmental economics? Our case for arguing that this is a meaningful exercise for economists to participate in is strengthened by the result that efficiency and sustainability need not be conflicting goals. It should be possible to seek a path that is both efficient and sustainable. Proposed steps that are viewed by their advocates as promoting sustainability will also have implications for efficiency. As a result, economists are being drawn into the debate.

As long as we are dealing with potential qualms of our economic colleagues, a second question also deserves attention. Some economists who will grant that sustainability is the potentially interesting from a theoretical perspective may still argue that the concept is irrelevant to policy, since economic growth can be expected to continue into the indefinite future. In the context of sustainability, economic growth in excess of growth rates in population implies ever expanding economic opportunities for successive generations. Witness for example, Beckerman's (1992) statement in the context of the debate over policies to address global warming,

> to give priority to highly speculative global environmental issues in general and to global warming in particular, in the interests of future generations who are likely to be far richer than we are today, and to take drastic action in pursuit of this goal, however costly it may be in terms of current living standards, would represent an unjustified sacrifice of the clearly apparent interests of billions of very poor people today.

In the context of this paper, such statements maybe interpreted as arguing that the sustainability constraint is not binding. Let us consider this view further using the concept of evolving intergenerational endowments.

A look at the relationship between economies and nature makes it hard to escape the feeling that future generations are in a vulnerable position. Each generation tends to treat as its endowment virtually all the natural resources that it has the technological and economic means to exploit. Historically, resource depletion and degradation were limited by technology, labor, and capital constraints. Exploitation of natural resources on the scale that is feasible today was impossible. The current generation, in contrast, is using non-renewable resources at an unparalleled rate. Furthermore, renewable resources are being more and more heavily exploited and degraded on a global scale. There can be little doubt that future generations will inherit natural resource endowments that are much reduced and much degraded.[8]

Societies have historically augmented their natural resource endowments through conquest and exploration to offset the depletion and degradation of their resources. Certainly, augmentation of resource endowments will continue to occur, but diminishing returns to efforts in this direction maybe felt. No more continents filled with nearly virgin resources are available. One has to wonder, for example, how many more oil producing areas with reserves as large as the Middle-East or even Alaska's North Slope are available for discovery.

With natural resource and environmental endowments declining, sustainability, if it can be achieved at all, will depend on increasing non-resource components of the endowment that future generations will receive. Just as capital can be augmented to makeup for reductions in the resource stock in the simple economy above, in the real world non-resource components are augmented by processes that we shall refer to collectively as "social progress". Progress takes many forms: scientific and technological innovations, improvements in institutions, increases in cultural items (e.g., art and music), and human and physical capital accumulation. Social progress creates substitution possibilities, reducing or overcoming the ill-effects of declines in the natural resource endowments. Institutions, such as those associated with markets, can also play a role, creating incentives for both substitution and social progress.

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[8] Of course, much can be done to reduce resource depletion and degradation. Still, the point is that human life as it exists at the current time, appears to be incompatible with increasing or even constant future resource endowments. Recycling, pollution control, and other approaches are less than perfectly effective in stemming the tide of depletion and degradation.

In recent decades and centuries, social progress and resource augmentation in many countries have been more than adequate. The result has been expanding per capita economic opportunities. Despite reductions in the resource stock, these nations have apparently not violated their sustainability constraint. Though this is encouraging, sufficient social progress to allow continued growth in per capita economic opportunities may not be automatic.

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.[9] 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 possibilities for social progress and resource augmentation. 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 here. Rather, these are issues about which sensible people ought to agree to disagree. Those who argue that the current economy is not sustainable ought to admit that they could be wrong, Perhaps social progress will be adequate to counterbalance depletion and degradation of natural resource endowments for the foreseeable future. And, those who have more confidence in social progress should admit that the economy could possibly be on an unsustainable path. Neither theoretical economic arguments nor empirical evidence are sufficient to justify a definite conclusion about the sustainability of the time paths on which the earth's economies find themselves. Accordingly, an investigation of the economic implications of combining efficiency and sustainability goals could have substantial policy relevance.

Uncertainty

An undercurrent in what has just been said about the Sustainability Debate now needs to be made explicit: Implementation of the concept of sustainability constraints in actual policies would have to

[9] Relevant literature is summarized in Hartwick and Olewiler (1986), Chapter 6.

be attempted in a world of extreme uncertainty. Our theoretical efforts here have been conducted under the assumption of perfect knowledge. In fact, we of the current generation are quite ignorant about how our use of environmental and other natural resources will affect the economic prospects of future generations. As has already been emphasized, it is not clear whether the sustainability constraint is even binding. Earlier generations have a limited basis for judging which resources can be exhausted and degraded with little or no harm to later generations and which might be extremely valuable. Furthermore, the nature of the trade-offs between environmental resource components of the endowment vector and non-resource components are difficult to anticipate. 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 any given case, it is difficult to predict whether future generations will be better off in terms of economic opportunities with more environmental resources or with more social progress to augment their non-resource endowments. Alternative endowment vectors (including various levels of natural resource and non-resource components) have highly uncertain potential economic implications.

The uncertainty associated with these decisions is of an extreme kind, which for convenience, we might term "ignorance."[10] If we think in traditional terms, "risk" is used to characterize situations where more than one future outcome is possible and where all outcomes are known in terms of their payoffs and probabilities. "Uncertainty," in the traditional terminology, involves situations with more than one possible outcome, where payoffs are known, but probabilities are completely unknown. Neither of these constructs seems quite appropriate here, Under "ignorance," as we shall use that term, not all possible outcomes are known and payoffs from known outcomes are not always clear. Probabilities are likely to be inestimable or very tentative at best.[11]

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[10] We believe this term was originally suggested to describe such uncertainty in natural resource problems in some of the unpublished work of Alan Randall. He used the term in Randall (forthcoming). Randall and Thomas (1991, p. 15) explicitly suggested that "the problem is one of ignorance rather than mere risk and uncertainty," thus anticipating the argument made here.

[11] For example, how does one deal with the logical requirement that probabilities summed across all outcomes must equal unity if some of the possible outcomes are not known?

As is clear from any recent issue of mainstream economic journals, the standard procedure for dealing with uncertainty involves assuming that outcomes and associated payoffs are known and probabilities are known at least in subjective terms. It is worth asking whether such approaches are applicable to ignorance. Perhaps strategies are needed that address ignorance directly, rather than trying to fit the problem into a risk framework. [12] At any rate, as we move from theory to policy, ignorance must be explicitly considered.

From Macro-Level Theory to Micro-Level Decision Criteria

Sustainability, as defined in this paper, is a macroeconomic concept. Either an economy, taken as a whole, is on a sustainable path or it is not. To ask whether a specific macroeconomic alternative is "sustainable" or not makes sense only in the context of the economy as a whole. A discussion of macroeconomic issues associated with sustainability and national income accounting are discussed in Appendix A. In the meantime, some attention needs to be devoted to considering how to go from the macroeconomic status of the economy **vis-à-vis** a sustainability constraint to criteria that can be applied to macroeconomic-level decision making.

In a sense, our goal is to develop microeconomic criteria for specific resource decisions. We take it for granted that actual decisions relating to sustainability will have to occur in a piecemeal fashion. In both the public and the private sectors, management of natural resources involves many individual choices over time. Our task is to explore whether criteria can be developed to judge whether each such decision is, in some sense, "sustainable."

As we are using the term macroeconomic, Pareto efficiency is also a macroeconomic concept. An economy as a whole is either on its Pareto frontier or it is not. It is instructive to consider how the transition from the macroeconomic level to the microeconomic level works for efficiency. That actual economic decision making about the allocation of specific resources must be piecemeal is taken for

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[12] Perrings (1991) suggests the use of a notion of uncertainty based on Shackle (1952) as an alternative to standard risk analysis in such situations.

granted. An economist who notes that a Pareto condition is violated in some specific instance, prescribes policies to make the economy “more efficient” with respect to that specific micro-level problem. Doing so raises second-best considerations. Given that inefficiencies are present in many sectors of the economy, applying the Pareto conditions piecemeal is unlikely to be fully optimal and the result of an intervention intended to improve economic efficiency could actually reduce aggregate social welfare. However, attempting to fine tune micro-level decision criteria to account for inefficiencies elsewhere is normally not practical. In practice, the economist hopes that application of simplified efficiency criteria in arriving at individual public decisions will improve efficiency most of the time.

Similar strategies will be required if sustainability is to be translated into workable criteria at the micro-level. A decision alternative maybe said to “enhance sustainability” or “make the economy more sustainable” if it expands the aggregate economic opportunities available to future generations. In a partial sense, it maybe relatively easy to determine how the policy is affecting a few components of the endowment. Much more difficult to anticipate, however, are the indirect effects of physical spillovers and reactions by economic agents to the new policy. As we have pointed out already, economic opportunities depend on the full endowment vector including non-resource components as well as natural resource components. If the policy indirectly leads to changes in the economy that affect other components of the endowment by diminishing their quantity or quality or inhibiting their growth, then, in net, the policy might have a negative effect on sustainability.

Such complications are analogous to the problem of the second best of efficiency analysis. For example, consider a policy that would encourage soil conservation and would not, in any identifiable way, impede social progress. Society might proceed with this intervention in order to enhance sustainability, only to learn that it led farmers to use more chemicals that contaminated groundwater. Just as sectors of the economy are interlined by market signals that affect whether a given projector policy is efficient, so resource and non-resource endowments are linked both in nature and through the economy in complex ways. Obviously such linkages should be identified and evaluated to the extent possible in considering whether public or private decisions will enhance sustainability. But, the ability to trace such effects is likely to be limited in practice. Following the efficiency analogy, the analyst can do little more than hope that the more obvious effects of choosing alternative courses of action will be sufficient most of the time to indicate whether those alternatives will enhance or reduce future economic opportunities.

Trade-offs between different components of the vector of endowments must be carefully considered in judging the sustainability-enhancing potential of a particular choice. Our example of soil versus groundwater illustrates this well. Suppose that, without a project, future generations living in a certain region will inherit less soil but purer groundwater. If the soil conservation project is adopted, the opposite will be true. Which alternative would contribute most to their utility possibilities is not obvious at first glance. If soil erosion is economically irreversible over relevant time spans, but groundwater could be purified using known technologies at modest cost, the soil erosion control project might be judged as contributing positively to sustainability. There are likely to be many judgment calls on such issues.

Confronted with ignorance and the possibility of unexpected consequences of interventions designed to enhance sustainability some will no doubt decide that the whole problem of sustainability is intractable and choose to ignore it. The theory of the second best and concerns about economic fairness have led some to adopt a similar attitude with respect to economic efficiency. Others, whether the issue is efficiency or sustainability, accept second best problems and ignorance as facts of life, and try to figure out how humankind might muddle through anyway. As part of the latter group, we will now proceed to consider policies that might help to achieve sustainability goals.

PRACTICAL STEPS TOWARD AN EFFICIENT, SUSTAINABLE ECONOMY

Two preliminary steps toward practical implementation of the framework developed here will be discussed. First, we shall consider the Safe Minimum Standard of Conservation for endangered species, reinterpreting this long discussed concept as a sustainability constraint. Second we turn to global warming, focusing on how a carbon tax would work in an economy seeking an efficient, sustainable path. In both of these examples, we emphasize that if sustainability is to be achieved, policies should explicitly consider this goal. Efficiency based analysis alone will not ensure sustainability.

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 the stability and productivity of the ecosystems within which human activities must be conducted. Furthermore, the earth's plants and animals provide a reservoir of potential new resources to produce food, building materials, aesthetic enjoyment, energy, paper products, pharmaceuticals, transportation, recreation, and other desired commodities and services. Maintaining a sufficiently diverse flora and fauna has the potential to contribute to both economic efficiency and sustainability.

As long as human-caused extinctions were rare, there was little need for concern. Species diversity was a free gift of nature. At the end of the Twentieth Century, however, species 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. Such steps, however, would 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. On the other hand, reducing the rate at which biological diversity is eroding will involve economic costs to the current generation that not only will harm its members but could conceivably affect the non-environmental endowments of future generations. In the terms developed here, extinctions threaten efficiency and sustainability, but measures to protect diversity could also have the potential to threaten both goals. Defining a sustainable, efficient course is not a simple problem.

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, 1995). Adopting the SMS strategy as a policy objective would mean avoiding extinction in day-to-day resource management decisions, Exceptions would occur only where it is explicitly decided that the 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, whereto 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 but is instead a crude step toward the ideal of a fully efficient, sustainable economy. Because of ignorance about the future and other issues (Bishop and Woodward 1994), such an ideal is far from attainable. The SMS should be thought of as a practical strategy to be implemented in lieu of the ideal. The goal of the SMS strategy is to safeguard the economic opportunities of future generations by preserving some species that will prove useful and valuable to them and that would otherwise have been lost. The first-best solution to the problem, were it attainable, would involve an optimal endowment composed of a wide range of species and other resource and non-resource components. The SMS strategy is intended to push economies in that direction by augmenting future endowments of species diversity. Under the SMS, we presume that substitution of other components of the endowment for the species is difficult but not impossible. Costs of protecting a species become "intolerable" when it is believed that protecting a species might be so restrictive that both efficiency and sustainability would be inhibited.

The SMS strategy also requires consideration, within the limitations imposed by ignorance, of the implications of preservation for efficiency and for the non-environmental endowments of future generations. The social costs of choosing the SMS are important indicators of potential losses in efficiency and sustainability. Ignorance means that the full benefits of preserving specific species cannot be known. The higher are costs, however, the more likely they are to exceed benefits, were the latter filly known. Furthermore, though obviously any generalization would be questionable, one might expect that the higher are costs, the more disruptive will preservation of species be to social progress and hence to the non-environmental endowments of future generations. The SMS seeks to increase the future endowments of biological diversity without large sacrifices in efficiency or social progress.

Social costs here include the out-of-pocket costs for protecting species of plants and animals. For example, guards may be needed to protect an animal species from poaching. Opportunity costs, reflecting foregone resource uses, would need to be added in. Such opportunity costs might include, for example, the timber value of old-growth forests that must remain unharvested to provide habitat. External costs, such as livestock losses to an endangered predator, may also occur and need to be counted. Against these costs must be counted any measurable benefits from preservation. Some species, though endangered, may provide aesthetic enjoyment. Some members of society may hold existence values for preservation of endangered species of wildlife (Boyle and Bishop 1987; Bowker and Stoll 1988). If so, these should be counted. Because the long-term benefits that biodiversity may contribute through ecosystem stability and discovery of new resources are so difficult to anticipate, probably no allowance for them will be possible in most cases. We stress this problem by defining the net social costs of the SMS as out-of-pocket costs, plus opportunity costs, plus external costs minus measurable benefits. Measurable benefits are those benefits that can be expressed in monetary terms with reasonable confidence.

Whether the net social costs of the SMS are within the bounds of acceptability or not is a social decision that may have to be left to Randall's "extraordinary decision process." What we are asking, in part, is whether or not it is reasonable for the current generation to be required to make a given level of sacrifice to enhance the species diversity endowments of future generations. Such decisions involve value judgments beyond those that most economists are comfortable making. Societies, through the institutions of government, may have to consider such issues without direct help from economists.

Since the SMS depends upon the current generation's judgment as to what represents "intolerable" costs, it is nearly 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 maybe saved.

Note also that the SMS would only be one of many objectives of policy. As Randall stated in the quotation presented earlier, the SMS would not have "trump status." Many worthwhile objectives must vie for economic attention and public resources, and preservation of biodiversity probably would not 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 can be saved only by bearing unacceptably high costs or through unacceptable sacrifices in other social objectives.

Randall (1991, 1995) has recently introduced a new and highly original framework for considering the SMS in the context of public policy formulation. This framework is useful in considering the relationships between efficiency and what we here term sustainability. Since loss of biodiversity raises intergenerational ethical questions, Randall reasoned that insights might be gained by considering it in the context of three major theories of ethics. Randall argued that making social choices based on benefit-cost analysis can draw some support from all of these schools but none would endorse benefit-cost analysis in an unqualified way. However, quoting Randall (1995, p.36),". . . it seems that the same general kind of decision rule - maximize net benefits subject to an SMS constraint --is admissible under the consequentialist, duty-based, and contractarian reasoning." Since concerns about sustainability are grounded in ethics, this would appear to be a promising direction for additional work.

Global Warming and the Carbon Tax

The possibility of global warming due to the accumulation of greenhouse gasses in the atmosphere poses a very real threat to global sustainability. Based on climatic models and some empirical evidence, scientists believe that emissions of carbon dioxide and other "greenhouse gases" into the atmosphere is setting in motion a gradual warming of the planet. Though highly speculative, global climatic models predict that by the end of this decade greenhouse gases that will have accumulated in the atmosphere will commit future generations to a planet as much as three degrees Celsius warmer than the climate we enjoy today (Cline, 1992, Table 2. 1). Over the long run, even greater changes in the globe's climate are predicted. With this increase in temperatures will come a wide range of effects on humankind. Some effects will be positive, such as regional increases in agricultural production. Other changes will negatively affect society, such as the destruction of coastal ecosystems and real-estate due to rising sea levels. In net, it is generally believed that the effects of global warming will impose costs upon future generations (see, for example, National Academy of Sciences, 1992).

Emissions of greenhouse gases are intimately linked with the economy. Virtually all productive activities in developed nations use carbon based energy, contributing to the greenhouse warming. To some extent, our economic activities today are carried out at the expense of the climate of the next century. Using the language of this paper, our production today diminishes the climatic endowment of future generations. The greenhouse problem therefore, is fundamentally one of sustainability.

Despite the very long term distributional consequences of global warming, the debate within economics about how to best address the problem has centered on issues of efficiency. Nordhaus (1993), for example, refers to the greenhouse effect as "the granddaddy of public goods problems" (p. 18). When seen in this light, the problem can be reduced to a standard externality problem in which the level of greenhouse gas production is inefficiently high. Analysis motivated entirely by an efficiency perspective, however, will fail to address what we see as primarily one of sustainability since, as we have shown above, pursuit of the efficiency will not necessarily lead to sustainability.

The policy option to address global warming concerns that is most frequently discussed is a tax on carbon emitted by the burning of fossil fuels. This tax would encourage a reduction in the level of CO_2 emitted but would impose costs on some sectors of the economy. The costs of a carbon tax policy would take the form of a reduction in the quantity of goods and services that are produced using carbon based fuel. These costs would be borne by both current and future generations. The benefits of a carbon tax, on the other hand, would accrue primarily to the generations of the next century and beyond. As a result of reductions in greenhouse gas emissions, the planet would warm less than it would have without the policy, reducing the costs that will be borne by those generations. The efficient level for the tax is where the marginal benefit of increasing the tax equals its marginal cost. At lower tax rates, the marginal present value of benefits exceeds costs, at higher rates the marginal cost exceeds the benefits.

Implicitly, such efficiency measures look for the point where the timers from an additional reduction in gases can no longer payoff the losers. Elsewhere (Woodward and Bishop, forthcoming) we have argued that standard efficiency analysis of global warming implies a distribution of rights in which "the current generation has the right to emit endlessly and future generations are obligated to accept the consequences unless 'they' are capable of compensating 'us'." While efficiency driven policies may diminish the warming experienced by future generations, under such a policy greenhouse gases would continue to accumulate and the planet will continue to warm. Efficient policies, therefore, will not eliminate the threat that the greenhouse effect poses to global sustainability.

As Beckerman argues above, it could be presumed that sustainability is not at risk because other components of the endowment vector are growing fast enough to more than compensate future generations for losses in the climatic endowment. In this case only the efficient level of reduction could be justified. The uncertainty in global warming analysis, however, is extreme. Of a surveyed group of experts, ten percent estimated that the damages associated with a three degree C warming would be 5.5 percent of world output or more while another ten percent had a median estimate of zero total loss or less (Nordhaus, 1993, p. 17). With such uncertainty on only one issue, how can we be certain that the multitude of changes in the endowment vector overtime will in net mean that the sustainability constraint is not binding? Sustainability may indeed be threatened, and if this is true, steps beyond those that can be justified on efficiency grounds maybe necessary.

In Woodward and Bishop (forthcoming) we propose that given these uncertainties, a prudent policy would be to address both efficiency and sustainability. Recognizing that global warming does have efficiency implications, a carbon tax should be used to reduce emissions at least to the point where the marginal benefits of a reduction in emissions equals the marginal cost. However, we argue that the carbon tax offers an opportunity to take "a full step in the direction of sustainability." Since a carbon tax would generate enormous revenues, we suggest that those revenues should be used to explicitly compensate future generations by augmenting other components of the endowment vector. This could be done by improving environmental components of the endowment, stimulating technological progress, expanding infrastructure, even diminishing the debt burden that we pass on to our children (Bromley, 1989). Moreover, when global warming is seen as threatening sustainability, it might be acceptable to adopt a policy which reduces emissions beyond the level which follows from efficiency analysis in order to augment the climatic endowment of future generations. Just as intratemporal distributions cannot be justified on efficiency grounds, there is no reason to believe that a policy that redistributes intergenerational endowments would have benefits in excess of the costs.

The issue of global warming demonstrates well the importance of explicitly recognizing sustainability as a goal within economic analysis. The concern about the greenhouse effect arises not because we see the problem as reducing our total economic productivity, but because a sense of fairness and moral responsibility makes the status quo unacceptable to many. As such, while efficiency is important in discussing any policy alternative, it cannot be the sole criterion on which economists base their policy recommendations.

Conclusion

We have demonstrated in this paper that, if sustainability is deemed to be a social objective, then it both can and should be incorporated directly into economic analysis. Economic efficiency does not necessarily lead to sustainability. To ensure sustainability society must be take care to avoid violating its sustainability constraints. In theory, sustainability constraints can be determined which establish exactly the endowments that need to be passed onto the next generation in order to provide them with opportunities equal to those enjoyed by the present generation. In practice, exact determination of the sustainability constraint is impossible given the enormous uncertainty that dominates long-term economic and environmental issues. However, despite our ignorance and the complexity of interactions between the economy and the environment some guidelines for policy can be established.

The SMS and the carbon tax with associated spending priorities illustrate how sustainability constraints tight be implemented in practice. Obviously, a fully general constraint would have to cover a wide range of other resource issues, possibly including contamination of groundwater, soil erosion, deforestation, ozone depletion, and the like. In each such case, the endowments of future generations would need to be carefully considered in making resource management policy. Furthermore, a distinct approach would need to be developed to protect each such resource to give due attention to efficiency as well as sustainability. Once a more or less general constraint is in place, then it should be possible for both public and private economic agents to re-optimize to pursue the efficiency goal within the new regime of intergenerational endowments. In this way, the economy would move toward an efficient and sustainable path.

Appendix A: Sustainability Constraints and Indicators of Sustainability

While in practice it may be impossible to find the sustainability constraint with precision, the construct can be used to understand the meaning of sustainability. Consider a capital-resource economy in which sustainability is possible so that the sustainability constraint converges to a single locus. An implicit function $O^*(K_g,S_g)=\underline{O}$, can be defined where $\underline{O}$ is a constant and $O^*(\cdot)$ closely approximates $\overline{O}_g(C^*)$. Taking the total differential of $O^*(\cdot)$, we find that along the sustainability constraint

$$\frac{\partial O^*}{\partial K}\cdot\Delta K+\frac{\partial O^*}{\partial S}\cdot\Delta S\approx 0.$$

Hence, an approximate rule for sustainability would be to ensure that

$$\frac{\partial O^*}{\partial K}\cdot\Delta K+\frac{\partial O^*}{\partial S}\cdot\Delta S\geq 0$$

This constraint is similar to many other linear rules for sustainability, such as Hartwick's (1977) rule that the scarcity rents from a resource should be reinvested to ensure sustainable growth. This relationship is also similar to the implicit rule that in natural resource accounting studies which estimate the depreciation of natural resources. What distinguishes the rule derived from the sustainability constraint is that it is grounded only in the production possibilities of the economy and does not assume that the economy is operating on the efficiency frontier.

Consider a simple estimate of the net domestic investment (NDI) as might arise from a natural resource accounting study. Accounting for both the appreciation and depreciation of the capital and resource sectors, net investment is estimated, $NDI=p_K\cdot\Delta K+p_S\cdot\Delta S$. If the estimated value of NDI were greater than zero, this might be interpreted as indicating that the economy is on a sustainable path since the value of the total endowment has not diminished. This rule will be consistent with sustainability, however, only if $\frac{\partial O^*}{\partial K}\Big/\frac{\partial O^*}{\partial S}=p_K/p_S$. Since prices in an economy are critically dependent upon the distribution of endowments across agents in the economy (see Howarth and Norgaard, 1990), it is not guaranteed that the market prices would be appropriate even in a perfectly functioning market economy. The problem becomes more severe if the endowment has public good characteristics (e.g., national parks), markets do not exist for portions of the endowment (e.g., the climate) or other sources of market failure are present. The sustainability constraint, therefore, provides a useful target for valuation in natural resource accounting studies.

This framework, therefore, provides a new perspective on economic indicators of sustainability. By working directly with the sustainability constraint we allow for substitution, but do not presume that markets provide all necessary information with perfection. Of course the framework is not fully developed and, would certainly have substantial informational needs, perhaps even more so than standard environmental accounts (United Nations, 1993). We would argue that the returns might be higher since such an approach leads directly to the societal sustainability constraint and, therefore, is a better indicator of the economy's sustainability.

References

Arrow, Kenneth Joseph. 1963. Social Choice and Individual Values. New Haven, Yale University Press.

Beckerman, W., 1992. "Economic growth and the environment: Whose growth? Whose environment?" World Development. 20(4):481-96.

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.

Bishop, Richard C. and Richard T. Woodward. 1994. "Efficieny and sustainability in imperfect market systems." University Graduate Faculty of Economics Lecture Series #6, Oregon State University.

Bowker, J.M. and J. R Stoll 1988. "Use of dichotomous choice nonmarket methods to value the whooping crane resource." American Journal of Agricultural Economics, 10:372-381.

Bromley, D. W., 1989. Entitlements, missing markets, and environmental uncertainty. Journal of Environmental Economics and Management 17(2):181-94.

Boyle, Kevin J. and Richard C. Bishop, 1987. "Valuing wildlife in benefit cost analysis: a case study involving endangered species." Water Resource Research, 23:943-50.

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

Ciriacy-Wantrup, S.V. and William E. Phillips. 1970. "Conservation of Calfornia Tule Elk: a socioeconomic study of a survival problem," Biological Conservation. 3(1): 23-32

Cline, W.R, 1992. The Economics of Global Warming. Institute for International Economics, Washington, D.C.

Fisher, Eric O'N. 1992. "Sustained growth in the model of overlapping generations," Journal of Economic Theory, 56:77-92.

Hartwick, John M. 1977. "Intergenerational equity and the investing of rents from exhaustible resources" American Economic Review 67(5)972-74.

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

Howarth Richard B. 1991. "Intertemporal equilibria and exhaustible resources: an overlapping generations approach." Ecological Economics 4:237-252.

Howarth Richard B., and Richard B. Norgaard. 1990. "Intergenerational resource rights, efficiency, and social optimality," Land Economics, 66(1): 1-11.

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. 1992. Policy Implications of Greenhouse Warming: Mitigation. Adaptation and the Science Base. National Academy Press, Washington D. C..

Nordhaus, William D. 1993. "Reflections on the economics of climate change" Journal of Economic Perspectives 7(4):11-25.

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

Perrings, Charles. 1971. "Reserved rationality and the precautionary principle: technological change, time and uncertainty in environmental decision making." In Robert Costanza, ed. Ecological Economics. New York. Columbia University Press.

Randall, Alan. 1991. "Thinking about the value of biodiversity," Unpublished manuscript, Department of Agricultural Economics and Rural Sociology, Ohio State University.

Randall, Alan and Michael C. Farmer. 1995. "Benefits, costs, and the safe minimum standard of conservation" In Daniel W. Bromley, ed. Handbook of Environmental Economics, Cambridge, Mass., Blackwell.

Randall, Alan. Forthcoming. "Thinking about the value of biodiversity," Unpublished manuscript, Department of Agricultural Economics and Rural Sociology, Ohio State University.

Randall Alan and Michael Thomas. 1991. "The role of limits of economics in decision-making regarding non-indigenous species." Draft prepared for the Office of Technology Assessment U.S. Congress.

Shackle, G.L.S. 1952. Expectations in Economics. Cambridge, England, The University Press.

United Nations, Department for Economic and Social Information and Policy Analysis. 1993. Integrated Environmental and Economic Accounting: Interim Version. United Nations, New York.

Woodward, Richard T. and Bishop, Richard C. forthcoming. "Efficiency, sustainability and global warming." Ecological Economics.

ACCOUNTING FOR THE ENVIRONMENT
IN AGRICULTURE

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Abstract

Detailed information derived from the national income and product accounts provide the basis for economic interpretations of changes in the nation’s income and wealth. Our intent in this paper is to more accurately measure agriculture’s contribution to national income. We develop a theoretically consistent framework for incorporating natural capital and environmental goods into the existing income accounts. Next, we apply the framework and adjust agricultural income and national income to reflect the depletion of natural capital (land and water) caused by agricultural production and the non-market effects of agricultural production on output in other sectors of the economy and consumers. Specifically, the effects of soil erosion on agricultural productivity and income, the economic effects of decreased water quality, and the depletion of water stocks are presented as examples of the potential scope of accounting adjustments needed in the agricultural sector. Estimated adjustments to net agricultural income are in the range of $4 billion and have declined as a percentage of net farm income since 1982. Our estimates suggest that agriculture’s contribution to social welfare far exceeds the environmental damages and deterioration of the stock of natural capital resulting from the production of food.

National income accounting is one of the most important economic policy making tools developed in the last 50 years. Detailed information derived from the accounts provide the basis for economic interpretations of changes in the nation's income and wealth. These national income and product accounts (NIPA) through their measures on Gross Domestic Product (GDP) and Net National Product (NNP) often provide the only meaningful indicator of the effects of public policy interventions, Nearly from the inception of national income accounting, however, economists have criticized the NIPA by identifying inconsistencies with the underlying theory and the empirical application of the theory.

Early criticism of the NIPA centered around the treatment of capital, leisure, and government expenditures. Recent critiques, with historical roots in the early 1970s, question the use of estimates of NNP as a measure of social welfare because it does not account for the value of changes in the stock of natural resources nor does it include the value of environmental goods and services. Critics question the credibility of the accounts because natural and reproducible capital are treated asymmetrically and the value of non-marketed environmental goods and services is not captured (Prince and Gordon, 1994).[1] NNP, it is argued, is not a useful measure of long-term sustainable growth partly because natural resource depletion and environmental goods are not considered. The failure to explicitly consider the environment in the accounts misrepresents the current estimate of well-being, distorts the representation of the economy's production and substitution possibilities, and fails to inform policy-makers on important issues related to economic growth and the environment.

Several attempts to adjust income measures to account for the environment exist. it is most common for these studies to focus on accounting for natural resource depletion (Repetto, 1992; Smith, 1992; Nestor and Pasurka, 1993; U.S. Department of Commerce, 1994).[2]

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[1] Our definition of non-marketed goods includes environmental amenities and disamenities.

[2] Smith (1992) suggests his work should be characterized as environmental costing rather than environmental accounting.

Theoretical and empirical problems persist, however, particularly when the level of environmental services and damages are estimated. For example, no consistent approach for the treatment of "defensive expenditures" in response to or in anticipation of environmental injury has emerged from the literature (Ahmad, El Serafy, and Lutz, 1989).

Our intent in this paper is to more accurately measure economic well-being. Improving the measure of current economic activity requires incorporating non-market final goods and bads into the existing accounts. Economic well-being, however, extends beyond current economic activity and must also reflect future production possibilities. We begin by developing a theoretically consistent framework for incorporating natural capital and environmental goods into the existing income accounts, Next, we empirically apply the framework and adjust agricultural income and national income to reflect the depletion of agricultural natural capital (land and water) and the non-market effects of agricultural production on output in other sectors and consumer utility.

The theoretical framework developed for this study is grounded on the work of Arrow and Kurz (1970), Weitzman (1976), Solow (1986), Hartwick (1990), and Mäler (1991). Weitzman has shown that the current-value Hamiltonian in a neoclassical growth model of the aggregate economy can be interpreted as NNP.[3] Solow incorporated exhaustible resources as distinct capital assets into Weitzman's treatment of NNP. Hartwick and Maler extended Solow's approach to capture renewable resources and environmental capital (pollution abatement). In our analysis, the Hartwick-Solow-Weitzman framework is extended to include three production sectors (agriculture, non-agriculture, and household production). This extension allows us to adjust both agricultural and national income. Rather than viewing non-market environmental goods as externalities, we follow the prescription of Solow (1992) and cast the environment as a set of natural capital assets providing flows of goods and services to the economy. Economic use of natural capital results in feedback effects: depletion of stock of natural capital reduce future flows of goods and services from the environment, degradation due to the disposal of residuals results in costs imposed on third

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[3] This interpretation requires a re-normalization of the current value Hamiltonian.

parties. In addition, firms and households are allowed to make expenditures for pollution abatement and control.

Results from a dynamic optimization model are utilized to adjust NNP and net farm product (NFP) for the use of natural capital assets. in addition, NNP reflects the value of net changes in capital goods (net investment) and the value of net changes in the stock of natural capital. Optimizing the current value Hamiltonian yields scarcity values for all capital stocks including natural capital. The optimization process, therefore, generates relationships for adjusting current NNP to account for the current value of the loss of natural capital stocks from using exhaustible resources and depleting and degrading renewable and environmental resources.

Theoretical results from our model mirror Hartwick's results. That is, GDP includes priced resource input flows and these flows from capital stocks should be off-set by deductions from GDP to incorporate the value of changes in natural resource capital stocks to arrive at NNP.[4] Our empirical application suggests only minor changes are necessary when agricultural natural resource effects are incorporated into the national income accounts. Adjustments to the national accounts are minor because agricultural production is a small component of GDP (less than 2 percent) and most extra-agricultural effects are currently captured in GDP. Larger changes are warranted, however, in the adjustment of net agricultural income, Most effects represent income transfers between agriculture and other sectors.

Agricultural income is adjusted to reflect the value of changes in the stocks of "effective" farmland, water quality, and the stock of ground-water. These natural capital stocks may change due to damages associated with agricultural production. Specifically, the effects of soil erosion on agricultural productivity and income, the economic effects of decreased surface-water quality, and the depletion of ground-water stocks are presented as examples of the potential scope of accounting adjustments needed in the agricultural sector. We adjust income for changes in the stock of ground-water because in some regions there has been a sustained withdrawal of ground-

[4] Possible increases in the value of natural or environmental capital are not excluded.

water stocks in some regions of the United States. Our estimated adjustments would require net agricultural income to be revised downward by $4 billion (6 percent). These estimates of adjustments to net farm income are consistent with a view of U.S. agriculture where environmental problems exist and the resource base is depreciating, but also suggest that agriculture's contribution to social welfare far exceeds the environmental damages and deterioration of the stock of natural capital resulting from the production of food.

National Income Accounting

The national income and product accounts (NIPA) were developed primarily to monitor the macroeconomic performance of the economy. The most widely used measure or statistic of economic activity is gross domestic product (GDP). GDP is highly correlated with employment and capacity utilization and therefore central to how business cycles are defined and tracked.

A simple circular flow diagram is a powerful model to illustrate the flow of final goods and services from the business sector to the household sector and the" concurrent flow of factor services from households to firms (Figure 1). In a monetized economy, goods and services exchange for consumer expenditures while primary factors of production (endowments of capital,

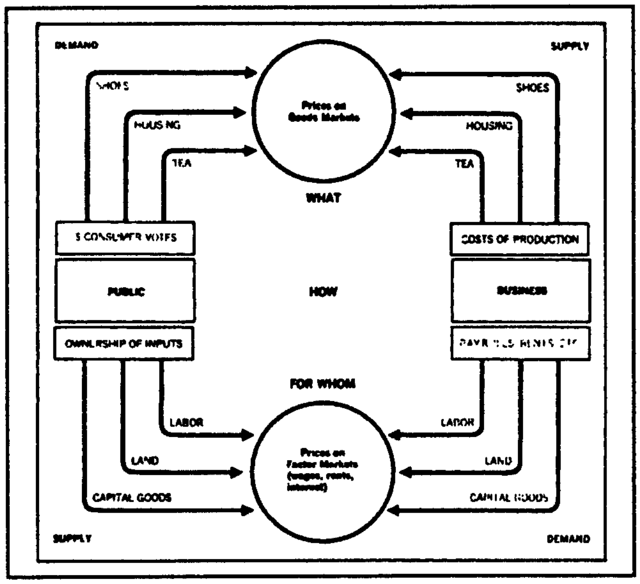

Figure 1. Circular Flow Model

labor, and land) exchange for wages and salaries, rent, interest, and profit. The circular flow model suggests two methods for measuring the monetary value of current GDP: flow-of-output and flow-of-income. In a flow-of-output approach, all expenditures on final goods and services are added together. This measure captures the transactions from the "upper loop" of the circular flow model and includes the value of new capital (gross investment), government purchases of goods and services, and net exports. The flow-of-income alternative yields an equivalent measure of GDP and is computed by summing payments to the primary factors of production. Because GDP is a measure of final goods and services, purchases of intermediate goods must be excluded. The failure to exclude intermediate goods and services from national income results in "double-counting" and an over-statement of the level of economic activity.

Table 1 provides a summary of the NIPA for 1992. The table illustrates the flow-of-income and flow-of-output approaches. Though arrived at in different ways, the calculation of national income and GDP are equal in either case ($6 trillion). The flow of income approach include compensation of employees ($3.6 trillion), proprietors income ($0.4 trillion), corporate profits ($0.4 trillion), net interest ($0.4 trillion), and rental income. The flow of output approach includes expenditures on final goods and services by households ($4.1 trillion), the government ($1.1 trillion), and gross investment by firms ($0.8 trillion).[6]

Net of taxes, the largest single item differentiating GDP from national income is the consumption of fixed capital or depreciation. For 1992, U.S. GDP exceeded $6 trillion while national income approached $5 trillion. Depreciation of the U.S. capital stock was estimated at $657.9 billion or about 11 percent of GDP. The concept of capital stock depreciation is particularly important when we turn our attention to natural capital and environmental assets.

Table 2 summarizes the calculation of farm income for 1992 using a flow-of-income approach. Gross farm income in 1992 was $84.4 billion or about 1.4 percent of U.S. GDP. While

[6] However, the current NIPA system attributes household and government investment to current consumption.

wage income (compensation to employees) is by far the largest income category at the national level (74 percent of U.S. national income), proprietors income (65 percent) and net interest (15 percent) are the largest components of net farm income. Consumption of fixed capital in agriculture is 26 percent of gross farm income, over twice as large as the aggregate national rate.

Income accounts are subject to mismeasurement either by improperly including or excluding items. Including the exchange of intermediate goods and services in the measure of national income is an example of improper inclusion. Similarly, counting transfer payments or non-productive redistributions such as social security payments, welfare payments, and agricultural deficiency payments as gross income is inconsistent with the received definition of national income.

Improper exclusion occurs when the value of a final good or service is not included in the accounts. This occurs when a good or service is traded in informal markets commonly referred to as the “underground economy.” Often these transactions in the form of “cash-only” arrangements are undertaken to avoid taxes. “Non-market” goods and services are also often excluded from the income accounts because they are difficult to measure. Examples include unpaid housework and child-care and environmental goods and services. In some cases, market values have been imputed for “non-market” goods and the income accounts adjusted accordingly. The value of housing services received from owner-occupied houses is the best example.

The treatment of several elements in the accounts remain controversial and unclear, Leisure, for example, has properties associated with a normal economic good. Yet, whether and how to include the consumption of leisure in the national income accounts is unresolved. Another example is criminal activity. Criminal activity is typically viewed as reducing not enhancing social welfare and therefore not included in GDP. Legal gambling services in Nevada and New Jersey are, however, included. Excluding criminal transactions reflects a moral judgement about the desirability of illegal goods and services as indicators of social well-being. The cost of this moral judgement is to reduce the accounts usefulness as a measure of economic activity.

Government expenditures on military defense, police, and environmental clean-up add to the conventionally measured income accounts. Nordhaus and Tobin (1972) argue, however, increases in these expenditures reflect the increasing “disamenities of urban life” that decrease social well-being. Similarly, increases in household “defensive” expenditures on items like mace and bottled water may signal a decrease in social welfare.

Environmental Accounting

Environmental accounting addresses the improper exclusion of the services provided by environmental goods and the asymmetric treatment of natural capital and reproducible capital within the existing accounts. Including the provision of environmental goods and services greatly increases the complexity of properly adjusting the income accounts. Environmental goods and services rarely have observed market prices or easily measurable market quantities. The absence or incompleteness of these markets can have distorting effects on the good for which markets exist. Thus, even if environmental goods and services are not included in the accounts, their existence may cause distortions in the relative prices in traditionally measured sectors. If so, the view of measured NNP as the current consumption value of a dynamically optimal resource allocation is flawed.

Income accounting in the U.S. does not correct for price distortions. In developing countries, however, significant effort is made to correct income accounts for market distortions when the correction may be important for deciding among competing investment projects. The implicit rationale for not adjusting market prices in developed countries is markets are well developed and distortions, to the extent they exist, are small. However, price distortions with respect to environmental and agricultural goods may be relatively large.

Changes in environmental quality have multiple effects across sectors and consumers. Producers are affected because changes in environmental quality can affect the productivity of other resources. Consumer utility is affected directly through changes in consumption and indirectly through effects in option or existence value. Environmental effects are, therefore, a mixture of private good, public good, and quasi-public good effects.

The income accounts can be extended using the flow-of-output approach to value environmental goods and services produced. To avoid double-counting it is important to capture only the value of the final environmental goods and services, Accounting for intermediate external effects is needed only to compute sectoral income. If, however, an accurate measure of national income alone is sought, then intermediate external effects can be ignored. In many cases externalities are intermediate goods whose value is imbedded in the bundle of final goods and services. Including the intermediate good in the income accounts is double-counting. A similar argument holds for the flow-of-income approach. Economic rents generated by a non-market externality are captured in payments to factors of production.

Accounting for non-market goods requires adjusting GDP for environmental goods and services and transactions from the informal or underground economy. If changes to income consist largely of accounting for environmental effects, then adjusted aggregate income might be termed "green GDP". Adjusting GDP requires deriving a shadow price and physical measure for each final non-market good. No information is necessary on intermediate goods.

There is considerable agreement that national accounts, although flawed, are useful measures of economic performance and these accounts can be modified or extended to improve the measure economic activity. Some economists have argued for developing alternative accounting systems. Satellite accounts, a related but separate set of environmental accounts, may be a preferred alternative to further diluting the quality of the market-based data with imputed transactions. Critics of integrating the accounts argue that although flawed, the current income accounts reasonably represent the market economy. Satellite environmental accounts would include current market environmental expenditures as well as shadow accounts for non-market environmental goods. A complete system of satellite environmental accounts would allow the analyst to calculate the non-market adjustments and trace productivity effects across sectors.

The United Nations System for Integrated Environmental and Economic Accounting (SEEA) is a set of satellite environmental accounts supplementing the current System of National Accounts (SNA).[6] The intent is to develop an environmental accounting framework consistent with the concepts and principles underlying conventional income. Harrison (1989) presents criteria for guaranteeing the satellite accounts are complementary to rather than a substitute for the current accounts. A primary requirement is the parallel treatment of "natural capital" (natural resources) and physical capital in the national accounts.

Although there have been other attempts to capture environmental effects in national accounts (Nordhaus and Tobin, 1972), Nestor and Pasurka (1993) is the most ambitious. Nestor and Pasurka disaggregate the U.S. input-output tables into environmental and non-environmental components, Adopting the framework of Schafer and Stahmer (1989), Nestor and Pasurka divide the environmental account into three categories. The "internal environmental protection sector" captures intermediate goods and services produced and used within the environmental protection industry. The "external environmental protection sector" captures the purchase of intermediate inputs from outside the sector. Examples include waste disposal, sewage treatment, and environmental construction activities. The "final demand sector" for environmental protection includes fixed capital formation for environmental protection, direct pollution abatement activities by governments and households and net exports of environmental protection goods.

The Nestor and Pasurka approach is consistent with the proposed system for environmental and economic accounts (United Nations, 1993) and indicates the importance of environmental protection activities in GDP. Through disaggregation, they estimate the 1982 total value-added for environmental protection to be 0.3 percent of GDP. This is less than 20 percent of the $80.6 billion (1.7 percent of real GDP) estimate of real pollution and abatement control expenditures for 1991 (Rutledge and Leonard, 1993). While the Nestor and Pasurka approach provides more information on the contribution of market expenditures on environmental protection, it does not

[6] See United Nations (1992) and Bartelmus, Stahmer, and von Tongeren (1991).

change the overall measure of GDP because it does not include non-market activities.

NNP and Welfare

NNP is the premier indicator of current market-based economic activity. NNP has also been promoted and, more importantly, interpreted as an indicator of social welfare. Samuelson (1961) rejected all current income concepts as meaningful welfare measures and argued instead for a "wealth-like magnitude" such as the present discounted value of future consumption. Weitzman (1976) bridged the gap between Samuelson's argument for a wealth-based indicator of welfare and current measures of income by demonstrating NNP captures both current consumption and the present value of future consumption. A current income concept and a wealth-like magnitude, he argues, "are merely different sides of the same coin." Weitzman's results are illustrated in figure 2.

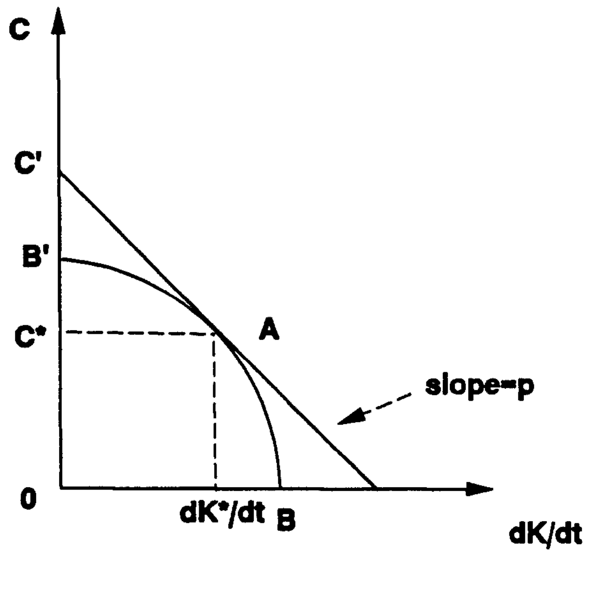

Figure 2. National Income

In figure 2, the production possibilities frontier B'B represents the economy's technical ability to transform investment goods into consumption goods. The budget constraint C'C represents society's willingness to trade-off future consumption for current consumption which depends on the rate at which society discounts future consumption. The economy is located at point A on the production possibilities frontier B'B. Optimal consumption and net investment are given by C* and dk*/dt. Real NNP, is geometrically represented as OC'. The only point where measured income is supported by production is at A. OC' is a strictly hypothetical consumption level at the present time, because the largest permanent consumption level obtainable is OB'. Production and income are equivalent only at A unless the transformation of investment goods into consumption goods does not exhibit diminishing marginal returns. That is, if the production possibilities frontier is linear, OB' is income, where income is interpreted as the maximum consumption possible. The correct measure of "income" or NNP at the dynamic optimum is indicated by A. The level of constant consumption OC' gives the same present value of welfare as the discounted maximum welfare received along the optimal consumption path. Thus, Weitzman calls OC' the stationary equivalent of future consumption.

Weitzman argues, income accounts, properly measured, provide a measure of the welfare of society and give concrete economic form to the concept of sustainability. The current income accounts do not adequately measure welfare or sustainable income because they fail to consider non-market environmental goods and services and the degradation or depletion of non-renewable resources.

If natural capital has a market, but is excluded from the accounts, then the accounts fail to accurately measure true NNP. The only correction needed is to adjust the national accounts is to deduct the value of the natural capital consumption (resource depletion). If natural capital does not have a market, however, or the market price is distorted, then adjusting the accounts for natural capital consumption is not as straightforward. Difficulties arise because there is a non-optimal level of resource depletion and the shadow-price of resource depletion, an endogenous value, differs from the socially optimal price. Similarly, if natural capital is substitutable for reproducible capital, properly measured NNP also represents the maximum level of sustainable income for society. However, if natural capital cannot substitute for reproducible capital, the link between aggregate NNP and sustainable income is more problematic.

Application Framework

In this analysis, the environment and natural resources are treated as natural capital assets generating a flow of services. Such a treatment allows for substitution between natural and reproducible capital and is consistent with notions of weak sustainability. By adjusting national income for changes in environmental quality and natural resource stocks, the national accounts provide a more accurate economic interpretation of changes in the nation's assets. This approach implies information about stocks on their own is not a sufficient statistic for well-being.

The model developed for this analysis draws significantly on Hartwick (1990) and Mäler (1991). Our work differs from previous work in that our model includes three production sectors (agriculture, non-agriculture, and household production), three roles for land, and equations describing the change in "effective" productivity of farmland, surface water quality, and the stock of ground-water over time. Land, surface-water quality, and the stock of ground-water are treated as natural capital.

Land in its natural state contributes directly to social welfare but is not used in any production sector. Land is used in the agricultural sector and also contributes directly to social welfare by providing rural landscape. We distinguish between the productivity of farmland and its role in providing rural landscape because efforts to increase productivity are not likely to provide added rural landscape. The third use of land is as an input in the production of non-agricultural goods. This land makes no direct contribution to social welfare, but influences welfare by contributing to the production of non-agricultural goods and services.

Water quality directly contributes to social welfare and is also an input into the production of non-agricultural goods. Agricultural production, however, adversely affects water quality as a result of soil erosion and chemical run-off. We adjust income for changes ground-water stocks because in some regions there has been sustained withdrawal ground-water over time.

Each of our natural capital assets are regenerative or renewable but may be exhausted from over-use if the rate of use exceeds the natural and managed regenerative rate of the asset. The net rate of regeneration is the rate at which the stock of the asset changes over time.[7] For land, surface-water quality, and the stock of ground-water, the net rate of regeneration depends on the intensity of use, the natural rate of regeneration, and the effectiveness of management to offset the intensity of use of the asset. Land, for example, is usable until the productivity of soil for producing agricultural goods approaches zero. The loss in soil productivity is offset by the soil's natural capability to regenerate itself. The productivity of soil to produce agricultural goods is also enhanced (managed) by applying labor, intermediate inputs (fertilizer), and capital to improve soil quality.

Surface-water quality is characterized in a similar fashion. Natural regenerative processes offset surface-water quality deterioration. The net rate of regeneration is a function of water quality damage from agricultural production, the natural rate of regeneration, and the effectiveness of management to offset degradation. The treatment of ground-water is potentially more problematic because there may be resource degradation associated with the water stock's quantity and quality. Treatment of ground-water in this analysis does not consider changes in ground-water quality.

While agriculture's share of NNP includes a deduction for the consumption of physical capital, a similar deduction is not made for other types of capital including farmland or natural resource stocks such as water quality or water quantity, In addition, NNP is not adjusted for externalities associated with agricultural production. For example, agriculture's contribution to NNP is not reduced by offsite damages to water quality associated with soil erosion.

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[7] The net rate of regeneration defines the equation of motion for each asset.

In this analysis, farm income is adjusted to reflect changes in the effective level of farmland in agriculture over time and the damages associated with soil erosion on surface-water quality. We also correct farm income for the sector's contribution to the overall decline in the stock of ground-water. Because data is limited, the value of scenic preservation of farmland and the value to society of land in its natural state are not addressed. We also do not correct for the value of leisure, We do not correct GDP or NNP for the value of leisure or the production of household output.

For the interested reader, the theoretical model is developed in detail Appendix A. The work of Weitzman and originally Arrow and Kurz (1970) provide the necessary connection between the current value Hamiltonian and NNP. In their work and our model, net welfare is expressed as the linearized version of the current value Hamiltonian, NNP is reduced to the sum of the social value of an economy's consumption and the social value of the changes in its capital stocks. By capital stocks we mean manufactured or reproducible capital as well as natural capital stocks.

Net welfare measure in terms of final goods and services is:

$$NWM = \frac{\partial U}{\partial q}\left[\frac{\partial q}{\partial n_1}n_1 + \frac{\partial q}{\partial k_1}k_1 + \frac{\partial q}{\partial Z_1}Z_1 + \frac{\partial q}{\partial T_1}T_1 + \frac{\partial q}{\partial W_1}W_1\right]$$

$$+ \frac{\partial U}{\partial x_2}\left[\frac{\partial x}{\partial n_2}n_2 + \frac{\partial x}{\partial k_2}k_2 + \frac{\partial x}{\partial Y}Y + \frac{\partial x}{\partial L_2}L_2\right]$$

$$- \frac{\partial U}{\partial x_2}\left[x_3 + x_4 + x_5 + x_6 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6\right]$$

$$+ \frac{\partial U}{\partial Y}Y$$

$$+ \sum_{i=1}^{6}\mu_i\dot{k}_i + \rho_3\dot{T}_1 + \rho_4\dot{Y} + \rho_5\dot{W}_1 \qquad (1)$$

The first line of equation (1) represents expenditures on final goods and services produced by the agricultural sector as the sum of the value of the marginal contributions of each input used in producing the agricultural good. That is, the expenditures on final agricultural goods is the sum of the value of labor (n_1), capital (k_1), an environmental input (Z_1), effective farmland (T_1), and the stock of ground-water (W_1) that is used to produce the agricultural good. The inputs used to produce the agricultural good are valued in terms of the marginal contribution of the agricultural good to the utility of society $(\partial U/\partial q)$. The second line in equation (1) represents expenditures on total goods and services produced in the non-agricultural sector. Expenditure on these goods is a function of the value of labor (n_2), capital (k_2) water quality (Y), and land (L_2) used to produce non-agricultural goods, valued in terms of the marginal contribution of these goods to the utility of society $(\partial U/\partial x_2)$. The third line in equation (1) represents expenditures on intermediate inputs used to produce the agricultural and non-agricultural goods and services. Intermediate expenditures are excluded from NNP to avoid double counting.

Deleterious environmental effects from agricultural production increase the cost of production and require devoting additional productive resources to improve damaged water quality. These additional intermediate inputs in the production of non-agricultural output are reflected in lower current measured output in final consumer goods. The long-term effects on the production of final consumption goods caused by environmental damages from agricultural production are not included in conventionally measured NNP.

The fourth line in equation (1) represents the value $(\partial U/\partial Y)$ of the stock of clean water (Y) to consumers. This value is also not captured in conventionally measured NNP. The final line in equation (1) reflects the addition of the value of net investment in both reproducible capital $(\dot{k}_i)$ and natural capital: effective farmland (T), water quality (Y), and ground-water quantity (W). Current period production is valued in terms of its marginal contribution to the utility of society today. Net investment in both reproducible and natural capital are valued by their marginal contributions to the utility of society today and their marginal contribution to the utility of society in the future. [8]

[8] The conditions for optimality are presented in Appendix B.

The last two lines in equation (1) represent our adjustment to NNP. We suggest that the conventional measure of NNP be corrected to reflect environmental impacts of agricultural production on the stock of clean water as well as the future environmental impacts of agricultural production on the stocks of effective farmland (T), water quality (Y), and ground-water quantity (W),

Effective Farmland/Soil Productivity

The link between agricultural production practices, erosion, and farmland's ability to produce output has been studied extensively (Crosson, 1986). In 1989, as part of the Second Resources Conservation Act (RCA) Appraisal, the USDA estimated a 3 percent loss in productivity over the next 100 years if farming/management practices remained as they were in 1982 (Table 3). Similarly, Alt, Osborn, and Colacicco (1989) found that the net present value of both the crop yield losses and the additional fertilizer and lime expenses associated with agricultural production totaled $28 billion, Both studies employ a crop production model, Erosion Productivity Impact Calculator (EPIC), which link production practices, erosion rates, and productivity, to provide estimates for physical depreciation rates of land.[9] Linking physical depreciation rates with crop prices can provide an estimate of economic losses attributable to soil erosion over time. However, a productivity loss of 3 percent over 100 years will not change NNP significantly.

While our theoretical model for adjusting NNP for the impact of erosion on loss of soil productivity is straightforward, it is more difficult to assess a more comprehensive view of land quality over time (National Academy of Sciences, 1993). For example, the RCA report also concluded that less than 50 percent of all agricultural land was "adequately" protected. Adequately protected soil was defined as soil within acceptable limits with respect to soil erosion and other factors limiting sustained use. Soil scientist have developed "soil loss tolerance" or "T-values" which vary by type of soil. A general rule of thumb is that erosion rates less than 5 tons

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[9] EPIC is a physical-process model that simulates interaction of the soil-climate-plant management processes in agricultural production. EPIC was developed by USDA/ARS scientists and has been used extensively in the RCA and elsewhere (e.g. Faeth, 1993).

per acre per year (T) do not result in damage to crop yields. Although results from the RCA seem to indicate soil erosions effect on productivity are economically unimportant, the report also indicates about 40 percent of cropland was eroding at rates greater than T.

<u>Water Quality</u>

More important than the productivity impacts of agricultural production on effective farmland are the impacts of erosion on water quality and therefore on recreation, commercial fishing, navigation, water storage, drinking supplies, industrial supplies, and irrigation. Ribaudo (1989) estimated the average annual offsite erosion costs for the U.S. at $1.78 per ton ($ 1986). Even if productivity effects are negligible, soil erosion associate with an acre of land causes, on average, $9 in offsite damages.

Because data is limited on wind erosion our estimates focus on the offsite effects associated with sheet and rill erosion, We link sheet and rill erosion and the adsorption of nutrients to soil particles to estimate the effects of agricultural production on siltation, stream sedimentation, and water pollution. Table 4 presents estimates of sheet and rill erosion for cropland and pastureland for 1982, 1987, and 1992 from the National Resources Inventory (USDA).

It is possible for agents to mitigate the effects of pollution through defensive expenditures of capital, labor, and other intermediate inputs. For example, increased siltation diminishes the usefulness of a reservoir for producing electricity. The effects of siltation can be offset by dredging. The attempt to offset the effects of soil erosion may result in additional costs (expenditures) in electricity generation. In this case, part of the costs of agricultural production are shifted to electricity generation. Similar arguments can be made for other industries. Economy-wide NNP, therefore, should not be increased or decreased to reflect the transfer of costs from one industry to another because aggregate NNP is correct. There is, however, a misallocation of income among sectors. Conventionally measured farm income is higher if the costs of repairing the reservoir are included as an intermediate expense of the affected industries rather than as an intermediate expense of agricultural production.

Soil erosion also affects consumer utility. An increase in sedimentation in a reservoir can reduce recreational activities. Because many recreational activities are unpriced and therefore are not included in conventionally measured NNP, the diminished value of the resource does not directly affect the income accounts although decreases in expenditures on complementary goods will appear. In the inter-industry example there was a misallocation of income but economy-wide NNP was accurate. In the second case, conventionally measured NNP fails to fully reflect the loss of welfare due to the loss of the recreational resource. Therefore, the off-site damages to consumers caused by agricultural production should be counted as an overall decline in NNP.

Similarly, the noncommercial loss of fish and waterfowl populations associated with increased sedimentation are not fully represented in NNP. In addition to the impacts on recreation, there may be an "existence" value component for the health of these riparian ecosystems. Such a value is also excluded from the national accounts as currently measured.

We do measure the stock of water quality (Y) or the marginal utility of water quality $(\partial U/\partial Y)$. Because no comprehensive measure exists, we use Ribaudo's (1989) estimate of the off-site damages to water quality from soil erosion. The off-site damages in dollars per ton of soil erosion (converted to $1982) are listed in table 5. The estimates reflect the off-site effects of soil erosion on freshwater and marine recreation, water storage, navigation, flooding, roadside ditches, irrigation ditches, freshwater and marine commercial fishing, municipal water treatment, municipal and industrial uses, and steam power cooling. We reorganize the damages into those affecting industry (water storage, navigation, flooding, roadside ditches, irrigation ditches, freshwater and marine commercial fishing, municipal water treatment, municipal and industrial uses, and steam power cooling) and those directly affecting consumers (freshwater and marine recreation). The industry and consumer damages per ton of soil erosion are highest in the Northeast.

The value of total damages presented in tables 6 and 7 are calculated by applying Ribaudo's per ton estimates to the total level of sheet and rill erosion for cropland and pasture by region.[10] Total damages are $4.4 billion 1992, with $3.0 billion associated with industry affects, Interestingly, while the dollar per ton effects are highest in the Northeast, the total industrial damages are greatest in the Southeast ($390 million).

The effects of sheet and rill erosion on consumers totaled $1.1 billion in 1982, $1.2 billion in 1987, and $1.3 billion in 1992. In addition to reducing farm income, these adjustments reflect a decline in NNP and overall welfare. The effects on other industries were about twice as large as the consumer impacts. Estimated industry effects are $2.4 billion in 1982, $2.7 billion in 1987, and $2.7 billion in 1992. While these adjustment lower agricultural income, they do not reflect a decline in NNP and overall welfare. They are treated as a transfer from one production sector of the economy to another.

Ground-Water Quantity

Our final adjustment to the national and agricultural sector accounts is an adjustment for the value of the change in the stock of ground-water over time. In the long-run, an equilibrium is generally reached in terms of recharges (precipitation, imports from other regions) and discharges (natural evapotranspiration, exports to other regions, consumptive use, and natural outflow) from any ground-water system. However, in five water resource regions, the rate of discharge has consistently been greater than the rate of recharge and has lead to a continued decline in the stock of ground-water (U.S. Department of the Interior). Those five regions are: the Missouri Basin (Montana, Wyoming, North Dakota, South Dakota, Nebraska, and parts of Colorado and Kansas), the Arkansas-White-Red (southern Kansas, Oklahoma, north Texas, and western Arkansas), the Texas-Gulf (most of Texas), the Lower Colorado (Arizona), and California. While it is difficult to assess agriculture's contribution to the overall change in the stock of ground-water in those regions, the sector accounted for 79 percent to 88 percent of total ground-water withdrawals in the U.S. (Table 8).

[10] Ribaudo's 1982 estimates are inflated to 1987 and 1992 by the change in the gross domestic product implicit price deflator.

Because the most recent estimate of the change in the stock of ground-water for the U.S. is for 1980 (U.S. Department of the Interior) and because the data are not specified by sector of use, we adopt the following four step procedure. First, we employ the 1980 water resource budgets and use agriculture's share of total ground-water withdrawals (Solley, et.al.) to allocate the change in the stock of ground-water for each of the five water resource regions exhibiting declines in the stock of ground-water in 1980. For example, in 1980 agriculture accounted for about 86 percent of ground-water withdrawals in the California water resource region. Therefore, we assume that agriculture accounted for 86 percent (1.2 billion gallons per day (BGD)) of the total decline in the stock of ground-water in the California water resource region (1.4 BGD) for 1980.

Second, because water use data is collected every five years, we use the change in total ground-water withdrawals to update the total change in the stock of ground-water for each of the water resource regions. For example, from 1980 to 1985, the total (both agriculture and non-agricultural) withdrawals of ground-water for the California region fell by about 30 percent from 21.0 to 14.8 BGD. Therefore, we assume that the rate of ground-water depletion in the region fell by about 30 percent from 1.4 BGD to 1.0 BGD.

Third, we again use agriculture's share of total ground-water withdrawals to allocate the change in the stock of ground-water. Continuing with our California example, in addition to the decline in overall ground-water withdrawals, the share of withdrawals attributed to agriculture fell from 86 percent to about 70 percent. Therefore, the rate at which agriculture contributed to the decline in the overall stock of ground-water in the California water resource region fell from 1.2 BGD in 1980 to 0.7 BGD in 1985 (Table 9).

This process leads to some interesting comparisons over time. The change in overall ground-water withdrawals coupled with changes in agricultural uses indicates that by 1990, agriculture's contribution to overall decline in the stock of ground-water declined since 1980 and remained stable since 1985. Regionally, however, there are some differences. For the Lower Colorado and California water resource regions both total ground-water withdrawals and the share of ground-water withdrawals attributed to agriculture has fallen significantly. In both regions, the share of ground-water withdrawals attributed to agriculture has fallen from close to 90 percent in 1980 to about 75 percent by 1990. Much of this decline in ground-water withdrawals can be attributed to the decline in irrigated acres in the Pacific coast over that period. [11] However, for the Missouri Basin, Arkansas-Red-White, and Texas-Gulf, agriculture's share of total withdrawals of ground-water has remained fairly constant since 1980.

Finally, we need to associate values with the estimated changes in the rate of ground-water depletion, We estimate the value of ground-water based on the ratio of energy expenses for on-farm pumping of irrigation water to the estimated amount of water applied to farms from wells. The data on energy expenses and water application is from Farm and Ranch Irrigation Surveys (U.S. Department of Commerce, Census of Agriculture). [12] The values range by water resource region and for 1992 range from $0.10 to $0.12 per 1,000 gallons in California, the Lower Colorado, and the Texas Gulf to $0.07 to $0.09 in the Missouri Basin and the Arkansas-Red-White region. While there is considerable uncertainty regarding the appropriate value of water, the estimates used in this analysis are similar to those used by Grambsch and Michaels (1994). Grambsch and Michaels estimate, based on water price data for the 120 largest metropolitan areas and government capital and operating expenses, was $0.09 per 1,000 gallons. The adjustment to farm income presented in table 9 combines the value of ground-water with the rate of ground-water depletion associated with agriculture. Total damages range from $212 million in 1987 to $291 million 1992.

Impacts on Income

Agriculture affects both production in other sectors of the economy and consumer utility through its use of environmental and natural resource assets. Production in other sectors of the

[11] Irrigated acres in the Pacific coast fell from 12 million to 10.5 million from 1978 to 1992 (USDA, ERS).

[12] The data in the Census of Agriculture are for 1979, 1984, and 1988. The GDP implicit price deflator is used to match census years with the dates used in this analysis.

economy are affected because changes in environmental assets affect the productivity of other inputs and therefore the cost of producing non-agricultural goods and services. Consumer utility is affected directly through changes in consumption and indirectly through changes in option or existence value.

The approach here is to extend the existing flow-of-output accounts to value environmental goods and services. Double-counting is avoided by recognizing that the inter-industry externalities caused by agricultural production are captured in the existing accounting framework as intermediate expenses in non-agricultural production. Accounting for intermediate external effects is needed only to compute sectoral income. If, however, an accurate measure of national income alone is sought, then intermediate external effects can be ignored. The production externality is an intermediate good whose value is imbedded in the bundle of final goods and services. Agriculture's contribution to the decline in surface-water quality cause a transfer of accounting income from the agricultural sector to the non-agricultural sector of the economy in 1982 of $2.4 billion, in 1987 of $2.7 billion, and in 1992 of $2.7 billion. These adjustments reduce agricultural income and increase income in other sectors of the economy but do not reduce economy-wide NNP. Including intermediate goods in the income accounts is double-counting. Similarly, economic rents generated by a non-market externality are captured in payments to factors of production in the flow-of-income approach. This is not the case, however, when consumer utility is affected directly through changes in consumption and indirectly through changes in option or existence value.

Our estimates suggest only minor adjustments to NNP are made necessary by the effects of agricultural production on the environment and natural resource base. This result follows partly from agriculture's small share (less than 2 percent) of GDP. Even large changes in net farm income have only modest effects on NNP. Adjustments to total farm income and economy-wide NNP for 1982, 1987, and 1992 are displayed in table 10. In each year, total farm income is reduced by about $4 billion when adjustments are made for agriculture's contribution to the decline in surface-water quality and stock of ground-water. Overall, agriculture's contribution to economy-wide NNP falls by $1.3 billion in 1982, $1.4 in 1987, and $1.6 in 1992 when adjustments are made for agriculture's contribution to the decline in surface water quality and stock of ground-water. About 85 percent of the adjustment is caused by agriculture's contribution to the decline in surface-water quality.

The relative effects on net farm product are significantly greater. Adjustments to net farm product range from 6 to 8 percent. The relative share of environmental adjustments to conventional net farm product, however, decreased from 1987 to 1992, Measured agricultural environmental costs per dollar of farm income are declining. This suggests estimated environmental costs flowing from agriculture are not growing as fast as farm income. One possible explanation is policies and programs for controlling soil erosion were effective during this period. In particular, highly erodible acreage enrolled in the Conservation Reserve Program increased from 13.7 to 35.4 million acres from 1987 to 1992. Removing nearly 22 million acres of highly erodible land from production contributed to a nearly 21 percent decrease in estimated soil erosion on cropland during this period even though planted acreage for grains increased by 6 percent. Conservation compliance requirements promulgated under the 1985 farm legislation have provided additional incentives for reducing erosion.

The estimates are consistent with Smith's (1992) work on environmental costing. Smith aggregates the effects of off-site soil erosion, wetland conversion, and ground-water contamination and estimates environmental costs relative to the value of crops produced in 1984. His estimates range from 0.08 to 7.5 percent in the Mountain region to 3.5 to 40 percent in the Northeast. Corn Belt estimates range from 6 to 7 percent. [13]

Our estimated adjustments represent average costs of environmental damages and resource use. Marginal costs are likely to be higher. It is possible that the distortionary effect of commodity

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[13] Smith suggests the work on Viscusi and Magat (1991) on energy implies that the environmental costs of agriculture are comparable to those estimated from several energy sources. Both the Smith and Viscusi and Magat work differ from Nestor and Pasurka's estimates of total value-added for environmental protection of 0.3 percent.

programs is alone sufficient to lead to marginal decreases in social welfare. Accounting for natural resource deterioration and environmental injury, in such a case, would lead to further reductions in social welfare. In addition, our national estimates may be masking significant regional or local problems. Estimated costs of erosion in terms of lost productivity, for example, is not a significant national problem, but may be a significant regional or state problem. Faeth (1993) shows negative net economic value per acre after accounting for soil depreciation and off-site costs for Pennsylvania’s best corn-soybean rotation over 5 years. The work demonstrates there may be significant regional variation in resource depreciation and off-site costs of agricultural production.

Summary

Growing interest in the environment has raised questions about the adequacy of current measures of national income particularly when these measures are used as social welfare indicators. The intent of this paper is to more accurately measure agriculture’s contribution to national income. Improving the measure of current economic activity requires incorporating non-market final goods and bads into the existing accounts. We focus attention on treating natural capital assets used or affected by agricultural production parallel to how reproducible capital is treated in the national accounts. Net national income and agricultural income are adjusted to reflect the value of changes in the stock of effective farmland, surface-water quality, and ground-water.

We first develop a theoretically consistent framework for incorporating natural capital and environmental goods into the existing income accounts. Next, we apply the framework and adjust agricultural income and national income to reflect the value of the depletion of agricultural natural capital (land and water) and the non-market effects of agricultural production on output in other sectors of the economy and consumers. Specifically, the effects of soil erosion on agricultural productivity and income, the economic effects of decreased surface-water quality, and the depletion of ground-water stocks are presented as examples of the potential scope of accounting adjustments needed in the agricultural sector. Our estimates suggests only minor adjustments to NNP are made necessary by the effects of agricultural production on the environment and the natural capital base. This result follows from agriculture's small share of GDP and because the environmental effects considered in this paper are largely captured in the existing accounts. Adjustments to net farm income are relatively greater and fall in the range of 6 to 8 percent.

Our estimates of “green” adjustments to net farm income are consistent with a view of U.S. agriculture where environmental problems exist and the resource base is depreciating, but the extent of the effects is in the range that can adequately be addressed by thoughtful policy. Our estimates suggest that agriculture's contribution to social welfare far exceeds the environmental damages and deterioration of the stock of natural capital resulting from the production of food.

Estimates of adjusted or “green” income presented here are incomplete. Because the objective of our analysis is to illustrate some of the adjustments necessary to improve NNP and NFP as measures of social welfare, we restrict our scope to consider a few key agricultural effects. Other adjustments, including additional environmental damages and valuing environmental services, are necessary before a credible measure of welfare or sustainability can emerge. We have not, for example, estimated the cost of farm chemical volatilization on air quality, or valued the benefits of landscape preservation or increasing wildlife habitat. In addition, on the cost side, we have not examined how soil quality characteristics, other than erodibility, affect productivity or wildlife habitat. Valuation of farm program benefits warrant further exploration. Program payments are currently treated as income transfers, included in net farm income but excluded from gross farm income. An alternative approach views the Government purchasing environmental benefits like scenic value or wildlife habitat.

References

Ahmad, Yusuf, Salah El Serafy, and Ernst Lutz. eds. (1989). Environmental Accounting for Sustainable Development. Washington, DC: World Bank.

Alt, Klaus, Osborn, C. Tim, and Dan Colacicco (1989). "Soil Erosion: What Effect on Agricultural Productivity." Agricultural Information Bulletin No. 556, U.S. Department of Agriculture, Economic Research Service.

Arrow, Kenneth and Mordecai Kurz (1970). Public Investment, The Rate of Return and Optimal Fiscal Policy. Baltimore, MD, Johns Hopkins University Press.

Bartelmus, P., Stahmer, C. and Van Tongeren, J. (1991). "Integrating Environmental and Economic Accounting: Framework for a SNA Satellite System. " The Review of Income and Wealth. Vol. 37. pp. 111-47.

Crosson, Pierre (1986). "Soil Erosion and Policy Issues." in Agriculture and the Environment (T. Phipps, P. Crosson, and K. Price, eds.) Resources for the Future. Washington, DC.

Dasgupta, Partha and Karl-Göran Mäler (1990). "The Environment and Emerging Development Issues." Proceedings of the World Bank Annual Conference on Development Economics, 1990. The World Bank. pp. 101-31.

Eisner, Robert (1988). "Extended Accounts for National Income and Product. " Journal of Economic Literature, December, pp. 1611-84,

El Serafy, Salah (1991). "The Environment as Capital." in Ecological Economics: The Science and Management of Sustainability. (R. Costanza, cd.) Columbia University Press, New York.

Faeth, Paul (1992). "National Economic Implications of a Transition to Sustainable Agriculture in the United States: Implications for Policy Reform. " Project Summary, World Resources Institute, Washington D. C., November.

Faeth, Paul (1993). "Evaluating agricultural Policy and the Sustainability of Production Systems: An Economic Framework. " Journal of Soil and Water Conservation, March/April pp. 94-99.

Faeth, Paul, Robert Repetto, Kim Kroll, Qi Dai, and Glenn Helmers (1991). "Paying the Farm Bill: U.S. Agricultural Policy and the Transition to Sustainable Agriculture." World Resources Institute, Washington D.C.

Grambsch, Anne and R. Gregory Michaels (1994). "The United Nations Integrated Environmental and Economic Accounting System: Is it Right for the U.S." Paper presented to the 1994 AERE Workshop Integrating the Environment and the Economy: Sustainable Development and Economic/Ecological Modelling. June.

Hartwick, John (1990). "Natural Resources, National Accounting and Economic Depreciation." Journal of Public Economics. Vol. 43, No.3. pp. 291-304.

Hicks, John (1939). Value and Capital. Oxford University press.

Hung, N.M. (1993). "Natural Resource, National Accounting, and Economic Depreciation: Stock Effects." Journal of Public Economics. Vol. 51, No.3. pp. 379-89.

Mäler, Karl-Göran (1991). "National Accounts and Environmental Resources." Environmental and Resource Economics. Vol. 1, No, 1. pp. 1-15.

National Academy of Sciences. National Research Council (1993). Soil and Water Quality: An Agenda for Agriculture. National Academy Press. Washington. DC

Nestor, Deborah Vaughn and Carl A. Pasurka (1994). "Environment-Economic Accounting and Indicators of the Importance of Environmental Protection Activities." Paper presented at the 1993 Annual Meeting of the Southern Economic Association. March.

Nordhaus, William and James Tobin (1972). "Economic Growth." National Bureau of Economic Research.

Prince, Raymond and Patrice Gordon (1994), "Greening the National Accounts." CBO Papers. Congressional Budget Office. March.

Repetto, Robert (1992). "Accounting for Environmental Assets." Scientific American, pp. 94-100, June.

Repetto, Robert (1992). "Earth in the Balance Sheet: Incorporating Natural Resources into National Income Accounts." Environment pp. 43-45, September.

Ribaudo, Marc (1986). "Reducing Soil Erosion: Offsite Benefits. " Agricultural Economics Report No. 561, U.S. Department of Agriculture, Economic Research Service.

Ribaudo, Marc (1 989). "Water Quality Benefits from the Conservation Reserve Program." Agricultural Economics Report No. 606, U.S. Department of Agriculture, Economic Research Service.

Ribaudo, Marc and Daniel Hellerstein (1992). "Estimating Water Quality Benefits: Theoretical and Methodological Issues." Technical Bulletin No. 1808, U.S. Department of Agriculture, Economic Research Service.

Rutledge, Gary, L. and Mary L. Leonard (1993). "Pollution Abatement and Control Expenditure, 1987-91." Survey of Current Business, U.S. Department of Commerce, Bureau of Economic Analysis, Vol. 73, No. 5, pp. 55-62, May.

Smith, V. Kerry (1992). "Environmental Costing for Agriculture: Will It Be Standard Fare in the Farm Bill of 2000?" American Journal of Agricultural Economics, Vol. 74, No. 5, pp. 1076-1088.

Solley. W. B., Chase, E. B., and W.B. Mann, IV (1983). "Estimated Use of Water in the United States in 1980." U.S. Geological Survey Circular 1001.

Solley. W. B., Pierce, R. R., and H.A. Perlman (1993). "Estimated Use of Water in the United States in 1990." U.S. Department of Interior Circular 1081.

Solow, Robert. (1986). "On the Intertemporal Allocation of Resources." Scandinavian Journal of Economics, Vol.88, No.2, pp. 141-56.

Solow, Robert. (1992). "An Almost Practical Step Towards Sustainability." An Invited Lecture on the Fortieth Anniversary of Resources for the Future. Mimeo.

United Nations (1993). “Integrated Environmental and Economic Accounting.” Interim Version. Studies in Methods. Series F. No. 61, Handbook on National Accounting. Department for Economic and Social Information Policy Analysis. United Nations: New York.

U.S. Department of Agriculture (1989). “The Second RCA Appraisal: Soil, Water, and Related Resources on Nonfederal Land in the United States, Analysis of Conditions and Trends.” June.

U.S. Department of Agriculture (1994). Soil Conservation Service. “Summary Report 1992 National Resources Inventory.” July.

U.S. Department of Agriculture (1994). Economic Research Service. “Agricultural Resource and Environmental Indicators.” Agricultural Handbook No, 705. December.

U.S. Department of Commerce (1982). Bureau of the Census. 1978 Census of Agriculture. “1979 Farm and Ranch Irrigation Survey.” AC78-SR-8. November.

U.S. Department of Commerce (1986). Bureau of the Census. “1984 Farm and Ranch Irrigation Survey.” AG84-SR-1. June.

U.S. Department of Commerce (1990). Bureau of the Census. 1987 Census of Agriculture. “Farm and Ranch Irrigation Survey.” AC87-RS-1. May.

U.S. Department of Commerce (1993). Bureau of Economic Analysis. “Survey of Current Business.” August.

U.S. Department of Commerce (1994). Bureau of Economic Analysis. “Accounting for Mineral Resources: Issues and BEA’s Initial Estimates.” April.

U.S. Department of the Interior (1984). U.S. Geological Survey. “National Water Summary 1983-Hydrological Events and Issues.” Water Supply Paper 2250, p.26.

Viscusi, W.K. and W.A. Magat (1991). “Interim draft report on efficient energy pricing.” Report to U.S. Environmental Protection Agency.

Weitzman, Martin (1976). “On the Significance of Net National Product in a Dynamic Economy.” Quarterly Journal of Economics, Vol. 90, No. 1, pp. 156-162.

Table 1. Overview of the Existing NIPA Accounts, 1992, $Billion

Flow of Income		Flow of Output	
Compensation of Employees	3,582.0	Personal Consumption Expenditures	4,139.9
Proprietors Income	414.3	Gross Domestic Investment	796.5
Corporate Profits	407.2	Government Purchases	1,131.8
Net Interest	442.0	Net Exports	-29.6
Rental Income	-8.9		
National Income	**4,836.6**	**Gross Domestic Product**	**6,038.6**
		Consumption of Fixed Capital	-657.9
Business Transfer Payments	27.6	Rest of World Net Factor Income	7.3
Individual Tax and Nontax Liability	502.8	Statistical Discrepancy	-23.6
Subsidies Less Government Surplus	-2.7	Business Transfer Payments	-27.6
Consumption of Fixed Capital	657.9	Individual Tax and Nontax Liability	-502.8
Gross National Income	6,022.2	Subsidies Less Government Surplus	2.7
Statistical Discrepancy	23.6		
Gross National Income	6045.8		
Rest of World Net Factor Income	-7.3		
Gross Domestic Product	**6,038.5**	**National Income**	**4,836.7**

Source: Survey of Current Business, 1993.

Table 2. Summary of Farm Income, 1982, 1987, 1992 $Billion

Flow of Income Components	1982	1987	1992
Compensation of Employees	10.2	9.4	11.9
Proprietors Income	24.6	31.3	43.7
Corporate Profits	1.1	1.1	1.0
Net Interest Income	18.1	12.5	10.2
Net Farm Income	**54.0**	**54.3**	**66.8**
Indirect Tax and Nontax Liability	3.3	3.6	4.4
Subsidies Less Current Government Surplus	-2.4	-13.9	-8.4
Consumption of Fixed Capital	22.0	22.0	21.6
Gross Farm Product	**76.9**	**66.0**	**84.4**

Source: Survey of Current Business, various years.

Table 3. Productivity Impacts on Cropland Associated with Soil Erosion, 1982

Region	Sheet and Rill	Wind
	%	%
Northeast	7.1	*
Appalachia	4.7	*
Southeast	1.3	*
Lake States	0.9	0.7
Corn Belt	3.5	*
Delta	1.6	*
Northern Plains	0.6	0.3
Southern Plains	0.2	2.1
Mountain	0.4	1.4
Total	**1.8**	**0.5**

* = less than 0.01%

Source: U.S. Department of Agriculture, The Second RCA Appraisal.

Table 4. Gross Annual Sheet and Rill Erosion (Cropland and and Pasture/Range)

Region	1982			1987			1992		
	Crop	Pasture	Total	Crop	Pasture	Total	Crop	Pasture	Total
	Million Tons			Million Tons			Million Tons		
Northeast	63	5	68	62	5	67	52	4	57
	166	43	209	152	44	197	108	46	154
Southeast	52	4	56	41	3	44	32	3	36
Lake States	124	4	128	118	4	122	99	3	102
Corn Belt	606	45	651	501	37	537	394	34	428
Delta	116	12	128	99	12	444	79	13	91
Northern Plains	256	80	336	224	78	320	189	79	268
Southern Plains	115	149	264	109	143	251	101	129	230
Mountain	91	210	301	84	201	285	66	211	277
Pacific	737	94	167	676	85	152	48	83	131
Total	**1,661**	**647**	**2,307**	**1,474**	**611**	**2,085**	**1,168**	**604**	**1,773**

Source: U.S. Department of Agriculture. Soil Conservation Service.

Table 5. Off-Site Damages Associated with Soil Erosion, 1982

Region	Industry	Consumer	Total
		$/ton	
Northeast	3.74	2.66	6.40
Appalachia	0.96	0.32	1.29
Southeast	1.74	0.00	1.74
Lake States	2.45	0.95	3.40
Corn Belt	0.49	0.55	1.04
Delta	1.97	0.25	2.22
Northern Plains	0.53	0.09	0.61
Southern Plains	1.22	0.61	1.83
Mountain	0.85	0.17	1.02
Pacific	1.39	0.77	2.16
Total	**1.05**	**0.49**	**1.52**

Source: Ribaudo, 1989.

Table 6, Estimated Inter-Industry Annual Soil Erosion Damages

Region	1982		1987		1992	
	$/ton	Million $	$/ton	Million $	$/ton	Million $
Northeast	3.74	255.0	4.47	298.3	5.41	305.5
Appalachia	0.96	200.7	1.15	225.7	1.39	214.6
Southeast	1.74	98.0	2.08	91.5	2.52	89.8
Lake States	2.45	312.0	2.92	355.5	3.54	360.5
Corn Belt	0.49	319.8	0.59	314.8	0.71	303.4
Delta	1.97	252.9	2.36	261.6	2.85	259.8
Northern Plains	0.53	176.3	0.63	200.6	0.76	203.3
Southern Plains	1.22	322.2	1.46	365.7	1.76	405.8
Mountain	0.85	255.3	1.01	288.7	1.23	339.2
Pacific	1.39	231.9	1.66	251.3	2.01	262.5
Total	**1.05**	**2,424.0**	**1.27**	**2,653.7**	**1.55**	**2,744.4**

Table 7. Estimated Annual Consumer Soil Erosion Damages

Region	1982		1987		1992	
	$/ton	Million $	$/ton	Million $	$/ton	Million $
Northeast	2.66	181.0	3.17	211.8	3.84	216.9
Appalachia	0.32	67.4	0.39	75.8	0.47	72.0
Southeast	0.00	0.0	0.00	0.0	0.00	0.0
Lake States	0.95	121.2	1.13	138.1	1.37	140.1
Corn Belt	0.55	359.5	0.66	353.9	0.80	341.1
Delta	0.25	32.0	0.30	33.1	0.36	32.9
Northern Plains	0.09	28.7	0.10	32.6	0.12	33.1
Southern Plains	0.61	162.4	0.73	184.3	0.89	204.4
Mountain	0.17	51.9	0.21	58.7	0.25	68.9
Pacific	0.77	128.3	0.92	139.0	1.11	145.2
Total	**0.49**	**1,132.3**	**0.59**	**1,227.3**	**0.71**	**1,254.7**

Table 8. Ground-Water Withdrawals by Water Resource Region (Billion Gallons per Day)

Region	1980		1985		1990	
	Agriculture	Total	Agriculture	Total	Agriculture	Total
Missouri Basin	11.3	12.0	8.4	9.5	7.4	8.5
Arkansas-Red-White	8.5	9.4	7.0	7.7	6.8	7.4
Texas-Gulf	4.0	5.1	3.7	5.1	4.0	5.5
Lower Colorado	3.9	4.5	2.6	3.3	2.3	3.1
California	18.0	21.0	10.3	14.8	10.8	14.4
Total	**45.7**	**52.0**	**32.0**	**40.4**	**31.3**	**38.9**

Source: Solley, et. al.

Table 9. The Effects of Agricultural Production on Ground-water Storage (Billion Gallons per Day, and Million $ per Year).

Region	1982		1987		1992	
	BGD	Million $	BGD	Million $	BGD	Million $
Missouri Basin	2.1	46	1.5	36	1.4	43
Arkansas-Red-White	3.2	60	2.7	53	2.6	68
Texas-Gulf	2.4	66	2.2	84	2.4	108
Lower Colorado	1.8	46	1.2	24	1.1	46
California	1.2	32	0.7	15	0.7	26
Total	**10.8**	**249**	**8.3**	**212**	**8.2**	**291**

Source: 1980 data from U.S. Department of the Interior, U.S. Geological Survey.

Table 10. Summary of Adjusted National Income and Product Accounts 1982, 1987 and 1992

Income Components	1982	1987	1992
	$ Billions		
Traditional Farm Income	54.0	54.3	66.8
Water Quality			
Industry Transfer	-2.4	-2.7	-2.7
Consumer Effects	-1.1	-1.2	-1.3
Water Quantity	-0.2	-0.2	-0.3
Green Farm Income	**50.2**	**50.2**	**62.5**
Traditional Non-Farm Income	2,468.5	3,638.0	4,769.8
Water Quality			
Industry Transfer	+2.4	+2.7	+2.7
Consumer Effects			
Water Quantity			
Green Non-Farm Income	**2,470.9**	**3,640.7**	**4,772.5**
Traditional National Income	2,522.5	3,692.3	4,836.6
Water Quality			
Industry Transfer	0.0	0.0	0.
Consumer Effects	-1.1	-1.2	-1.3
Water Quantity	-0.2	-0.2	-0.3
Green National Income	**2,521.1**	**3,690.9**	**4,835.0**