Assigning Economic Value to Natural Resources

Commission on Geosciences, Environment, and Resources, National Research Council

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ASSIGNING ECONOMIC VALUE TO NATURAL RESOURCES

Commission on Geosciences, Environment, and Resources
Commission on Behavioral and Social Sciences and Education
National Research Council

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Cover art by Terry Parmelee. The artist expresses emotion with movement, symbol, and geometric form to create a poetic and imaginative version of nature. Parmelee is represented by the Jane Haslem Gallery in Washington, D.C.

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COMMISSION ON GEOSCIENCES, ENVIRONMENT, AND RESOURCES

COMMISSION ON BEHAVIORAL AND SOCIAL SCIENCES AND EDUCATION

Preface

On July 1-3, 1993, the National Research Council's (NRC's) Commission on Geosciences, Environment, and Resources (CGER) and Commission on Behavioral and Social Sciences and Education (CBASSE) convened a retreat at the J. Erik Jonsson Study Center in Woods Hole, Massachusetts. This workshop on "Valuing Natural Capital in Planning for Sustainable Development" investigated the prospects for, and problems of, incorporating natural resource and environmental assets into economic frameworks, particularly into the national income accounts (such as gross national product or gross domestic product). Within this context, the specific goals of the workshop were to identify crucial technical and conceptual issues, uncover points of consensus and controversy, chart directions for future research and action, and select areas for high priority attention.

The workshop assembled individuals with a wide spectrum of views on environmental, scientific, public policy, and economic issues (see Appendix). Attendees included prominent researchers in environmental and natural resource economics, behavioral, social, and decision sciences, and biologic and earth sciences. Commissioned papers and background articles were distributed in advance to the workshop participants. Together with the presentations, these materials were designed to establish a common basic level of understanding. On this basis, the workshop organizers hoped to increase the sensitivity of different disciplines to the concerns and perspectives of those in other fields, foster common understanding, and summarize some of the major issues of environmental accounting for scholars and policymakers unfamiliar with the debate. At the workshop, basic theoretical issues including the implications of the different concepts of "sustainability" were outlined, work in progress that applied economic techniques to valuing natural resources was presented, and procedures for representing environmental and natural resource issues in an economic framework were suggested. There was considerable disagreement about the definitions and implications of many of the concepts discussed, and no consensus emerged as to immediate remedies for the perceived weaknesses in the present system of accounting.

One major theme dominates this volume: the rationale for, and the problems faced in expanding conventional measures of economic activity to encompass changes in natural capital—that is, in the stock of renewable and nonrenewable natural resources and in the quality of the environment. Short-hand and somewhat casual references to such conceptual and staffs tical reform ideas have sometimes employed the term "greening the GDP." Without wishing to be pedantic, we have chosen to avoid the "green" characterization. For one thing, the word suggests only the environmental part of our dichotomous concern. (Depletion of, say, copper ore is not viewed as primarily an environmental issue.) Moreover, in a number of countries, "green" frequently describes political institutions or platforms that go beyond both environmental and natural resource problems. In this overview, we therefore adopt the term "natural resource and environmental accounting" when discussing the problem of integrating these two elements into the prevailing system of economic measurement.

Secretary of the Smithsonian Robert McC. Adams chaired the workshop and was a speaker. Nobelist Robert Solow delivered the keynote address. Other speakers included Peter Bartelmus, Norman Bradburn, Carol Carson, Paul Craig, Pierre Crosson, Eric Fischer, Baruch Fischhoff, Thomas Lovejoy, Mohan Munasinghe, Henry Peskin, Francis Pierce, Raymond Prince, Claudia Sadoff, David Simpson, and Brian Skinner. M. Gordon Wolman delivered the closing remarks. The workshop sessions and panels were chaired by Robert McC. Adams, Edith Brown Weiss, Joel Darmstadter, Helen Ingram, and William Morrill.

The planning group that organized the workshop was chaired by Joel Darmstadter. It included Edith Brown Weiss, Pierre Crosson, Ernst Lutz, Mohan Munasinghe, Raymond Prince, Stephen Rattien, Craig Schiffries, Miron Straf, Michael Toman, E-an Zen, and M. Gordon Wolman.

This volume includes both an overview of major issues in valuing natural capital and more technical background papers contributed by individual authors. The material presented reflects the wide variety of views and opinions expressed, at times contentiously, by those participating in the event. The overview section draws on the proceedings of the retreat, on the background papers, and on selected scholarly literature listed in the bibliography. It attempts to show the reader the lay of the land without claiming to have discovered a road map for traversing it.

The CGER and the CBASSE gratefully acknowledge the generous contributions of time and expertise by the retreat participants. Special thanks are extended to those who made formal presentations and acted as session chairs, to Alice Killian who served as reporter at the workshop and drafted the overview section with oversight from the committee, and to Morgan Gopnik and Angela Brubaker who produced this volume. It is hoped that the material presented here will help to stimulate new ideas, research, and policy formulation, and perhaps encourage further inquiry into such issues by units of the NRC.

M. Gordon Wolman, Chair
Commission on Geosciences, Environment and Resources
Robert McC. Adams, Chair, 1990-1993
Commission on Behavioral and Social Sciences and Education

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Overview

INTRODUCTION

On Earth Day, 1993, President Clinton, acknowledging that America needs to incorporate environmental values into economic and political decisionmaking, called on the Department of Commerce to develop methods for incorporating the use of natural resources into the U.S. national economic accounts, particularly the income and product accounts (e.g., gross domestic product (GDP) and gross national product (GNP)). Recognizing that "standard of living" involves many factors—among them per capita income, protection of our environment, rate of resource depletion, and enhancement of human resources—maximizing GDP, under current definitions, is clearly a limited surrogate for maximizing "standard of living," "quality of life," or "human welfare." The Joint Economic Committee of Congress has already held hearings on the subject, and instructed the Congressional Budget Office to conduct a study (CBO, 1994) on the conceptual framework and information needed to revise the national accounts to incorporate environmental and natural resource concerns. The Environmental Protection Agency and the Department of Agriculture have begun pilot projects designed to identify potential problems involved in attempting to revise the national accounts in this fashion. The United Nations (UN) and the World Bank have for some time been engaged in efforts in this area, and have incorporated natural capital estimates in partially revised GDP accounts for a number of countries (Lutz, 1993; UN, 1993; UNEP, 1989). Thus, adjustments to consider natural capital might well represent the next major milestone in the continuing evolution of the national accounts.

At the National Research Council (NRC) 1993 workshop on "Valuing Natural Capital for Sustainable Development," considerable attention was focused on the national income accounts, which, in their calculations of GNP or GDP, make no or very inadequate allowance for natural resource use and environmental degradation. As a consequence, there is concern that national policy underprotects natural assets, leading to their excessive depletion and degradation, relative to what would be a more balanced national strategy. Some argue that if the national accounts reflected a more accurate picture of environmental values, there would be reduced losses on the environmental and natural resource side, and greater concern about the loss of future economic potential. Others believe that revising such economic balance sheets to handle the multiplicity and complexity of natural assets is difficult, perhaps impossible, and that decision frameworks should recognize that a variety of strategies and accounts is needed to address issues of national welfare.

Incorporating environmental values and concerns in forecasting, assessing, and making policy for the nation poses formidable challenges. And yet, the incompleteness of the current national income accounts forces us to reexamine our definitions of economic progress and national prosperity. Revising these indices also demands consideration of our obligations to future generations—what sort of environmental legacy and natural resource endowment we wish to leave them. It also, finally, raises the question of international scale. The environment does not stop at our country's borders. Many of our most valuable resources, the atmosphere and oceans, are shared by a number of countries and may be considered global "commons."

The workshop sought to address some of these difficulties, explore the state of the methodology, and gauge the adaptability of the national income accounts. Basic theoretical issues were outlined, including the implications of the different concepts of "sustainability," work in progress was presented, and suggested approaches for future research were considered.

ENVIRONMENTAL VALUES AND THE NATIONAL ACCOUNTS

Historical Background

Rudimentary efforts to measure a nation's income and wealth go back several hundred years. But the comprehensive, systematic, and regular collection and analysis of national accounts statistics date from the first part of the twentieth century. In the United States, formal national income estimation began in the Department of Commerce in 1933, at the depth of the Great Depression. The timing was not entirely coincidental. The severity of the slump gave rise to theoretical studies and policy guidance, largely associated with the work of British economist John Maynard Keynes, designed to spur macroeconomic revival. The prevailing climate of anxiety inspired the launching of major statistical programs that would provide the means of tracking national economic performance. Among many experts contributing to this undertaking in the U.S. was the scholar Simon Kuznets, whose work in this field earned him the Nobel Memorial Prize in Economics in 1971.

Over the years, national accounting concepts have become more refined, anomalies have been corrected, and statistical detail has increased. The scope of national accounts has also expanded to comprise not merely income and product accounts, the components with which we are most familiar, but input-output transactions, national wealth statements, and financial flow-of-funds tables. (A useful collection of articles on the evolution of national accounts and some key conceptual issues appeared in "The Economic Accounts of the United States: Retrospect and Prospect," in the *Survey of Current Business*, 1971.) Many countries currently maintain elaborate systems of national accounts, and the UN Statistical Office has pursued efforts at standardizing accounting treatment and concepts among nations.

National Accounts Dilemmas

Although natural capital is the focus of this report, shortcomings in the scope and content of the GDP accounts, and caveats in their interpretation and use, have been addressed in scholarly writing and analysis over many decades. A recurrent issue during that time span, for example, has been the extent to which the GDP actually tracks human welfare. A frequent criticism concerns the treatment of "defensive" expenditures in the national accounts. For example, additions to the GDP from oil spill cleanup operations in Prince William Sound may seem unusual until we are reminded of the many inherently "unproductive" things we pay for to protect the gains, or overcome the indulgences, that rising income makes possible—spending on items like residential security systems, diet plans, and national defense. A third GDP dilemma relates to the adequate measurement of certain government activities, such as research. Finally, there is a recognized failure to deal with "voluntary" activities, such as unpaid household work, which, if purchased in the marketplace, would merit an addition to GDP. While there has been no theoretical reluctance to improve the accounts, the translation of principles into practice poses formidable challenges.

With respect to natural resources and the environment, defects in our measurement practices have also been recognized for many years. A landmark 1972 National Bureau of Economic Research volume, The *Measurement of Economic and Social Performance* (NBER, 1972), anticipated a major need for linking resource and environmental quality trends to national accounts, recognizing that conventional practice "gives incorrect indications of changes in welfare . . . because it fails to allow for the disamenities associated with industrial growth, particularly pollution of air and water."

Overcoming these shortcomings in the treatment of nonrenewable and renewable resources, much less the more elusive phenomenon of environmental quality, is problematic. While the estimated depreciation of reproducible physical capital (plant and equipment) allows, albeit roughly, for the lost stream of future income that must be compensated for in order to keep a country's economy whole (" sustainable"), no such allowance has been made for changes in the stock of natural capital. Recognition of this anomaly in national income measurement practices has stirred increased research and debate about how best to reform nations' social accounts in a more environmentally sensitive direction.

In recent years, contributions to study of the problem have emerged from four quarters.

- Some analysts, notably Herman Daly and his collaborators, acknowledge the defects of GDP measures that exclude resource depletion and environmental damage. They devote little attention to this particular problem, however, because they challenge the utility of GDP accounts in general.
- Other analysts accept the inherent usefulness of a system of national accounts but, both through argument and actual case studies, recommend specific ways of embodying natural capital in the accounts. This group includes Robert Repetto, Henry Peskin, Salah El Serafy, David Pearce, and numerous other scholars.
- International institutions, principally the World Bank and the UN Statistical Office, have incorporated natural capital estimates in partially revised GDP accounts for a number of countries.

- Finally, a number of nations' official statistical organizations, including those in Norway and the Netherlands, have begun limited implementation of environmental and natural resource accounting reforms.

Studies by Repetto, Peskin and others have broken new ground in this area. Beginning with his 1989 World Resources Institute study, *Wasting Assets*, Repetto, at times in collaboration with others, has not merely critiqued prevailing accounting practice on conceptual grounds, but has attempted at least partial recalculation of some developing economies' national accounts to reflect net natural resource depletion. Thus, the 1989 study suggested that Indonesia's net domestic product (NDP) growth fell markedly below GDP growth once allowance was made for natural resource depletion. A more recent example of such estimates is a recalculation of Costa Rica's NDP, again reflecting not only the conventional, and relatively constant, annual depreciation charges against the country's GDP but also the rapidly rising estimated depletion of three major natural resource categories: forests, soils, and fisheries (Repetto et al., 1991). Such divergence between conventional and resource-adjusted accounts, particularly should it show signs of widening, could send a potentially significant message to policy planners concerned with economic growth. It should be noted, however, that even when natural resource depletion goes on at what may be deemed an unsustainable pace, the ultimate consequences for social welfare will be much affected by the nature of the investments into which the proceeds of natural resources liquidation are plowed. A country depleting, say, its phosphate stocks can squander the proceeds of the sales, unsustainably, on luxury cars for government officials or invest the proceeds in education.

Paralleling and often including the work of academic scholars, international institutions such as the World Bank and the UN Statistical Office have for some years been pursuing an active research program in resource and environmental accounting. In the case of the UN, that work represents a subset of the organization's involvement, over many decades, in developing, independent of natural resource and environmental concerns, a standardized global System of National Accounts (SNA). Two notable studies, published by the World Bank, are *Environmental Accounting for Sustainable Development* (World Bank, 1989) and *Toward Improved Accounting for the Environment* (Lutz, ed., 1993). The latter volume contains case studies which apply alternative resource and environmental accounting techniques formulated by the UN Statistical Office to Mexico and Papua New Guinea. For Mexico, whose statistical system is, as one might expect, far more robust and developed than that of Papua New Guinea, the adjusted NDP tends to be in the range of 90 percent of the conventionally measured NDP. But what is more significant is that Mexico's *net investment*, when corrected for natural resource depletion and environmental effects, is roughly half the conventionally measured estimate of net investment. To be sure, such revaluation experiments are far from comprehensive and methodologically definitive. Yet they offer valuable insights, exposing measurement problems and demonstrating opportunities and directions in further pursuit of such efforts, particularly in developing countries where natural resource sectors, in most cases, constitute a proportionately much larger share of the economy than in industrial countries. They may also have profound implications for economic policymaking. A nation pursuing an aggressive industrialization strategy because it produces increased investment and rapid economic growth by conventional measures might reconsider that course of action if its national accounts revealed only modest investment and growth figures and rapid depletion of valuable assets.

A number of advanced countries have themselves actively engaged in experimentation which could, in time, lead to natural capital-adjusted modification of their official accounts. To date, however, these efforts have been exploratory and selective and have not followed any cross-country standardization rules that would permit international comparison. France, the Netherlands, Norway, and the U.S. have emerged as the principal players in the field, with France and the Netherlands emphasizing development of an integrated conceptual framework, and Norway and the United States concentrating on mobilizing extensive resource and environmental databases that are used for many independent accounts or policy objectives, but have not been incorporated into the main national accounts.

ENVIRONMENTAL ACCOUNTING CHALLENGES

It is clear that social accounting reforms embodying natural capital, if they are to materialize at all, must proceed in a step-wise, evolutionary, and pragmatic manner. To press for short-order, comprehensive, and defensible accounting treatment of natural resources and environmental assets is to both harbor illusions and probably doom the whole effort in its infancy. The success of policies aimed at valuing natural capital for sustainable development demands innovations in accounting acceptable to policymakers, experts, and a large lay public. Consider just three major stumbling blocks, all of which need to be overcome to ensure the viability of any environmental accounting framework.

- **Establishing definitional boundaries**. While it may prove feasible to incorporate, say, changes in the stock of certain minerals or in ground-level ozone concentrations in an urban airshed, the outer limits of the scope of natural capital are quite blurred. Species extinction, encroachment on biodiversity, impairment of visibility, or noise pollution are legitimate examples of resource or environmental degradation; but for now, these effects may be beyond our ability to measure.
- **Estimating net physical depletion**. Depending on the resource in question, quantifying the net volume depleted can prove to be a formidable undertaking, as Sadoff's paper (in this volume) shows in dealing with the tropical hardwood sector of Thailand. Even where the statistical basis is well established, as in the case of U.S. petroleum resources, the extent to which a year's oil use has been offset by new finds or upward revision of economically recoverable reserves is subject to statistical uncertainty and, frequently, to disagreement among estimators. Many depletable resources—for example, copper—are not truly depleted but become embodied in products from which they may at some point be reclaimed. Further, over some time scales, many seemingly renewable resources (such as old-growth forest, ground water aquifers, or top soil) can be lost to the benefit of society, meaning, in essence, that they behave as depletable resources.
- **Monetization**. Full integration of natural resource and environmental quantities into national accounts requires monetization (i.e., assignment of dollar values) consistent with the valuation basis and principles governing conventional GDP measures. This task presents

multiple challenges. Some resource and environmental services are not mediated through market transactions and so require the application of imputed prices. Even in the case of items traded in markets, the choice of a price which appropriately captures the discounted present value of future income foregone by depletion of the resource stock is at best ambiguous. In numerous cases, there remains widespread disagreement, even among scholars familiar with the issues, about both the feasibility and desirability of imposing market-like valuation to environmental assets and processes.

ISSUES IN ENVIRONMENTAL ACCOUNTING

In response to the challenges posed by environmental accounting, workshop participants examined a number of conceptual, technical and philosophic issues. The discussion revolved around four distinct, though interrelated, topics: sustainability, substitutability, irreversibility, and intergenerational equity.

Sustainability

In addressing measurement and methodological issues raised by environmental accounting, experts in both the social and physical sciences have focused considerable attention on the concept of sustainability. This concept was the starting point for discussion at the workshop, where it was examined from a variety of different viewpoints, including those of the life and physical sciences, economics, and industrial, technical, and commercial fields.

Sustainability implies a process which can be continued indefinitely, a course of action that does not include within itself the seeds of its own end or defeat. "A sustainable path," according to the Brundtland Commission definition, "fulfills the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). A more immediate way to put this is to ask whether we, as a world community, are living on interest or capital, and whether our children will inherit as much as we did from our parents. Different economists define economic sustainability in different ways. Solow, for example, identifies a sustainable path as one "that allows every future generation the option of being as well off as its predecessors" (Solow, in this volume). Pearce et al. (1989) suggest that "sustainable *economic growth* means that real GNP per capita is increasing over time and the increase is not threatened by 'feedback' from either biophysical . . . or social impacts," while "sustainable *development* means that per capita utility or well-being is increasing over time, or . . . that a set of 'development indicators' is increasing over time," and that the development, again, is not endangered by negative feedback. Sustainable development clearly does not presuppose a fixed composition of the capital stock; within limits, there is ample opportunity for substituting among various types of capital. Of course, these economic definitions of sustainability assume an anthropocentric frame of reference. They are concerned with sustainability of an ecosystem only so far as it impinges on human welfare.

Economic production involves a transformation of raw materials into finished goods, and the success of many economic enterprises is tied, to some degree, to the cost and availability of raw material. Whenever a society or economy depletes its stock of resources it reduces its future productive capacity. Unless the stock can be renewed, or unless some substitution for the depleted stock can be made, the path is unsustainable. For a sustainable economy, the net "disinvestment" of natural capital or any other forms of wealth which contribute to economic activity, must be minimized or prevented. As noted already, this does not necessarily require replacing identical stocks, as long as nations and firms can renew or substitute for depreciated resources. Thus, in the view of some experts, economic sustainability need not require conservation or replacement of original resource stocks.

While conserving natural capital does imply absolute protection against net physical depreciation or depletion, such a rigidly conservationist view is not inherent in all variants of the sustainability concept. Biologic sustainability, for example, is not tied to preservationism; every single biological entity does not need to be conserved, indeed cannot be, in order for a biological system to qualify as sustainable. Any determination of biological sustainability depends on the scale of the population or ecosystem in question. Policies might protect the spotted owl population in the northwest, but fail to protect owl habitats on a national or international scale. Conversely, the bison population in the U.S. as a whole might be sustained, while an individual herd is wiped out.

Experts have experimented with a number of strategies to promote biologic sustainability. Compensatory mitigation is one replacement strategy that has been tried (*Science*, 1993). Policies of compensatory mitigation mandate ecologic restoration or creation to replace natural areas, primarily wetlands, lost to development. The limited success of such strategies is due not only to the difficulty of enforcing proper compliance with regulations, but also to the fact that even with the best attempts, the resulting "artificial" ecosystems have often proved flawed, lacking the complexity, adaptive properties, and dimensional depth of the natural ecosystems they were intended to replace. For example, artificial ecosystems are often constructed in relation to one set of environmental variables but may have lower resistance and resilience to changes in driving variables (such as global climate) than their natural counterparts.

Considerations of sustainability often draw a distinction between natural resources which are possible to replenish, such as municipal water reservoirs refilled by water treatment, and resources which cannot be replenished, such as fossil fuels or species near extinction. But this distinction is not always clear-cut. For example, forest lumber may be replenished, in the sense that the forest may be managed as a farm, with new tree crops planted regularly to ensure steady yield, but it may not be possible to similarly renew the forest's value as part of an ecological system. Wetlands replaced according to compensatory mitigation policies may fulfill established guidelines, but they do not reproduce the specific ecosystem of the lost wetland, and often fail to secure a habitat for that original wetland's species.

Substitutability

As noted above, in discussing replenishment one must consider the closely related concept of substitutability, in both its economic and environmental or biologic senses. Lost natural assets may be compensated for by other natural assets. For example, if a given industry is dependent on some particular resource which becomes increasingly scarce, it is possible that the industrial processes may be reconfigured to rely on some alternative material or process. Whale oil lamps were replaced by alternate lighting methods and mineral-based oil replaced whale oil as a lubricant. (It should be noted that while this was an effective substitute for the economy as a whole, the whaling industry itself all but disappeared, and some whale species never recovered.)

A much more recent example of substitutability, based on a less direct aspect of depletion, involves the refrigeration and electronics industries that previously employed chlorofluorocarbons (CFCs) as a refrigerant and in some of their industrial processes. As these chemicals have become increasingly implicated in ozone depletion, the industry appears to be successful in finding substitutes, albeit at higher cost. In this case, it was stratospheric ozone, not the chlorofluorocarbons, that were depleted; CFC use led to the depletion of another natural resource. Not only can different natural resources substitute for each other, but it is also possible to substitute greater inputs of labor, reproducible capital, or renewable resources (e.g., solar energy) for inputs of a nonrenewable resource.

Whether or not a given material is an adequate substitute for a specific resource depends on the viewpoint and particular needs of the user, and on the available technology. The influence of advancing technology is readily apparent in the extractive industries. In mining, for example, due to technical advances in extraction and processing, ores of progressively lower grades are being profitably extracted. What were considered "tailings" or waste rock left over from mining operations in the past, would today be considered as source rock. Similarly, today's tailings may be valuable one day given future technologic advances. This has raised speculation that today's landfills may be tomorrow's ore bodies, in a twist on the ecological notion of composting (Adams, 1993). It also suggests that in some cases we may be underestimating the size of our depletable resource base.

Compensatory mitigation, as described above, is yet another type of substitutability, in which a man-made ecosystem is substituted for a natural one. But as has been seen, biologic substitutability is often more complex than economic substitutability. In an economic process, a resource may be limited to a small number of readily defined uses, perhaps even one single use, whereas a component of an ecosystem may play a vast number of complex roles, whose nature we can only begin to grasp. For example, while more than one species of bird can act as a predator of a certain insect, each of those bird species may be unique as to the precise niche it fills in the ecosystem. Not only is there no actual substitutability for species, but even for cases of near substitutability, the time scales that are involved often exceed many human lifetimes. Some have in fact argued that natural capital and man-made capital are complementary and only marginally substitutable (Daly, 1990).

Irreversibility

One of the implications of an emphasis on sustainability is that irreversibilities—losses of resources that cannot be recovered—should be avoided wherever possible. An exception to this might include an irreversibility such as the extinction of a harmful microbe or virus, although there are those who would even argue for their preservation in the interests of future research. An irreversible effect implies that there is no going back, that what has been lost has been lost forever. The extinction of a species, such as the passenger pigeon, is an example of a biological irreversibility, and natural species are lost yearly. The destruction of a unique ecosystem, which is beyond our technological capacity to recreate, is another. One of the dangers of irreversibilities is that, due to the limitations in our knowledge of the functioning of environmental processes, we often don't know what we have lost until it is too late. Such irreversibilities may result in incalculable, but potentially enormous, economic and social losses, as would be incurred, for example, through the extinction of plants that might potentially produce important pharmaceuticals.

Intergenerational Equity

Inherent in the fact that different experts employ competing concepts of sustainability is the diversity of viewpoints prevailing on the issue of intergenerational equity. While there is agreement on the need to include intergenerational considerations in environmental accounting, there still remains considerable dispute over the proper definitions and approaches. For example, what is the extent of our obligation to the next generation? Must we bequeath to them an inheritance of wealth commensurate in size to the legacy our own generation received? As Robert Solow has noted (Solow, 1992; included in this volume), we make trades with posterity: we consume natural resources, but substitute for them by investment in (reproducible) man-made capital and knowledge. We hope that the value of the latter more than makes up for any depletion of the former. For Solow, this "ethic of sustainability" defines each generation's obligation to its successor; if a generation adds to social capital in all its forms amply enough to maintain the aggregate value of all social capital, then it has made sufficient recompense for the nonrenewable resources it has depleted. However, measuring the value of natural resources, particularly as components of complex, interactive ecosystems, presents daunting challenges for such calculations. And many experts, including several in attendance at the workshop, question this conception of intergenerational equity, seeing it as anthropocentric and overly biased toward development now at the expense of conservation for the future.

Technical Issues

If environmental economic approaches are to be successful, cooperative research is needed to address not only the conceptual, definitional problems described above, but also to overcome technical challenges in valuing natural assets and to devise suitable methods and practices for accurate environmental accounting. Four principal technical issues were identified at the workshop: monetization, externalities, data unavailability, and data accuracy.

- First are the technical challenges of monetization, introduced earlier. To view natural resources as capital, and to incorporate them into economic analyses, economic value must be assigned to them. Many measurement techniques have been proposed, but all are fraught with difficulties. In general, among the many obstacles to assigning a monetary value to a natural resource is the question of what an asset is. If one defines a single component of a natural system as an asset (for example, forest timber), how does one define its role as part of the larger asset that is the natural system (for example, the forest itself, with its myriad ecological, recreational, and aesthetic functions)? Of course, broadening the asset definition greatly complicates the problem of monetary valuation.

- Second, externalities need to be incorporated in economic decisions. Externalities are costs (or benefits) that arise as a result of an economic process, but which are not borne (internalized) by the firm or system engaged in that process as in the case of environmental damage. These costs are generally absorbed by third parties or the public at large. In other words, externalities are costs (or benefits) that appear to be "free" to those controlling the process, but are costly (or valuable) to someone else. What is or is not an externality depends on accounting practices, and on legal and regulatory systems. For instance, if a manufacturing plant does not have to pay to clean up the air pollution resulting from the chemicals emitted from the plant's smoke stacks, then the creation of that pollution is an externality the plant imposes on society. The costs are not reflected anywhere on its books.

Agricultural activities, for example, involve numerous externalities. Farming may have damaging or beneficial effects on the off-farm environment but these are usually not accounted for in financial terms. On the one hand, farms preserve land from commercial development, thereby preserving limited natural ecosystems, and providing scenery of relative beauty. On the other hand, damaging effects may be created by farming, such as the sedimentation of neighboring streams and pollution problems associated with runoff of fertilizer or pesticides.

Many natural resources, although vital inputs to production processes, remain externalities. For example, a company may not treat water used in production as capital to be paid for and maintained, but consider only the costs of having it conveyed to the desired location. Common property resources, such as water and air, have been frequently exploited because of their unrestricted accessibility. In recent years, degradation of air and water has become a matter of public concern, and measures, such as the U.S. Clean Air Act amendments of 1990, have been taken to curb pollution. Deteriorating environmental conditions have also aroused growing concern in such urban centers as São Paulo, Mexico City, and Bangkok.

If a company is required to pay the costs of external damage, or is able to charge for external benefits, these externalities become internalized in the company's financial accounts. But finding ways of bringing externalities into the economy is difficult. Many externalities are not only physically difficult to measure but, even when measured, are troublesome to translate into monetary equivalents. We can force a utility to restrict its emissions through tradable emission permits or other policies, but we cannot accurately compare the costs of these restrictions against the damage to health these emission controls prevent, much less express such health damage in monetary terms.

Compelling individuals and institutions to reduce these external social costs by incurring some internal costs is not sufficient to yield the kind of environmentally sensitive national accounts reformers advocate. Comprehensive accounting reform requires that all the quantitative or qualitative deterioration of such natural capital as air, water, or soils would need to be charged against the nation's GDP. But at least the partial internalization of costs is a step in the direction of forcing some explicit economic manifestation of the effects of an eroding natural capital base. How would this come about? Take an electric generating plant whose degradation of the environment through its SO_2 emissions fails to be treated as a charge against GDP, leaving the measure of NDP higher than it ought to be. Assume that the utility installs costly scrubbers in order to comply with the U.S. 1990 Clean Air Act amendments mandating limits on SO_2 releases. In an economy-wide sense (assuming full employment of resources), a given volume of electricity production requires shifting resources into the production of scrubbers at the expense of, say, widgets, whose decline signifies a level of GDP lower than would otherwise be the case.

Thus, even in the absence of a formal recasting of the national accounts along environmental lines—which would have dictated quantifying the deterioration of air quality prior to the installation of scrubbers and its improvement thereafter—the GDP penalty in this example at least alerts us to the economic implications of environmental protection. A similar point emerges from Crosson's paper (in this volume). Losses of soil quality which reduce farm production should be reflected in the national accounts. But if farmers compensate for soil quality losses by changes in farm practices entailing an increase in operating expenses, the soil-loss effect will show up as lower net farm income and GDP, assuming a full employment economy.

- A third problem is the difficulty of characterizing and quantifying the natural environment. Even when there are applicable units of measurement, and when their rate of use can be charted, natural resource features are difficult to characterize. For example, it would be extremely difficult to calculate how much of a given resource exists within the environment, especially for resources such as air and water that are constantly depleted and created and used in different forms within different natural cycles.

This challenge exists even for so discrete a problem as determining animal populations, for which there are few accurate measures. Even in the case of species on the verge of extinction, whose numbers are so small that wildlife enforcement officials know individual animals, the exact population of the species may be unknown. Computing meaningful subsets of an animal population, such as the number of species within any given ecosystem, has aroused even more scientific controversy. Biologic inventories are necessary for proper valuation of natural resources, and some steps are being taken in this direction. While biologists have expressed Skepticism over the possibility of assigning a monetary value to biological entities, they have supported the creation and maintenance of biologic inventories as useful and valuable for research. The Department of the Interior is in the process of forming a new agency, the National Biological Survey, whose functions will include the inventorying, mapping and monitoring of biologic resources. Comparable efforts in other parts of the world are rare.

Physical accessibility to sources of key data poses another problem for information collection. Terrain and topography may prove difficult to traverse, unstable political situations may hamper research, and the costs involved in data collection may be prohibitive. For example, forest inventories are very expensive and very rare in developing countries, and few such inventories are performed. Because of such difficulties, relatively little data has been collected or research conducted. While remote sensing methods, such as Landsat, can contribute information about overall resource size, they may not be able to capture information about resource quality. For example, trends in total forest acreage can be obtained, but changes in forest density, ratios of new growth to old growth, or decline in health of trees are difficult to assess at present.

Even for simple inventories, much uncertainty is associated with the measurement process. When attempts are made to combine measurements, added levels of uncertainty are introduced. Macroeconomic frameworks and indicators such as the national accounts deal with aggregates, and aggregation necessarily requires additive monetary units derived from many subsidiary measurements. In combining these figures, uncertainties associated with the measurements are also combined, in ways which are difficult to track. The cumulative or additive effect of these uncertainties, and the loss of information through aggregation, can only be guessed at. This opens the question of the extent to which the aggregate figures produced can be trusted as a basis for policymaking. The explicit inclusion of uncertainty figures as a major component of natural capital accounting frameworks may be one way to deal with this problem. Alternatively, a probabilistic approach for calculating uncertainties could be employed, with an aggregation or totaling of uncertainties implying a corresponding totaling of probabilities.

- Finally, accuracy issues involved in measurement processes go beyond simple technological inadequacy. Even when we are able to gather data on a certain phenomenon, if these data do not fit earlier experience or preconceived ideas, they may be "filtered out" of our data bases. We measure what we are looking for and what we expect to find. We do not measure what we are not looking for (do not value in a scientific sense), and we do not always know how to deal with what we don't expect to find. We sometimes write off these "unexpected" results as "errors" or "noise." For example, as Craig and Glasser have noted (in this volume), data revealing the Antarctic ozone hole were systematically removed from satellite data through numerical filters designed to remove data that were too far from expectation. Many other examples of this can be seen throughout the history of science. Consider, for example, the elaborate mathematical structures designed to reconcile observed planetary orbits with the socially constructed concept that the Earth was the center of the universe.

Philosophical Questions

In addition to, and partially because of, the above-mentioned difficulties, there is much disagreement among experts as to the proper measurement procedures, and as to the method of incorporating these physical measurements into economic frameworks. For example, although the Netherlands has been one of the more active promoters of environmental accounting reforms, Dutch statisticians are wary of moving too aggressively in monetizing environmental resources or damage within economic frameworks, arguing that physical measurements and monetary quantities are too dissimilar to be validly compared (*The Economist*, 1993). Yet other statisticians maintain that without such comparisons, fundamental accounting reforms and related efforts such as cost-benefit analyses cannot be undertaken.

As noted above, all economic valuation techniques involve aggregation. Aggregation requires comparable units for the quantities being combined, giving rise to the problems mentioned earlier. Thus, experts debate the validity of assigning additive monetary values to such widely varying elements as air quality, species population, and ecosystem value. Some scholars assert that no legitimate comparison or aggregation is possible.

Poorly defined property rights or open access will depress the price of a resource, and such underpricing of a resource means it will tend to get wasted. This point is borne out by both contemporary and historical experience. In some developing areas, ill-defined or poorly enforced property rights (such as in the frontier regions of Amazonia) may encourage destructive and unsustainable land-use practices, inimical to the long-term environmental services the land could provide. Similarly, nineteenth century U.S. resource policy distributed land, water, mineral rights, and timber resources to private individuals for negligible prices, diligence requirements, and lease terms, which promoted rapid growth, but also encouraged wasteful, inefficient and frequently destructive mining, lumbering and farming practices. These are all examples of "externalities," as discussed earlier.

While the problems involved in measurement and integration of natural resources into economic accounts are difficult to grapple with, the thorniest issues confronting environmental accounting are philosophical ones. Ideological, moral, and even metaphysical values are embedded in the questions considered here. These ethical dilemmas cannot be avoided, nor would it be advisable to proceed with valuation procedures without examining the underlying conceptual concerns involved.

Another issue central to both environmental and economic valuations is the common tradeoff between short term economic growth and poverty alleviation on one hand, and long term sustainable development, on the other. It is difficult to calculate social values for resources that are not traded in conventional markets, for example, "scenery." Scenery is not bought and sold, though it does have economic impact—just ask a real estate developer or tourist industry employee. Yet, despite such obvious social and even economic impacts, it is often difficult to assign an economic value to such an intangible quality of the environment.

In the absence of public preferences as revealed in markets, valuation can be attempted through alternative approaches, such as "contingent valuation." This technique is based on assessing what people would be willing to pay in order to preserve a given resource. Such "willingness to pay" estimates are derived from interviews and questionnaires. Different users of a resource naturally differ in how much they are willing to pay to preserve it. Even individuals who have no direct contact, and expect to have none, with a given natural resource, are frequently willing to pay to preserve it for a variety of reasons ranging from patriotism to altruism. Certain unique natural features such as those found in the National Park System, for example, inspire such a public response.

Concomitant with willingness to pay is the flip-side of the concept, that is, "willingness to accept." This is basically a question of what people are willing to accept as compensation for environmental damage, that is, what compensation they would demand as recompense for the destruction of a particular natural resource. The advantages of such a measurement technique are that it can be used to calculate values for things which have been deemed invaluable. Through questionnaires eliciting willingness to pay or accept, numbers are produced which can be used in value calculations. The problems with such measurements, however, are associated with the highly subjective nature of the data source and the fact that the value can change dramatically over time and between one community and another. What a given individual answers to such a question may be very circumstantial and contextual. Opinions may vary over time, with social circumstances, and with education; even when they can be pin-pointed through questionnaires, they may change rapidly. Additionally, the phrasing of the question, even its placement within the questionnaire, may strongly affect the outcome.

Another problem arising here is the issue of different groups of users with different sets of values. A rainforest, for example, may be valued very differently by vacationing foreign tourists than by local villagers fighting for subsistence. Also, since tourists are usually foreigners, a money valuation derived from willingness-to-pay methods will have to be calibrated for different currencies, and relative wealth. Setting dollar amounts for groups of people of different economic backgrounds may be difficult. For a variety of reasons such as these, contingent valuation and related survey techniques are sometimes viewed with distrust.

Furthermore, some people are uncomfortable with monetizing natural assets held in common, such as oceans or national parks. They reject such valuations as morally repugnant or anthropocentric. In fact, some physical scientists suggest that environmental accounting is a flawed concept because it deals with issues, such as preservation of wetlands, from the point of view of affected humans. Environmental accounting might allow us to consider the value of a wetland to bird watchers as well as developers, but cannot allow us to consider wetlands preservation from say, the "perspective" of hundreds of thousands of migratory birds whose feeding ground along a major flyway is threatened by human activity.

ISSUES FOR FURTHER STUDY

Seven issues were identified at the workshop for urgent attention and further study: criteria for selecting appropriate natural capital assets for economic valuation; actually selecting them; developing techniques for environmental accounting appropriate for national policymaking, firm-level decisionmaking and complex dynamic systems analysis; developing nonmonetized inventories for selected natural assets; tracking irreversible processes; identifying points of leverage for future action; and, finally, determining priorities for revising the national income accounts and other economic indices versus alternative means for characterizing the broader societal consequences of economic decisions with significant resource depletion and environmental degradation impacts.

A crucial first step is selecting particular natural resource or environmental assets for prospective incorporation into economic indices, or for consideration in some other fashion appropriate for policymaking. Clearly, both the technical challenges and the policy implications of environmental accounting will vary if the initial work concentrates on resources such as mineral stocks for which monetary values are easily derived and stocks are fairly well known, rather than on "free goods" such as air and water, or interactive processes such as maintenance of biodiversity or wetlands preservation.

Second, a feasible early step is to experimentally incorporate measurements for one particular resource for which ample data exist, and the value of which may even be determined from existing markets. The natural resource that most closely fits this description is the nation's mineral wealth. Mineral and ore deposits have been well surveyed and inventoried since the establishment of the U.S. Geological Survey and the Bureau of Mines, and are being exploited by a relatively robust and mature industrial sector. Although there are problems in assessing the present value of prospective commercialized resource flows, the monetary values of many minerals can be derived from existing markets, and need not be subject to serious dispute. Economic issues regarding extractive industries and their sustainability have been extensively explored. There are established cases of substitutability between different minerals in different industries, although the elasticity of substitution between classes of rare and common minerals is debatable and varies over time as a function of technology and societal need. Selected minerals (excluding those like the precious metals gold and silver whose prices have been subject to wide swings over time) would thus seem to be an ideal initial resource to be incorporated into an accounting framework.

Indeed, at the Woods Hole workshop, Carol Carson, Director of the Commerce Department's Bureau of Economic Analysis (BEA), reported that the Bureau had already begun such calculations. In the April 1994 issue of its *Survey of Current Business*, the BEA recounts the results of its initial efforts along this line. However, while the use and depletion of mineral stocks might offer the readiest initial opportunity for revising the national accounts, many scientists and policymakers, including a number of workshop participants, have expressed reservations about such an approach. They cautioned that the results of calculations which included only minerals would present a distorted view, and hamper efforts to achieve a more comprehensive valuation of natural capital flows. The most urgent arena for implementing environmental accounting, these experts maintain, is precisely those areas for which no clearly defined markets and price structures exist. They suggest immediate work on essentially nonmarket goods—such as air and water—and on interactive processes—such as maintenance of biodiversity. This line of argument, then, demands primary attention be given not just to those areas most easily amenable to monetization, but to assets not easily monetized or even measured.

Even after targeting priority considerations for revised environmental accounting procedures, considerable technical challenges remain in devising environmental valuations. Techniques are needed to update the national income accounts or other official economic indicators so that national debate and policy decisions accurately reflect the importance of natural assets. The nation requires continual improvement in methodologies by which people can assess these benefits and damages. New systems of measurement must remain flexible and dynamic so that they can cope with the constant new problems posed by measuring complex, dynamic, interactive natural systems.

There is considerable disagreement about whether assigning monetary values to any, many, most, or all natural processes or assets is wise or appropriate. Some workshop participants believe that the research community needs to develop alternate tools, such as nonmonetized inventories of natural assets, in order to equip policymakers with accurate data in areas where monetary valuation is either inappropriate or unavailable.

CONCLUSION

Two broad conclusions emerged from these intense and at time contentious workshop discussions. First, that incorporating environmental and natural resource values into economic recordkeeping and policymaking is an arduous task, fraught with technical and conceptual difficulties. It will require considerable ingenuity and effort to solve these problems. Future directions in the development of environmental accounting include the identification of productive avenues of research, the promotion of innovative and significant work, and the furtherance of interdisciplinary communication and cooperation, all of which should be encouraged.

The second conclusion was that, despite the difficulties, efforts must continue. Although it is probably premature to alter the official national accounts, attempts should be made to experiment with new environmental accounting methodologies as they are developed and refined. These revised numbers can then be disseminated side-by-side with the conventional accounts.

National policymakers, and the data sources on which they base their decisions, must soon begin to take into account resource depletion, ecological balance, and the sustainability of economic development. The nation's future economic strength and environmental integrity depend on it.

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Issue Papers

1

An Almost Practical Step Toward Sustainability[1]

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You may be relieved to know that this talk will not be a harangue about the intrinsic incompatibility of economic growth and concern for the natural environment. Nor will it be a plea for the strict conservation of nonrenewable resources, even if that were to mean dramatic reductions in production and consumption. On the other hand, neither will you hear mindless wish fulfillment about how ingenuity and enterprise can be counted on to save us from the consequences of consuming too much and preserving too little, as they have always done in the past.

Actually, the argument I want to make seems to be particularly appropriate on the occasion of the fortieth anniversary of Resources for the Future; it is precisely about resources for the future. And it is even more appropriate for a research organization: I hope to show how some fairly interesting pure economic theory can offer a hint—though only a hint—about a possible improvement in the way we talk about and think about our economy in relation to its endowment of natural resources. The theoretical insight that I will present suggests a potentially important line of empirical research and a possible guideline for long-term economic policy. Then I will make a naive leap and suggest that, if we talked about the economy in a more sensible and accurate way, we might actually be better able to conduct a rational policy in practice with respect to natural and environmental resources. That is probably foolishness, but I hope you will find it a disarming sort of foolishness.

PREVIEWING THE ARGUMENTS

It will be useful if I tell you in advance where the argument is leading. It is a commonplace thought that the national income and product accounts, as currently laid out, give a mis

[1] Reprinted, with permission, from Resources for the Future, 1992. First presented at the Resource and Conservation Center in Washington, D.C., on October 8, 1992, on the occasion of the fortieth anniversary of Resources for the Future.

leading picture of the value of a nation's economic activity to the people concerned. The conventional totals, gross domestic product (GDP) or gross national product (GNP) or national income, are not so bad for studying fluctuations in employments or analyzing the demand for goods and services. When it comes to measuring the economy's contribution to the well-being of the country's inhabitants, however, the conventional measures are incomplete. The most obvious omission is the depreciation of fixed capital assets. If two economies produce the same real GNP but one of them does so wastefully by wearing out half of its stock of plant and equipment while the other does so thriftily and holds depreciation to 10 percent of its stock to capital, it is pretty obvious which one is doing a better job for its citizens. Of course the national income accounts have always recognized this point, and they construct net aggregates, like net national product (NNP), to give an appropriate answer. Depreciation of fixed capital may be badly measured, and the error affects net product, but the effort is made.

The same principle should hold for stocks of nonrenewable resources and for environmental assets like clean air and water. Suppose two economies produce the same real net national product, with due allowance for depreciation of fixed capital, but one of them is wasteful of natural resources and casually allows its environment to deteriorate, while the other conserves resources and preserves the natural environment. In such a case we have no trouble seeing that the first is providing less amply for its citizens that the second. So far, however, the proper adjustments needed to measure the stocks and flows of our natural resources and environmental assets are not being made in the published national accounts. (The United Nations has been working in this direction for some years, so the situation may change, although only with respect to environmental accounting.) The nature of this problem has been understood for some time, and individual scholars, beginning with William D. Nordhaus and James Tobin in 1972, have made occasional passes at estimating the required corrections.

That is hardly news. The additional insight that I want to explain is that there is a "fight" way to make that correction—not perhaps the easiest or most direct way, but the way that properly charges the economy for the consumption of its resource endowment. The same principle can be extended to define the fight adjustment that must be made to allow for the degradation or improvement of environmental assets in the course of a year's economic activity. The properly adjusted net national product would give a more meaningful indicator of the annual contribution to economic well-being.

The corrections are more easily defined than performed. The necessary calculations would undoubtedly be more error-prone that those the U.S. Department of Commerce already does with respect to the depreciation of fixed capital. Nevertheless, I would suggest that talk without measurement is cheap. If we—the country, the government, the research community-are serious about doing the fight thing for the resource endowment and the environment, then the proper measurement of stocks and flows ought to be high on the list of steps toward intelligent and foresighted decision.

The second and last step in my argument is more abstract. It turns out that the measurements I have just been discussing play a central role in the only logically sound approach to the issue of sustainability that I know. If "sustainability" is anything more than a slogan or expression of emotion, it must amount to an injunction to preserve productive capacity for the indefinite future. That is compatible with the use of nonrenewable resources only if society as a whole replaces used up resources with something else. As you will see when I return to this point for a full exposition, the very same calculation that is required to construct an adjusted net national product for current evaluation of economic benefit is also essential for the construction of a strategy aimed at sustainability. This conclusion confirms the importance of a serious effort to dig out the relevant facts.

That is a brief preview of what I intend to say, but before going on to say it, I would like to mention the names of the economists who have contributed most to this line of thought. They include professors John Hartwick of Queen's University in Canada, Partha Dasgupta of the University of Cambridge, England, and Karl-Göran Mäller of the Stockholm School of Economics; my sometime colleague Martin L. Weitzman, now of Harvard University; and, more on the practical side, Robert Repetto of the World Resources Institute. I have already mentioned the early work of Nordhaus and Tobin; Nordhaus has continued to contribute common sense, realism, and rigorous economic analysis. Finally, I should confess that I have contributed to this literature myself. My idea of heaven is an occasion when a piece of pretty economic theory turns out to suggest a program of empirical research and to have implications for the formulation of public policy.

FINDING THE TRUE NET PRODUCT OF OUR ECONOMY

Now I go back to the beginning and make my case in more detail. Suppose we adopt a simplified picture of an economy living in some kind of long run. What I mean by that awkward phrase is that we are going to ignore all those business-cycle problems connected with unemployment and excess capacity or overheating and inflation. From quarter to quarter and year to year this economy fully exploits the resources of labor, plant, and equipment that are available to it.

To take the easiest case—that of natural resources—first, imagine that this economy starts with a fixed stock of nonrenewable resources that are essential for further production. This is an oversimplification, of course. Even apart from the possibility of exploration and discovery, the stock of nonrenewable resources is not a pre-existing lump of given size, but a vast quantity of raw materials of varying grade, location, and ease of extraction. Those complications are not of the essence, so I ignore them.

It is of the essence that production cannot take place without some use of natural resources. But I shall also assume that it is always possible to substitute greater inputs of labor, reproducible capital, and renewable resources for smaller direct inputs of the fixed resource. Substitution can take place on reasonable terms, although we can agree that it gets more and more costly as the process of substitution goes on. Without this minimal degree of optimism, the conclusion might be that this economy is like a watch that can be wound only once: it has only a finite number of ticks, after which it stops. In that case there is no point in talking about sustainability, because it is ruled out by assumption; the only choice is between a short happy life and a longer unhappy one.

Life for this economy consists of using all of its labor and capital and depleting some of its remaining stock of resources in the production of a year's output (GDP approximately). Part of each year's output is consumed, and that gives pleasure to current consumers; the rest is invested in reproducible capital to be used for production in the future. There are various assumptions one could make about the evolution of the population and employment. I will assume them to have stabilized, since I want to talk about the very long run anyway. Next year is a lot like this year, except that there will be more plant and equipment, if net investment was positive this year, and there will be less of the stock of resources left.

Each year there are two new decisions: how much to save and invest, and how much of the remaining stock of nonrenewable resources to use up. There is a sense in which we can say that this year's consumers have made a trade with posterity. They have used up some of the stock of irreplaceable natural resources; in exchange they have saved and invested, so that posterity will inherit a larger stock of reproducible capital.

This intergenerational trade-off can be managed well or badly, equitably or inequitably. I want to suppose that it is done well and equitably. That means two things. First, nothing is simply wasted; production is carried on efficiently. Second, although the notion of intergenerational equity is much more complicated and I cannot hope to explain it fully here, the idea is that each generation is allowed to favor itself over the future, but not too much. Each generation can, in turn, discount the welfare of all future generations, and each successive generation applies the same discount rate to the welfare of its successors. To make conservation an interesting proposition at all, the common discount rate should not be too large.

You may wonder why I allow discounting at all. I wonder, too: no generation "should" be favored over any other. The usual scholarly excuse—which relies on the idea that there is a small fixed probability that civilization will end during any little interval of time—sounds farfetched. We can think of intergenerational discounting as a concession to human weakness or as a technical assumption of convenience (which it is). Luckily, very little of what I want to say depends on the rate of discount, which we can just imagine to be very small.

Given this discounting of future consumption, we have to imagine that our toy economy makes its investment and resources-depletion decisions so as to generate the largest possible sum of satisfactions over all future time. The limits to this optimization process are imposed by the pre-existing stock of resources, the initial stock of reproducible capital, the size of the labor force, and the technology of production.

This assumption of optimality is an embarrassing load to carry around. Its function is primarily to allow the semi-fiction that market prices accurately reflect scarcities. A similar assumption is implicit whenever we use ordinary GDP as a measure of economic well-being. In practice, no doubt, prices reflect all sorts of distortions arising from monopoly, taxation, poor information, and other market imperfections. In practice one can try to make adjustments to market prices to correct for the worst distortions. The conceptual points I want to make would survive. They are not to be taken literally in any case, but more as indicators of the sort of measurements we should be aiming at in principle.

Properly Charging the Economy for the Consumption of Its Resource Endowment. Now I come to the first major analytical step in my argument. If you look carefully at the solution to the problem of intergenerational resource allocation I have just sketched, you see that an excellent approximation of each single period's contribution to social welfare emerges quite naturally from the calculations. It is, in fact, a corrected version of net domestic product. The new feature is precisely a deduction for the net depletion of exhaustible resources. (I use the phrase "net depletion" because it is possible to extend this reasoning to allow for some discovery and development of new resources. In the pure case, where all discovery and development have already taken place, net and gross depletion coincide.)

The correct charge for depletion should value each unit of resource extracted at its net price, namely, its real value as input to production minus the marginal cost of extraction. As Hartwick has pointed out, if the marginal cost of mining exceeds average cost, which is what one would expect in an extractive industry, then the simple procedure of deducting the gross margin in mining (that is, the value of sales less the cost of extraction) will overstate the proper deduction and thus understate net product in the economy. If I may use the jargon of resource economics for a moment, the correct measure of depletion for social accounting prices is just the aggregate of Hotelling rents in the mining industry. That is the appropriate way to put a figure on what is taken from the ground in any given year, that year's withdrawal from the original endowment of nonrenewable resources.

This proposal presents two practical difficulties for national income accounting. The first is that observed market prices have to be corrected for the worst of the distortions I have just listed (that is, the distortion that would result from deducting the gross margin in mining—overstatement of the proper deduction and understatement of the net product in the economy). Making adjustments to market prices to correct for distortions is attempted routinely by the World Bank and other agencies in making project evaluations in developing countries. We seem to ignore the problem of such distortions when we use our own national income accounts to study and judge the economies of advanced countries. If we are justified in that practice, the same casual treatment may be satisfactory in this context. (Not always, however: the large observed fluctuations in the price of oil cannot be accepted as indicating "true" values.) Either way, this is a surmountable problem.

I am not sure whether it is safe to be so casual about the second practical difficulty that my proposal for deducting net depletion of exhaustible resources presents for national income accounting. In principle, the proper measurement of resource rents requires the use of a numerical approximation to the marginal cost of mining. As I said, if marginal cost exceeds average cost by a lot, then taking the easy way out Oust deducting the gross margin in mining) would entail a large error by overstating the depreciation of the resource stock. It seems to me that this is exactly where the fund of knowledge embodied in an organization like RFF can find its application. Tentative calculations for the main extractive industries would tell us something important about the true net product of our own economy. That would be important not merely because it would allow a more accurate evaluation of the path the economy has been following, but also, as you will see, because the measurement of resource rents should be an input into policy decisions with a view to sustainability.

Correcting National Accounts to Reflect Environmental Amenities. Pretty clearly, similar ideas should apply to a program of correcting the conventional national accounts to reflect environmental amenities. Much more attention has been lavished on environmental accounting than on resource accounting, and I have very little to add. Henry M. Peskin's work (much of which was done here at RFF) goes back to the early 1970s, and the Organization for Economic Cooperation and Development, the World Bank, and the U.S. Department of Commerce are preparing a framework for integrating national income and environmental accounts. The sooner it happens the better. My only comment is a theoretical one. Without too much strain, it may be possible to treat environmental quality as a stock, a kind of capital that is "depreciated" by the addition of pollutants and "invested in" by abatement activities. In such cases the same general principles apply as to other forms of capital. The same intellectual framework will cover reproducible capital, renewable and nonrenewable resources, and environmental "capital."

The data problems may be altogether different, of course, especially when it comes to the measurement of benefits, a nicety that does not arise in the case of resource depletion. But the underlying treatment will follow the same rules. This counts for more than fastidiousness, I think. It would be a real achievement if it were to become a commonplace that capital assets, natural assets, and environmental assets were equally "real" and subject to the same scale of values, indeed the same bookkeeping conventions. Deeper ways of thinking might be affected.

That completes the first phase of my argument, so I will summarize briefly. The very logic of the economic theory of capital tells us how to construct a net national product concept that allows properly for the depletion of nonrenewable resources, and also for other forms of natural capital. Carrying out those instructions is far from easy, but that only makes the process more interesting. The importance of doing the work and doing it right is that theory underlines the basic similarity among all forms of capital, and that is a lesson worth learning. It will be reinforced by routine embodiment in the national accounts. Perhaps RFF could take the lead, as it has done with respect to environmental costs and benefits.

ANALYZING SUSTAINABLE PATHS FOR A MODERN INDUSTRIAL SOCIETY

Now I want to start down an apparently quite different path, but I promise that it will eventually link up with the unromantic measurement issues I have discussed so far, and will even reinforce the argument I have made.

I do not have to remind you that "sustainability" has become a hot topic in the last few years, beginning, I suppose, with the publication of the Brundtland Commission's Report, *Our Common Future*, in 1987. As far as I can tell, however, discussion of sustainability has been mainly an occasion for the expression of emotions and attitudes. There has been very little analysis of sustainable paths for a modem industrial economy, so that we have little idea of what would be required in the way of policy and what sorts of outcomes could be expected. As things stand, if I express a commitment to sustainability, all that tells you is that I am unhappy with the modem consumerist life-style. If I pooh-pooh the whole thing, on the other hand, all you can deduce is that I am for business as usual. It is not a very satisfactory state of affairs.

Understanding What It Is That Must Be Conserved. If sustainability means anything more than a vague emotional commitment, it must require that something be conserved for the very long run. It is very important to understand what that something is: I think it has to be a generalized capacity to produce economic well-being.

It makes perfectly good sense to insist that certain unique and irreplaceable assets should be preserved for their own sake; nearly everyone would feel that way about Yosemite or, for that matter, about the Lincoln Memorial, I imagine. But that sort of situation cannot be universalized: it would be neither possible nor desirable to "leave the world as we found it" in every particular.

Most routine natural resources are desirable for what they do, not for what they are. It is their capacity to provide usable goods and services that we value. Once that principle is accepted, we are in the everyday world of substitutions and trade-offs.

For the rest of this talk, I will assume that a sustainable path for the national economy is one that allows every future generation the option of being as well off as its predecessors. The duty imposed by sustainability is to bequeath to posterity not any particular thing—with the sort of rare exception I have mentioned—but rather to endow them with whatever it takes to achieve a standard of living at least as good as our own and to look after their next generation similarly. We are not to consume humanity's capital, in the broadest sense. Sustainability is not always compatible with discounting the well-being of future generations if there is no continuing technological progress. But I will slide over this potential contradiction because discount rates should be small and, after all, there is technological progress.

All that sounds bland, but it has some content. The standard of living achievable in the future depends on a bundle of endowments, in principle on everything that could limit the economy's capacity to produce economic well-being. That includes nonrenewable resources, of course, but it also includes the stock of plant and equipment, the inventory of technological knowledge, and even the general level of education and supply of skills. A sustainable path for the economy is thus not necessarily one that conserves every single thing or any single thing. It is one that replaces whatever it takes from its inherited natural and produced endowment, its material and intellectual endowment. What matters is not the particular form that the replacement takes, but only its capacity to produce the things that posterity will enjoy. Those depletion and investment decisions are the proper focus.

Outlining Two Key Propositions. Now it is time to go back to the toy economy I described earlier and to bring some serious economic theory to bear. There are two closely related logical propositions that can be shown to hold for such an economy. The first tells us something about the properly defined net national product, calculated with the aid of the fight prices. At each instant, net national product indicates the largest consumption level that can be allowed this year if future consumption is never to be allowed to decrease.

To put it a little more precisely: net national product measures the maximum current level of consumer satisfaction that can be sustained forever. It is, therefore, a measure of sustainable income given the state of the economy—capital, resources, and so on—at that very instant.

This is important enough and strange enough to be worth a little explanation. How can this year's NNP "know" about anything that will or can happen in the future? The theorist's answer goes something like this. The economy's net product in any year consists of public and private consumption and public and private investment. (I am ignoring foreign trade altogether. Think of the economy as representing the world.) The components of investment, including the depletion of natural resources, have to be valued. That is where the "tightness" of the prices comes in. If the economy or its participants are forward-looking and far-seeing, the prices of investment goods will reflect the market's evaluation of their future productivity, including the productivity of the future investments they will make possible. The fight prices will make full allowance even for the distant future, and will even take account of how each future generation will look at its future.

This story makes it obvious that everyday market prices can make no claim to embody that kind of foreknowledge. Least of all could the prices of natural resource products, which are famous for their volatility, have this property; but one could entertain legitimate doubts about other prices, too. The hope has to be that a careful attempt to average out speculative movements and to correct for the other imperfections I listed earlier would yield adjusted prices that might serve as a rough approximation to the theoretically correct ones. We act as if that were true in other contexts. The important hedge is not to claim too much.

While it is closely related to the proposition that NNP measures the maximum current level of consumer satisfaction that can be sustained forever, the second theoretical proposition I need is considerably more intuitive, although it may sound a little mysterious, too. Properly defined and properly calculated, this year's net national product can always be regarded as this year's interest on society's total stock of capital. It is absolutely vital that "capital" be interpreted in the broadest sense to include everything, tangible and intangible, in which the economy can invest or disinvest, including knowledge. Of course this stock of capital must be evaluated at the right prices. And the interest rate that capitalizes the net national product will generally be the real discount rate implicit in the whole story. Investment and depletion decisions determine the real wealth of the economy, and each instant's NNP appears as the return to society on the wealth it has accumulated in all forms. There are some tricky questions about wage incomes, but they are off the main track and I shall leave them unanswered.

Maintaining the Broad Stock of Society's Capital Intact. Something interesting happens when these two propositions are put together. One of them tells us that NNP at any instant is a measure of the highest sustainable income achievable, given the total stock of capital available at that instant. The other proposition tells us that NNP at any instant can be represented as that same stock of capital multiplied by an unchanging discount rate. Suppose that one goal of economic policy is to make investment and depletion decisions this year in a way that does not erode sustainable income. Then those same decisions must not allow the aggregate capital stock to fall. To use a Victorian phrase, preserving sustainability amounts to maintaining society's capital intact.

Let me say that in a slightly different way, speaking more picturesquely of generations rather than of instants or years. Each generation inherits a capital stock in the very broad and inclusive sense that matters. In turn, each generation makes consumption, investment, and depletion decisions. It enjoys its own consumption and leaves a stock of capital for the next generation. Of course, generations do not make decisions; families, firms, and governments do. Still, if all those decisions eventuate in a very large amount of current consumption, clearly the next generation might be forced to start with a lower stock of capital than its parents did. We now know that this is equivalent to saying that the new sustainable level of income is lower than the old one. The high-consumption generation has not lived up to the ethic of sustainability.

In the opposite case, consider a generation that consumes very little and leaves behind it a larger stock of capital than it inherited. That generation will have increased the sustainable level of income, and done so at the expense of its own consumption. Obviously that is what most past generations in the United States have done. Equally obviously, they were helped by ongoing technological progress. I have left that factor out of account, because it makes things too easy. It could probably be accommodated in the theoretical picture by imagining that there is a stock of technological knowledge that is built up by scientific and engineering research and depreciates through obsolescence. We know so little about that process that the formalization seems almost misleading. But the fact is very important.

A concern for sustainability implies a bias toward investment. That does not mean investment *über alles*; it means just enough investment to maintain the broad stock of capital intact. It does not mean maintaining intact the stock of every single thing; trade-offs and substitutions are not only permissible, they are essential. Unfortunately, I have to make the limp statement that the terms on which one form of capital should be traded off against another are given by those adjusted prices—" shadow prices" we call them—and they involve a certain amount of guesswork. The guesswork has to be done; it cannot be avoided by defining the problem away. It is better that the guesswork be based on careful research than that the decision be fudged.

CONNECTING UP THE ARGUMENTS

Knowing What and How Much Should Be Replaced. Now I can connect up the two halves of my argument. Every generation uses up some part of the earth's original endowment of nonrenewable resources. There is no alternative. Not now anyway. Maybe eventually our economy will be based entirely on renewables. (The theory I have been using can be applied then too, with routine modifications.) Even so, there will be a long meanwhile. What should each generation give back in exchange for depleted resources if it wishes to abide by the ethic of sustainability? We now have an answer in principle. It should add to the social capital in other forms, enough to maintain the aggregate social capital intact. In other words, it should replace the used up resources with other assets of equal value, or equal shadow value. How much is that? The shadow value of resource depletion is exactly the aggregate of Hotelling rents. It is exactly the quantity that should be deducted from conventional net national product to give a truer NNP that takes account of the depletion of resources. A research project aimed at estimating that deduction would also be estimating the amount of investment in other forms that would just replace the productive capacity dissipated in resource depletion. This is sometimes known as Hartwick's rule: a society that invests aggregate resource rents in reproducible capital is preserving its capacity to sustain a constant level of consumption.

Once again, I should mention that the same approach can be applied to environmental assets—the most complete treatment is by Karl-Göran Mäler—and to renewable resources—as in the work of John Hartwick. The environmental case is more complex, because even a stylized model of environmental degradation and rehabilitation is more complex than a model of resource depletion. The principle is the same, but the execution is even more difficult. Remember that even the simplest case offers daunting measurement problems.

Translating Sustainability into Policy. It is possible that the clarity brought to the idea of sustainability by this approach could lift the policy debate to a more pragmatic, less emotional level. But I am inclined to think that a few numbers, even approximate numbers, would be much more effective in turning discussion toward concrete proposals and away from pronunciamentos.

Suppose that the Department of Commerce published routinely a reasonable approximation to the "true" value of each year's depletion of nonrenewable resources. We could then say to ourselves: we owe to the future a volume of investment that will compensate for this year's withdrawal from the inherited stock. We know the rough magnitude of this requirement. The appropriate policy is to generate an economically equivalent amount of net investment, enough to maintain society's broadly defined stock of capital intact. Of course, there may be other reasons for adding to (or subtracting from) this level of investment. The point is only that a commitment to sustainability is translated into a commitment to a specifiable amount of productive investment.

By the way, the same sort of calculation should have a very high priority in primary producing countries, the ones that supply the advanced industrial world with mineral products. They should also be directing their—rather large—Hotelling rents into productive investment. They will presumably want to invest more than that, because sustainability is hardly an adequate goal in poor countries. In this perspective, the cardinal sin is not mining; it is consuming the rents from mining.

It goes without saying that this concrete translation of sustainability into policy leaves a lot of questions unanswered. The split between private and public investment has to be made in essentially political ways, like the split between private and public saving. There are other reasons for public policy to encourage or discourage investment, because there are social goals other than sustainability. One could hope for more focused debate as trade-offs are made more explicit.

I want to remind you again that environmental preservation can be handled in much the same way. It is a more difficult context, however, for several reasons. Many, though not all, environmental assets have a claim to intrinsic value. That is the case of the Grand Canyon or Yosemite National Park, as noted earlier. The claim that a feature of the environment is irreplaceable, that is, not open to substitution by something equivalent but different, can be contested in any particular case, but no doubt it is sometimes true. Then the calculus of trade-offs does not apply. Useful minerals are in a more utilitarian category, and that is why I dealt with them explicitly.

Yet another difficulty is the deeper uncertainty about environmental benefits and costs. Marketed commodities, like minerals or renewable natural resources, are much simpler. I have admitted, fairly and squarely, how much of my argument depends on getting the shadow prices approximately right. Ordinary transaction prices are clearly not the whole answer; but they are a place to start. With environmental assets, not even that benchmark is available. I do not need to convince this audience that the difficulty of doing better does not make zero a defensible approximation for the shadow price of environmental amenity. I think the correct conclusion is the one stated by Karl-Göran Mäler: that we are going to have to keep depending on physical and other special indicators in order to judge the economy's performance with regard to the use of environmental resources. Even so, the conceptual framework should be an aid to clear thinking in the environmental field as well.

Maybe this way of thinking about environmental matters offers a way out of a dilemma facing less developed countries. The dilemma arises because they sometimes find that the adoption of developed-country environmental standards makes local industries uncompetitive in world markets. The poor countries then seem to have a choice between cooperating in the degradation for their own environment or acquiescing in their own poverty. At least when pollution is localized, the resolution of the dilemma appears to be a controlled trade-off between an immediate loss of environmental amenity and a gain in future economic well-being. Temporary acceptance of less-than-the-best environmental conditions can be made more palatable if the "rents" from doing so are translated into productive investment. Higher incomes in the future could be spent in part on environmental repair, of course, but it is general well-being that counts ultimately.

Notice that I have limited this suggestion to the case of localized pollution. When poor countries in search of their own economic goals contribute to global environmental damage, much more difficult policy questions arise. Their solution is not so hard to see in principle, but the practical obstacles are enormous. In any case, I leave those problems aside.

CONCLUDING COMMENTS

That brings me to the end of my story. I have suggested that an innovation in social accounting practice could contribute to more rational debate and possibly to more rational action in the economics of nonrenewable resources and the approach to a sustainable economy. There is a trick involved here, and I guess I should confess what it is. In a complex world, populated by people with diverse interests and tastes, and enmeshed in uncertainty about the future (not to mention the past), there is a lot to be gained by transforming questions of yes-or-no into questions of more-or-less. Yes-or-no lends itself to stalemate and confrontation; more-or-less lends itself to trade-offs. The trick is to understand more of what and less of what. This lecture was intended to make a step in that direction.

2

What Can Policymakers Learn From Natural Resource Accounting?[1]

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THE NEED FOR NATURAL RESOURCE ACCOUNTING

Whatever their shortcomings, and however little their construction is understood by the general public, the national income accounts are undoubtedly one of the most significant social inventions of the twentieth century. Their political and economic impact can scarcely be overestimated. However inappropriately, they serve to divide the world into "developed" and "less developed" countries. In the "developed" countries, whenever the quarterly gross national product (GNP) figures emerge, policymakers stir. Should they be lower, even marginally, than those of the preceding three months, a recession is declared, the strategies and competence of the administration are impugned, and public political debate ensues. In the "developing" countries, the rate of growth of gross domestic product (GDP) is the principal measure of economic progress and transformation.

The national accounts have become so much a part of our life that it is hard to remember that they are scarcely fifty years old. They were first published in the United States in the year 1942. It is no coincidence that the period during which these measures have been available, with all their imperfections, has been the period within which governments in all major countries have taken responsibility for the growth and stability of their economies, and during which enormous investments of talent and energy have been made in understanding how economies can be better managed. Forecasting the next few quarterly estimates of these statistics has become, with no exaggeration, a hundred million dollar industry.

The aim of national income accounting is to provide an information framework suitable for analyzing the performance of the economic system. The current system of national accounts reflects the Keynesian macroeconomic model that was dominant when the system was developed, largely through the work of Richard Stone, Simon Kuznets and other economists writing in the English tradition. The great aggregates of Keynesian analysis—Consumption, Savings, Invest

[1] Paper originally presented at the Conference on Natural Resource Accounting held by the Organization of American States in Washington, D.C. on April 14-15, 1993.

ment, and Government Expenditures—are carefully defined and measured. But Keynes and his contemporaries were preoccupied with the Great Depression and the business cycle; specifically, with explaining how an economy could remain for long periods of time at less than full employment. The least of their worries was a scarcity of natural resources. Unfortunately, as Keynesian analysis largely ignored the productive role of natural resources, so does the current system of national accounts.

In fact, natural resource scarcity was of little concern to 19th-century neo-classical economics, from which tradition Keynesian and most contemporary economic theories are derived. Gone were the dismal predictions of Ricardo, Malthus, Marx, and other earlier classical economist that scarcity of agricultural land in industrial economies would cause stagnation or collapse because of rising rents and falling real wages. In 19th-century Europe, steamships and railroads were markedly lowering transport costs, while foodgrains and raw materials were flooding in from North America, Argentina, Australia, Russia, and the imperial colonies. What mattered to England and other industrializing nations was the pace of investment and technological change.

The classical economists had regarded income as the return on three kinds of assets: natural resources, human resources, and invested capital (land, labor, and capital, in their vocabulary). The neo-classical economists virtually dropped natural resources from their model, and concentrated on labor and invested capital. When these theories were applied after World War II to problems of economic development in the Third World, human resources were also left out on the grounds that labor was always "surplus," and development was seen almost entirely as a matter of savings and investment in physical capital. Ironically, low-income countries, which are typically most dependent on natural resources for employment, revenues, and foreign exchange earnings are instructed to use a system for national accounting and macroeconomic analysis which almost completely ignores their principal assets. It is not far from the truth that the system of national accounts represents one of the last vestiges of British colonialism.

As a result, there is a dangerous asymmetry in the way we measure, and hence, the way we think about, the value of natural resources. Man-made assets—buildings and equipment, for example—are valued as productive capital. The increase in the stock is recorded as capital formation. Decreases in the stock through use are written off against the value of production as depreciation. This practice recognizes that a consumption level maintained by drawing down the stock of capital exceeds the sustainable level of income. Natural resource assets are not so valued, and their loss entails no debit charge against current income that would account for the decrease in potential future production. A country could exhaust its mineral resources, cut down its forests, erode its soils, pollute its aquifers, and hunt its wildlife and fisheries to extinction, but measured income would not be affected as these assets disappeared.

The proper definition of income encompasses the notion of sustainability. In accounting textbooks and economics principles, income is defined as the maximum amount which the recipient could consume in a given period without reducing the amount of possible consumption in a future period. This income concept encompasses not only current earnings but also changes in asset positions. The depreciation accounts reflect the fact that unless the capital stock is maintained and replaced, future consumption possibilities will inevitably decline. Thus, proper evaluation of changes in the stock of assets is crucial as a way of evaluating the sustainability of an economic development strategy. In resource-dependent countries, failure to extend this concept to the capital stock embodied in natural resources, which are such a significant source of income and consumption, is a major omission and inconsistency.

Underlying this anomaly is the implicit and inappropriate assumption that natural resources are so abundant that they have no marginal value. This is a misunderstanding. Whether they enter the marketplace directly or not, natural resources make important contributions to long-term economic productivity, and so are, strictly speaking, economic assets. Many are under increasing pressure from human activities and are deteriorating in quantity or quality.

Another misunderstanding underlies the contention that natural resources are "free gifts of nature," so that there are no investment costs to be "written off." The value of an asset is not its investment cost, but the present value of its income potential. Many billion-dollar companies have as their principal assets the brilliant ideas and inventions of their founders: the Polaroid Camera, the Apple Computer, the Lotus Spreadsheet, for example. These inspired inventions are worth vastly more than any measurable cost to their inventors in developing them, and could also be regarded as the products of genius—free gifts of nature. Common formulas for calculating depreciation by "writing off" investment costs (e.g., straight-line depreciation) are just convenient rules of thumb, or artifacts of tax legislation. The true measure of depreciation, which statisticians have tried to adopt for fixed capital in the national accounts, is the capitalized present value of the reduced future income stream obtainable from an asset, because of its decay or obsolescence. Thus, in the same sense that a machine depreciates, soils depreciate as their fertility is diminished, since they can produce only at higher costs or lower yields.

Codified in the United Nations System of National Accounts (SNA) closely followed by most countries, this bias provides false signals to policymakers. It reinforces the false dichotomy between the economy and the "environment" that leads policymakers to ignore or destroy the latter in the name of economic development. It confuses the depletion of valuable assets with the generation of income. Thus it promotes and seems to validate the idea that rapid rates of economic growth can be achieved and sustained by exploiting the resource base. The result can be illusory gains in income and permanent losses in wealth.[2]

The United Nations SNA recognizes certain natural resources, such as forests, land, and subsoil minerals, as assets in national balance sheets, the "stock" accounts. The recommended treatment for natural resources in the balance sheet accounts is very similar to the recommended treatment of other capital assets. If possible, the assets' values should be derived from market transactions. Otherwise, the accounts should be based on the discounted present value of estimated future income flows derived from the assets. However, the income and product accounts are not treated consistently with these balance sheet accounts. On the income side, for example, the total value added from resource extraction is included in wages and salaries, in

[2] It is sometimes maintained that natural resources should not be subject to depreciation because they are free gifts of nature, and consequently there are no costs to be written off. This mistakes the basis of asset value, which is not cost but the present value of future income streams, and the basis of depreciation, which is the loss of potential income.

rental incomes and in company profits. In other words, the total value of natural resources current production, net of purchased inputs, is imputed to current income.

The problem is that, in contrast with the treatment of man-made capital assets, there are no accounting entries in the flow accounts for changes in natural resource stocks. Notwithstanding the economic significance of wasting natural resources, the SNA does not provide a debit on the product side of the national income accounts to show that depreciation of natural resources is a form of disinvestment. And it does not provide a depreciation factor on the income side to show that consumption of productive natural resource assets must be excluded from gross income.

Indeed, natural resource assets are legitimately drawn upon to finance economic growth, especially in resource-dependent countries. The revenues derived from resource extraction finance investments in industrial capacity, infrastructure, and education. A reasonable accounting representation of the process, however, would recognize that one kind of asset has been exchanged for another, which is expected to yield a higher return. Should a farmer cut and sell the timber in his woods to raise money for a new barn, his private accounts would reflect the acquisition of a new asset, the barn, and the loss of an old asset, the timber. He thinks himself better off because the barn is worth more to him than the timber. In the national accounts, however, income and investment would rise as the barn is built, but income would also rise as the wood is cut. Nowhere is the loss of a valuable asset reflected. This can lead to serious misestimation of the development potential of resource-dependent economies, by confusing gross and net capital formation. Even worse, should the proceeds of resource depletion be used to finance current consumption, then the economic path is ultimately unsustainable, whatever the national accounts say. If the same farmer used the proceeds from his timber sale to finance a winter vacation, he would be poorer on his return, and no longer able to afford the barn, but national income would only register a gain, not a loss, in wealth.

Consider the sad exemplary tale of Kiribati, the small atoll republic of the Solomon Islands, which depended throughout the 20th century on its phosphate mines for income and government revenues. While the mines ran, gross domestic product was high and rising, but the mining proceeds were treated as current income rather than as capital consumption. When the deposits were mined out in the 1970s, income and government revenues declined drastically, because far too little had been set aside for investment in other assets that would replace the lost revenues.

THE SCOPE OF NATURAL RESOURCE ACCOUNTING

A growing body of expert opinion has recognized the need to correct the SNA's environmental blindspots. Many leading economists, including several Nobel prizewinners, have identified the need for better accounting for natural resource assets. A number of Organization for Economic Cooperation and Development (OECD) nations, including Canada, France, Germany, the Netherlands, Japan, Norway, and the United States have set up or are working on systems of environmental accounts.

The French natural patrimony accounts, for example, are intended as a comprehensive statistical framework to provide authorities with the data they need to monitor changes in "that subsystem of the terrestrial ecosphere that can be quantitatively and qualitatively altered by human activity."[3] Like their Norwegian counterparts, these accounts cover nonrenewables, the physical environment, and living organisms. Since material and energy flows to and from economic activities form only a subset of these accounts, they are conceptually much broader than the national income accounts, and are compiled largely in physical terms.

Such environmental statistics may well encourage decisionmakers to consider the impacts of specific policies on the national stock of natural resources. However, physical accounting by *itself* has considerable shortcomings. It does not lend itself to useful aggregation: aggregating wood from various tree species in cubic meters obscures wide differences in the economic value of different species. Aggregating mineral reserves in tons obscures vast differences in the value of different deposits, due to grade and recovery costs. Yet, maintaining separate physical accounts for particular species or deposits yields a mountain of statistics that are not easily summarized or used.

A further problem is that accounts maintained only in physical units do not enable economic planners to understand the impact of economic policies on natural resources and thereby integrate resource considerations into economic decisions—presumably, the main point of the exercise. Yet, there is no conflict between accounting in physical and economic units because physical accounts are necessary prerequisites to economic accounts. If the measurement of economic depreciation is extended to natural resources, physical accounts are inevitable by-products.

The limits to monetary valuation are set mainly by the remoteness of the resource in question from the market economy.[4] Some resources, such as minerals, enter directly. Others, such as groundwater, contribute to market production, and can readily be assigned a monetary value although they are rarely bought or sold. Others, such as noncommercial wild species, do not contribute directly to production and can be assigned a monetary value only through quite roundabout methods involving many somewhat questionable assumptions. While research into the economic value of resources that are remote from the market is to be encouraged, common sense suggests that highly speculative values should not be included in official accounts.

In industrial countries where pollution and congestion are mounting while economies are becoming less dependent on agriculture, mining, and other forms of primary production, the focus has been on "environmental accounting" rather than natural resource accounting. Several approaches to developing more comprehensive systems of national income accounting go well beyond the scope of natural resource accounting.

There are sound reasons to begin by focusing on accounting for natural resources: the principal natural resources, such as land, timber, and minerals are already listed in the SNA system as economic assets, although not treated like other tangible capital, and their physical and economic values can be readily established. Demonstrating the enormous costs to a national

[3] Corniere, P., 1986. Natural Resource Accounts in France. An Example: Inland Water. In Organisation for Economic Cooperation and Development, "Information and Natural Resources." Paris: OECD.

[4] Ibid.

economy of natural resource degradation is an important first step in establishing the need for revamping national policy.

Developing countries whose economies are dependent on natural resources are becoming particularly interested in developing an accounting framework that accounts for these assets more adequately. Work is already under way in the Philippines, China, Thailand, India, Brazil, Chile, Colombia, Costa Rica, E1 Salvador, and other countries.

SETTING UP NATURAL RESOURCE ACCOUNTS

Physical Accounts

Natural resource physical stocks at any time, and changes in those stocks during an accounting period, can be recorded in physical units appropriate to the particular resource. The basic accounting identity is that opening stocks *plus* all growth, increase, or addition *less all* extraction, destruction, or diminution *equals* closing stocks. Although the following discussion refers to petroleum reserves and timber stocks as examples, the principles are applicable to many other resources.

Petroleum resources consist of identified reserves and other resources: identified reserves can be divided into proven reserves and probable reserves. Proven reserves are the estimated quantities of crude oil, natural gas, and natural gas liquids which geological and engineering data indicate with reasonable certainty to be recoverable from known reservoirs under existing market and operating conditions (i.e., prices and costs as of the date the estimate is made). Probable reserves are quantities of recoverable reserves that are less certain than proven reserves. Thus, one limit on the stock of reserves is informational. Additional proven reserves can usually be generated by drilling additional test wells or undertaking other exploratory investments to reduce uncertainty about the extent of known fields. The boundary between reserves and other resources is basically economic. Vast quantities of known hydrocarbon deposits cannot be extracted profitably under current conditions. They are thus known resources, but cannot be counted as current reserves, although price increases or technological improvements might transform them into reserves in the future.

For other mining industries, geological characteristics tend to be known with more certainty, so there is less distinction between proven and probable reserves but a sharp division between economic reserves and total resources. Many minerals are present at very low concentrations in the earth's crust in almost infinite total amounts. Technological changes in mining and refining processes have markedly reduced the minimum ore concentrations that can profitably be mined, correspondingly expanding mineral reserves.

Changes in oil and gas stocks may be classified under various headings: "discoveries," the quantity of proven reserves that exploratory drilling finds in new oil and gas fields, or in new reservoirs in existing oil fields; "extensions," increases in proven reserves because of subsequent drilling showing that discovered reservoirs are larger than originally estimated; and, "revisions," increases in proven reserves because oil or gas firms acquire new information on market conditions or new technology. Extensions of and revisions to oil and gas reserves have historically been significantly larger than new discoveries. Reserve statistics generally produce very conservative estimates of the total resource stocks that will ultimately enter the economic system: actual production from new U.S. fields and reservoirs was over seven times the amount initially reported as discovered.

Reserve levels fall because of extraction and downward revisions. In the United States, oil and gas companies are required by the Securities and Exchange Commission to disclose net annual changes in estimated quantities of oil and gas reserves, showing separately: opening and closing balances; revisions of previous estimates (from new information); improved recovery (resulting from improved techniques); purchases and sales of minerals in place; extensions and discoveries; and production (Financial Accounting Standards Board, 1982).

The accounting framework for timber resources in physical units could be expressed in hectares, in tons of biomass, or in cubic meters of available wood, although the last is probably the most important economic measure. As in the case of minerals, the total resource is larger than the economic reserve, since a substantial part of the total stock of standing timber in any country cannot be profitably harvested and marketed with current technologies and market conditions.

Additions to the timber stock can originate from growth and regeneration of the initial stock, and from reforestation and afforestation. Reductions can be classified into production (harvesting), natural degradation (fire, earthquake, etc.), and deforestation by man. Separate accounts might be established for different categories of timber stands, for example, virgin forests, logged (secondary) forests, unproductive or protected forests, and plantations. In temperate forests, where species diversity is limited, timber stocks are further disaggregated by species.

Physical accounts can be constructed along similar lines for agricultural land. Land and soil maps and classification systems are used to disaggregate land into productivity categories. Changes in stocks of each land category within a period reflect various phenomena: conversion to nonagricultural uses; conversion to lower productivity classes through physical deterioration by erosion, salinization, or waterlogging; and conversions to higher productivity classes through physical improvements by irrigation, drainage, and other investments. A set of physical accounts for agricultural land would record stocks of land at each accounting date by productivity class, and flows among classes and to other land uses according to cause.

Similarly, physical accounts can be set up for other biological resources, such as wildlife or fish populations. The principles are essentially those of demography. Additions to initial populations are attributed to fertility, estimated from reproduction rates and the size of the breeding population, and inmigration. Subtractions from stocks are attributed to natural mortality, estimated from age-specific or general mortality rates, harvesting operations, other special sources of mortality, and outmigration.

Valuation Principles

The concept of economic rent is central to natural resource valuation. Economic rent is defined as the return to any production input over the minimum amount required to retain it in its present use. It is broadly equivalent to the profit that can be derived or earned from a factor of production (for example, a natural resource stock) beyond its normal supply cost. For example, if a barrel of crude oil can be sold for $10 and costs a total of $6 to discover, extract, and bring to market, a rent of $4 can be assigned to each barrel. in forest economics, the concept of "stumpage value" is very close to that of economic rent. Stumpage value represents timber sale proceeds, less the costs of logging, transportation and processing. Better quality and more accessible timber stands will command a higher stumpage value.

Rents to natural resources arise from their scarcity, and from locational and other cost advantages of particular stocks. In principle, rents can be determined as the international resource commodity price less all factor costs incurred in extraction, including a normal return to capital but excluding taxes, duties and royalties. Thus, the economic rent is equivalent to the net price.

This is equivalent to the economic rent in a Ricardian scarcity model, which assumes that resources from different "deposits" will be supplied at a rising incremental cost until profit on the marginal source of supply is completely exhausted. In this Ricardian model, rents arise on relatively low-cost, inframarginal sources of supply.

It is also equivalent to a user cost in a Malthusian stock scarcity model, which assumes that a homogeneous exhaustible resource is exploited at an economically efficient rate, a rate such that the profit on the marginal amount brought to market is equal to the expected return derived from holding the asset in stock for future capital gain. In such a Malthusian model, if the resource is being extracted at an efficient rate, the current rent on the last unit of resources extracted is thus equal to the discounted present value of future returns from a unit remaining in stock.

The gross operating surplus of the extractive sector in the SNA, represented by the sum of the profits made by all the different enterprises involved in resource extraction activities, does not represent true rewards to factors of production alone but also reflects rents from a "one time only" irredeemable sale of a nonrenewable natural asset. The basic definition of income as the amount which can be consumed without becoming worse off is clearly being infringed as the value of the asset base declines.

Asset transactions in natural resources, such as competitive auction sales of fights to extract timber or minerals, closely follow estimated stumpage values or rents, with allowance for risk. Because holders of those fights can usually hold the resources in stock or bring them to market immediately, the current rent or stumpage value tends to reflect the present value of expected future net income that can be derived from them. This principle is readily extended to other resources: agricultural land can be valued directly on the basis of its current market worth, or indirectly as the present value of the future stream of net income, or annual rent, that can be derived from it. The value of subsurface irrigation water deposits can be estimated from market transactions in "water fights," or by comparing the value of agricultural land overlaying a usable, known aquifer with that of otherwise equivalent land without subsurface water. Alternatively, it can be estimated as the present value of future rents, calculated as the difference between the costs (per cubic meter) of supplying the water for irrigation and the incremental net farm income attributable to the use of the water for irrigation.

In order for adjustments to national income accounts for natural resource stock changes to attain broad acceptance, a credible standard technique for valuing natural resources must be adopted that can be applied to a variety of resources by statisticians in different countries. That method must be as free as possible from speculative estimates (about future market prices, for example), and must depend on underlying data that is reasonably available to statistical agencies.

The three principal methods for estimating the value of natural resource stocks are: 1) the present value of future net revenues; 2) the transaction value of market purchases and sales of the resource *in situ*; and 3) the net price, or unit rent, of the resource multiplied by the relevant quantity of the reserve. The present value method requires that future prices, operating costs, production levels, and interest rates be forecast over the life of a given field after its discovery. The present value of the stream of net revenue is then calculated, net revenue representing the total revenue from the resource less all extraction costs. The United Nations Statistical Office has recommended use of the present value method when market values for transactions in resource stock are not available.

The net price method applies the prevailing average net price per unit of the resource (current revenues less current production costs) to the physical quantities of proved reserves and changes in the levels of proved reserves. While the net price method requires only current data on prices and costs, it will be equivalent to the other two methods if output prices behave in accordance with long-run competitive market equilibrium. The assumption here is derived from the theory of optimal depletion of exhaustible resources, that resource owners will tend to arbitrage returns from holding the stock into future periods with returns from bringing it immediately to market, adjusting current and future supplies until price changes equate those returns.

WHAT CAN POLICYMAKERS LEARN FROM RESOURCE ACCOUNTING?

Macroeconomic Policy and Structural Adjustment

National accounts that incorporate natural resource accounting provide a more adequate means of evaluating an economy's performance and progress toward sustainable development. World Resources Institute has collaborated on a pioneering report using Indonesia as a case study. Over the past 20 years, Indonesia has drawn heavily on its considerable natural resource endowment to finance development expenditures. Revenues from production of oil, gas, hard minerals, timber, and forest products have offset a large share of government development and routine expenditures. Primary production contributes more than 43 percent of gross domestic product, 83 percent of exports, and 55 percent of total employment. Indonesia's economic performance over this period is generally judged to have been successful: per capital GDP growth averaging 4.6 percent per year from 1965 to 1986 has been exceeded by only a handful of low and middle-income countries and is far above the average for those groups. Gross domestic investment rose from 8 percent of GDP in 1965, at the end of the Sukarno era, to 26 percent of GDP (also well above average) in 1986, despite low oil prices and a difficult debt situation.

Estimates derived from the Indonesian country case study illustrate how much this evaluation is affected by "keeping score" more correctly. Figure 2-1 compares the growth of gross domestic product at constant prices with the growth of "net" domestic product, derived by subtracting estimates of natural resource depreciation for only three sectors: petroleum,

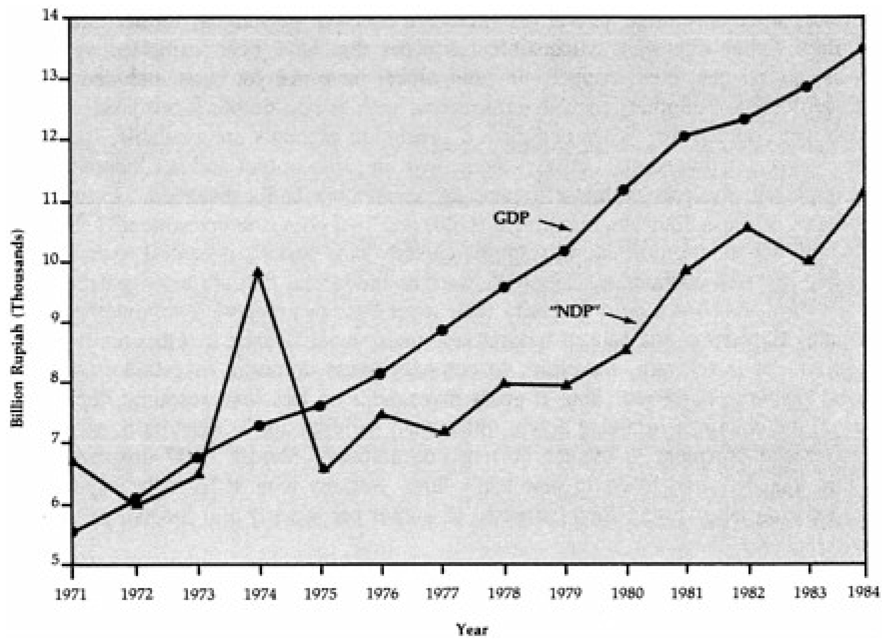

FIGURE 2-1 GDP and "NDP" in constant 1973 rupiah.

timber, and soils. It is clear that conventionally measured gross domestic product substantially overstates the growth of net income, after accounting for consumption of natural resource capital. In fact, while GDP increased at an average annual rate of 7.7 percent from 1970 to 1984, the estimate of "net" national product rose by only 3.9 percent per year. In other words, one-half of recorded growth was generated, not by sustainable productivity increase, but by drawing down natural resource assets.

The overstatement of income growth is actually considerably more than these depreciation estimates indicate, since only three natural resources are covered: petroleum, timber, and soils on Java and Bali. Other important exhaustible resources that have been exploited over the period, such as natural gas, coal, copper, tin, and nickel have not yet been included in the accounts. The depreciation of other renewable resources, such as non-timber forest products and fisheries is also unaccounted for. When complete depreciation accounts are available, they will inevitably show a greater divergence between the growth in gross output and net income.

Other important macroeconomic estimates are even more badly distorted. Figure 2-2 compares estimates of gross domestic investment (GDI) and "net domestic investment" ("NDI"), the latter reflecting depreciation of natural resource capital. This statistic is central to economic planning in resource based economies. Countries, such as Indonesia, that are heavily dependent on exhaustible natural resources *must* diversify their asset base to preserve a sustainable long-term growth path. Extraction and sale of natural resources, must finance investments in other productive capital. It is relevant, therefore, to compare gross domestic investment with the value of natural resource depletion. Should gross investment be less than resource depletion, then, on balance, the country is drawing down, rather than building up, its asset base, and using its natural resource endowment to finance current consumption. Should "net" investment be positive but less than required to equip new labor force entrants with at least the capital per worker of the existing labor force, then increases in output per worker and income per capita are unlikely.

In fact, the results from the Indonesian case study show that the adjustment for natural resource asset changes is large in many years relative to gross domestic investment. In a few years, the adjustment is positive, due to additions to petroleum reserves. In most years during the period, however, the depletion adjustment offsets a good part of gross capital formation. A fuller accounting of natural resource depletion might conclude that in some years, depletion exceeded gross investment, implying that natural resources were being depleted to finance current consumption expenditures.

Such an evaluation should flash an unmistakable warning signal to economic policymakers that they were on an unsustainable course. An economic accounting system that does not generate and highlight such evaluations is deficient as a tool for analysis and policy in resource-based economies and should be amended.

Countries throughout Africa, Latin America, and Eastern Europe and north Asia are undergoing dramatic economic transformations, undoing decades of state intervention and market distortion. The international agencies of the World Bank and the International Monetary Fund (IMF) are being called upon to support structural adjustment and stabilization programs with policy advice and capital flows.

How economic reforms should be designed to ensure a successful transition to sustainable economic progress is a matter of urgent concern. In all these regions now undergoing structural

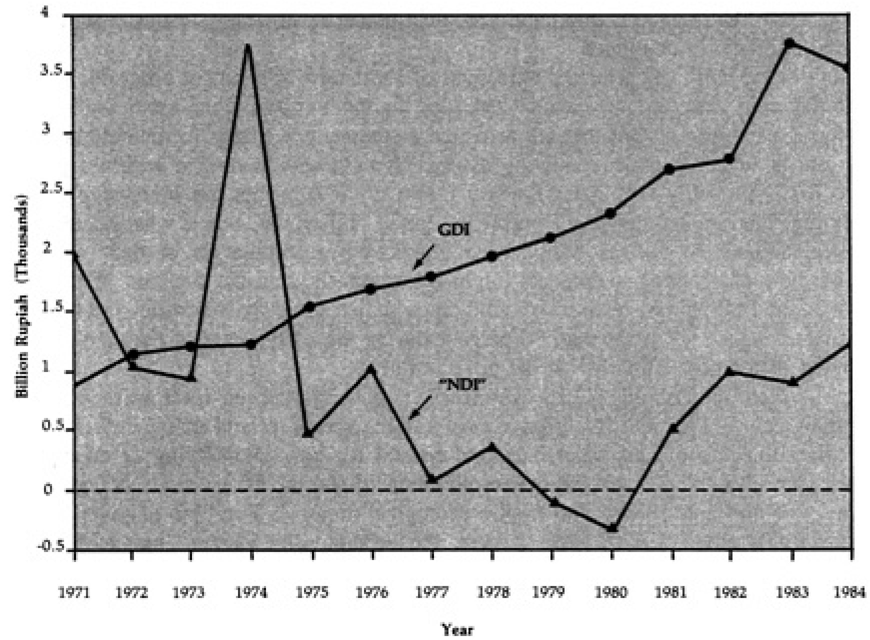

FIGURE 2-2 GDI and "NDI" in constant 1973 rupiah.

reforms, environmental degradation has been as obvious a symptom of the failure of the previous policies as economic collapse. Uncontrolled pollution, excessive environmental hazards, and overexploitation of natural resources have accompanied the decline of living standards. New economic policy packages must address and reverse ecological as well as economic deterioration.

In many developing countries the national balance sheet has deteriorated more from depreciation of natural resources than from foreign borrowing. In the Philippines, for example, depreciation in just three sectors—forests, soils, and coastal fisheries—averaged 4.5 percent of GDP per year in the dozen years leading up to the debt crisis, while foreign borrowing averaged only 4 percent of GDP. Unlike the highly publicized debt problem, however, resource depletion went unmeasured and largely unnoticed.

According to the IMF, the principal objectives of short-term adjustment programs are to reduce the internal and external imbalances that lead to the unsustainable accumulation of domestic and foreign liabilities. But the rate at which a country can safely accumulate debt is related to the rate at which it is accumulating assets. If both should double within a given period, the process is probably not unsustainable. However, if liabilities are increasing while assets are declining, there is undoubtedly a problem. In the Philippines, this is what occurred.

Moreover, adjustment polices designed to reduce the accumulation of debt without consideration of their environmental impacts might inadvertently increase the loss of natural resource assets. In the Philippines, restrictive stabilization policies sharply increased poverty and unemployment. Real wages fell more than 30 percent during the early years of the debt crisis, leaving 58 percent of the population below the poverty line.

Poverty "pushed" households out of overcrowded, poverty-stricken rural areas. Instead of facing unemployment in the cities, the prospects of gaining access to land sharply accelerated rural-to-rural migration into upland watersheds and coastal regions, intensifying deforestation and erosion of upland watersheds and the overexploitation of coastal fisheries and mangroves. Succeeding waves of migrants spilled into fragile ecological areas—2.5 million of them in the first half of the 1980s alone. With each harvest, the eroded soils yielded less, and more migrants competed for land. Poverty drove agricultural workers from crowded lowland rice farms, but poverty also awaited them in the cities and the fragile uplands.

To be successful, stabilization programs should be designed to stabilize both sides of the balance sheet—reducing the decumulation of assets as well as the accumulation of debts. Otherwise, adjustment programs will not lead to sustainable development. The IMF, the World Bank, and other development agencies should base their macroeconomic analysis on an accounting system that treats natural resources as the important assets that they are, and extend their analyses to examine the potential environmental effects of adjustment programs.

Sectoral Policy

Natural resource accounting is also extremely useful in formulating and evaluating sectoral economic policy. For example, the resource accounts drawn up for the Indonesian timber sector estimated the stumpage value or resource rents available from harvest of that country's natural tropical hardwood forests. As the following table indicates, there have been large resource rents generated by exploitation of primary forest.

Those forests are in very large part within the public domain, as national forests. The government of Indonesia licenses concessionaires to extract timber under long-term contract. Many of the concession-holders are controlled by non-Indonesian interests, in partnerships with local elites. The government captures some of the resource rents from concessionaires through a variety of license fees, property taxes, royalties, and fees. In theory, since the calculation of stumpage values makes allowance for a normal return on capital invested in the logging operation, the government of Indonesia could have captured a large fraction of the available rents.

It was a small step from the estimation of sectoral accounts to the question whether the government was actually collecting as much of the value from forest exploitation as it might. A leading Indonesian environmental organization, in cooperation with academic economists, undertook to examine the issue of rent capture, and found that in recent years the government had succeeded in capturing only 10 to 15 percent of resource rents, losing potential revenues of $2 billion annually—equivalent to 40 percent of annual ODA.

This study led to reexamination of the supply of logs at prices well below international levels to domestic mills, to the lag in forest taxes behind inflation, and to weaknesses in the supervision of timber concessions. These issues axe important not only for fiscal reasons, but also to promote more efficient and sustainable utilization of Indonesia's rich forests.

TABLE 2-1 Forest Resource Accounts-Indonesia (1970-76)

PHYSICAL UNITS (million cu. meter)	1970	1971	1972	1973	1974	1975	1976
OPENING STOCK(1)	21713	21651	21587	21522	21450	21383	21325
ADDITIONS:							
Growth(2)	51.9	51.9	51.9	51.9	51.9	51.9	51.9
Reforestation(3)	1.3	3.4	5.5	7.6	9.7	11.8	13.8
REDUCTIONS:							
Harvesting(4)	10.0	13.8	16.9	26.3	23.3	16.3	21.4
Deforestation(5)	99.0	99.0	99.0	99.0	99.0	99.0	99.0
Degradation(6)	6.6	6.6	6.6	6.6	6.6	6.6	6.6
	----	----	----	----	----	----	----
NET CHANGE	62.4	64.1	65.1	72.4	67.3	58.2	61.3
(ROUNDED)	(62)	(64)	(65)	(72)	(67)	(58)	(61)
	----	----	----	----	----	----	----
CLOSING STOCK(1)	21651	21587	21522	21450	21383	21325	21264
UNIT VALUES ($U.S. per cu. meter)							
FOB Export Price	10.90	15.10	17.10	29.30	41.60	26.40	44.70
Harvesting Costs	4.90	6.80	7.90	13.18	18.72	11.88	20.12
	----	----	----	----	----	----	----
'Primary' Rent(7)	6.00	8.30	9.20	16.12	22.88	14.52	24.58
'Secondary' Rent(7)	3.78	5.23	5.80	10.16	14.41	9.15	15.48
MONETARY ACCOUNTS ($ million)							
	1970	1971	1972	1973	1974	1975	1976
OPENING STOCK	----	105224	145064	160339	280137	396227	250782
ADDITIONS:							
Growth	196	271	301	527	748	475	803
Reforestation	0	0	0	0	0	0	0
REDUCTIONS:							
Harvesting	60	115	155	424	533	237	526
Deforestation & Degradation	399	552	612	1073	1522	966	1635
	----	----	----	----	----	----	----
NET CHANGE	-263	-396	-466	-970	-1307	-728	-1358
REVALUATION:							
Opening Stock	----	32620	12764	97798	95039	-117258	140777
	----	----	----	----	----	----	
CLOSING STOCK	105525	145495	160823	281077	397468	251464	424581

PHYSICAL UNITS (million cu. meter)	1977	1978	1979	1980	1981	1982
OPENING STOCK(1)	21264	21204	21144	21085	21028	20973
ADDITIONS:						
Growth(2)	51.9	51.9	51.9	51.9	51.9	51.9
Reforestation(3)	15.9	18.0	20.1	22.1	24.2	26.3
REDUCTIONS:						
Harvesting(4)	22.2	24.2	25.3	25.2	16.0	13.4
Deforestation(5)	99.0	99.0	99.0	99.0	108.0	108.0
Degradation(6)	6.6	6.6	6.6	6.6	6.6	6.6
	----	----	----	----	----	----
NET CHANGE	60.0	59.9	58.9	56.8	54.5	49.8
(ROUNDED)	(60)	(60)	(59)	(57)	(55)	(50)
	----	----	----	----	----	----
CLOSING STOCK(1)	21204	21144	21085	210288	20973	20923
UNIT VALUES ($U.S. per cu. meter)						
FOB Export Price	47.50	46.70	85.21	106.93	95.84	100.59
Harvesting Costs	21.38	21.05	29.84	34.24	37.93	41.00
	----	----	----	----	----	----
'Primary' Rent(7)	26.12	25.65	55.37	72.69	57.91	59.59
'Secondary' Rent(7)	16.46	16.16	34.33	45.07	35.90	36.95
MONETARY ACCOUNTS ($ million)						
	1977	1978	1979	1980	1981	1982
OPENING STOCK	423362	448617	439298	945662	1238129	983843
ADDITIONS:						
Growth	854	839	1782	2339	1863	1918
Reforestation	0	0	0	0	0	0
REDUCTIONS:						
Harvesting	580	621	1401	1832	927	799
Deforestation & Degradation	1738	1706	3625	4759	4114	4234
	----	----	----	----	----	----
NET CHANGE	-1464	-1149	-3244	-4252	-3178	-3115
REVALUATION:						
OPENING STOCK	26525	-8072	621808	296719	-251107	29225
CLOSING STOCK	448617	439298	945662	1238129	983843	1009953

PHYSICAL UNITS (million cu. meter)		
	1983	1984
OPENING STOCK(1)	20923	20875
ADDITIONS:		
Growth(2)	51.9	51.9
Reforestation(3)	29.6	35.3
REDUCTIONS:		
Harvesting(4)	15.2	16.0
Deforestation(5)	108.0	108.0
Degradation(6)	6.6	6.6
	----	----
NET CHANGE	48.3	43.4
(ROUNDED)	(48)	(43)
	----	----
CLOSING STOCK(1)	20875	20832
UNIT VALUES .($U.S. per cu. meter)		
FOB Export Price	78.75	93.15
Harvesting Costs	43.31	51.23
	----	----
'Primary' Rent(7)	35.44	41.92
'Secondary' Rent(7)	22.33	26.41
MONETARY ACCOUNTS ($ million)		
	1983	1984
OPENING STOCK	1009953	602974
ADDITIONS:		
Growth	1159	1371
Reforestation	0	0
REDUCTIONS:		
Harvesting	539	671
Deforestation & Degradation	2559	3027
	----	----
NET CHANGE	-1939	-2327
REVALUATION:		
OPENING STOCK	-408918	106424
	----	----
CLOSING STOCK	602974	711725

3

The Feasibility of Incorporating Environmental and Natural Resource Availability into the National Accounts

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National income accounting is among the most important policymaking tools to appear in the last fifty years. The accounts contribute to policymaking by taking detailed economic data and computing aggregate indicators such as gross domestic product (GDP). Aggregate measurements, such as the percentage of GDP spent on health care, often alert decisionmakers of the need for new policy initiatives. Researchers can also use the detailed data to analyze policy alternatives.

This information supports the three basic functions of the national accounts which are (a) to provide an economic interpretation of changes in the nation's assets and national wealth, (b) to provide measures of income based on the actual or imputed market value of goods and services, and (c) to measure financial and factor input flows in the economy.

DEFICIENCIES IN THE TREATMENT OF NATURAL RESOURCES AND THE ENVIRONMENT

Demands to add more information on natural resources and the environment reflect concerns that the ability of the accounts to perform their basic functions is inhibited by a deficient treatment of natural resources and the environment. The current accounts do not, for example, record changes in environmental quality and most natural resource reserves. The nation could severely degrade or vastly improve the environmental quality of its land, air, and water; nearly exhaust or greatly add to its mineral reserves, forests, fisheries, and soil fertility; and suffer—or not experience—permanent losses of biodiversity through the extinction of flora and fauna with little or no discernable effect on aggregate measures of national income or wealth. Thus, aggregate measures from the accounts may fail to alert decisionmakers of problems with the management of these national assets.

The current accounts also ignore or mislabel many of the costs and benefits associated with natural resources and the environment. They treat the costs of reducing the adverse effects of natural resource depletion and environmental degradation as ordinary investment and consumption expenditures. Damages caused by pollution affect estimates of national income only to the extent that they influence productivity and even those effects are not separately identified in the accounts. Waste disposal services provided by air, land, and water in absorbing pollution are assigned a zero value because no one charges for them. The benefits of maintaining natural resources and a clean environment, such as preservation of biodiversity and enhanced recreation opportunities, are ignored for the same reason. These acts of omission and commission make it difficult for analysts to trace the linkages between environmental and natural resource policies and employment, trade balances and growth in GDP.

A comprehensive amending of the accounts to correct for this deficient treatment would require three kinds of revisions: (1) expanding the asset boundary to record changes in environmental quality and natural resource assets; (2) expanding the production boundary to include services of natural resources and the environment that are not counted in measures of national income such as GDP; and (3) reorganizing the production boundary to more clearly identify the input of environmental factor service flows and the costs of reducing pollution damages counted in GDP.

The data needed to make these revisions to the accounts could provide information that would be potentially useful in many policy debates. Some of the more important issues are the effect of environmental protection on economic growth, the distributional impacts of environmental and natural resource policies, and the linkages between trade and environmental and resource policies. In addition, compiling a set of more integrated information on natural resources and the environment could yield new insights into the workings of the economy and represent an important step towards a goal of producing a measure of national income compatible with the concept of sustainable income.

ASSET AND PRODUCTION BOUNDARIES UNDERLYING THE NATIONAL ACCOUNTS

The National Income and Product Accounts measure the flow of products and income in the U.S. economy. The *product side* of the national accounts measures the flow of goods and services currently produced in the economy. The *income side* of the accounts measures the income earned by factors (inputs) contributing to the production of these outputs. The two sides of the accounts represent two different measures of the same continuous flow.

The economic model underlying the accounts assumes that the production of any good or service can be linked to the flow of services provided by capital assets. That is, the goods and services sold in the market reflect the capital services of the plant and equipment used in their manufacture. Table 3-1 lists the major types of fixed capital and examples of service flows from that capital. The two general types of capital stock are reproducible capital and natural capital. Reproducible capital is subdivided into privately-owned and publicly-owned tangible capital and human capital. Natural capital is divided between the environment and natural resource reserves.

TABLE 3-1 Examples of Major Service Flows from Various Types of Capital and An Interpretation of Their Current Treatment in the National Accounts

Type of Capital		Category of Service Flow		
		Marketed[^]	Nonmarketed	
		Now in GDP	Now in GDP	Not now in GDP
Reproducible capital	A. Tangible, privately-owned	1 Factor services of business-owned plant and equipment to industry and commerce	7 Factor services of owner-occupied housing	13 Final services of business-owned capital
	B. Tangible, publicly-owned	2 Factor services paid for through user fees	8 Nonpecuniary factor services of infrastructure to industry and commerce	14 Final services of infrastructure to households
	C. Human	3 Factor services of labor paid for by wages and salaries	9 Nonpecuniary volunteer services	15 Final services (benefits) of education
Natural capital	D. Environmental	4 marketable permits for use of the waste disposal services of the environment	10 Waste disposal and other services to industry and commerce of clean air, land and water	16 Final services of the environment (effects on health, aesthetics)
	E. Renewable natural resource	5 Food, lumber, water, and recreation paid for by user fees	11[*]	17 Other recreation services, biodiversity, nonuse benefits
	E Nonrenewable natural resource	6 Energy, minerals, water, and recreation paid for by user fees	12[*]	18 Nonpecuniary final services of nonrenewable resources (recreation services, nonuse benefits)

SOURCE: Congressional Budget Office

[*] Major service flows not identifiable

[^] Underground market activities are not included in GDP and are not represented

Factor Services

The flows of factor services provided by various capital stock for producing final products are shown in cells 1 through 12. The factor services provided by privately owned tangible reproducible capital to businesses appear in cell 1. The factor services from this capital to households are shown in cell 7. The services to households are listed as nonmarketed because homeowners do not really pay themselves rent. The value of these services do not represent actual market exchanges but rather are imputed.

Much publicly owned reproducible capital stock adds value to GDP; the factor services from this type of capital appear in cell 2 (for marketed services) and cell 8 (for nonmarketed). The amount of human capital contributing to GDP is a function of the total number of workers plus their skills and knowledge. The services of human capital, labor services, is represented in cell 3 (for marketed services) and cell 9 (for nonmarketed).

Natural capital is made up of air (atmosphere), water (hydrosphere), and land (lithosphere) which provide both environmental and natural resource factor services. Natural capital provides marketed environmental waste disposal services (cell 4) and nonmarketed environmental waste disposal services (cell 10). The atmosphere absorbs greenhouse gases (carbon dioxide, methane, hyrdoflourocarbons, etc.), ozone depleting substances including chloroflourocarbons (CFCs), emissions of particulate matter, nitrous oxides (NO_x), sulphur oxides (SO_x), and volatile organic compounds (VOCs) contributing to atmospheric ozone. Water resources (the hydrosphere) absorb such pollutants as heavy metals, chlorides, plastics, acid rain, pesticides, organic wastes, and chemical fertilizers. Paper, glass, metals, rubber products, plastics, pesticides, and chemical fertilizers are also deposited on land (the lithosphere). These waste disposal services are implicit in the production boundary and, therefore, affect GDP.

Natural resources are divided into renewable and nonrenewable stocks. Renewable resources include agricultural lands, recreational areas, forests, lakes, streams, grasslands, wetlands, fisheries, and wildlife. These resources provide marketed factor services (cell 5) which serve as inputs into the production of final goods and services such as food, wood products, and drinking water and recreation.

Nonrenewable natural resource stocks include reserves of mineral fuels (petroleum, natural gas, coal and uranium), nonfuel minerals (e.g., lead, copper, gold) and groundwater. Nonrenewable resources provide inputs (cell 6) into the production of energy, metal products, and final products such as drinking water, and recreation.

Final Services

Assets can also generate service flows which go to households (final users) rather than to business as primary inputs to production. These service flows are not currently recorded in the accounts; including them would require expanding the definition of GDP. The services of these assets are represented in the production boundary of Table 3-1 and labeled nonmarketed and not now included in GDP. The types of final services of these capital stocks are rarely bought and sold in organized markets because of the difficulty of excluding nonpayers.

The Golden Gate Bridge and Empire State Building, for example, contribute to the ambience of San Francisco and New York in a way that differs from their service as an input into the production of other goods and services. These services appear in cells 13 and 14. The final services of education, such as being a more informed citizen and having a heightened appreciation of historical sights, are nonpecuniary; they appear in cell 15.

Natural resources and the environment—the Grand Canyon and clean water—derive much of their value to society from the aesthetic, free recreation, and health benefits they provide. The final services to households of people who travel to beaches and mountains to enjoy the clean air and water as well as the unspoiled land (cell 16) is another example. Many natural resources also provide nonmarketed final services known as nonuse benefits (cells 17 and 18). Evidence that these services are considered valuable to final users is indicated by the willingness of individuals, who may never actually see a blue whale, to spend money to protect them.

Current Asset and Production Boundaries of U.S. Accounts

The asset and production "boundaries" define the set of goods and services that are included in the national accounts. The asset boundary contains real assets which include fixed capital. An asset must be included in the asset boundary if it is to be assigned a value in the balance sheets and must be designated as fixed capital if its depreciation is to be subtracted from GDP. The production boundary delineates the set of goods and services which are treated as either intermediate or final products. Only final products in the production boundary are counted toward GDP.

The contents of the current production boundary are shown in Table 3-2. Presently, GDP includes all final goods and services involving an exchange of money (a market transaction) with the exception of certain market activities in the underground economy.[1] This is equivalent to the income earned from all the factor services of capital used in the production of these final goods and services. Marketed service flows are represented in cells 1-6. There are also some nonmarketed flows not involved in any market transaction that are included in GDP. The biggest single item currently recorded in the accounts in this category is the services of owner-occupied housing (cell 7). In addition, there are the nonmarketed factor services of publicly-owned reproducible capital (cell 8); the factor services—human capital—of volunteers (cell 9); environmental waste disposal factor services (cell 10); and the factor services from natural resources (cells 11 and 12).

None of the services in cells 8 through 12 appear, however, as distinct entries in the accounts because there are no direct payments to these factors for their housing). Other forms

[1] A number of marketed activities are not reflected in the present taxonomy because they are a part of the underground economy. Examples include illegal activities such as drugs, prostitution, and gambling; these underground transactions also include payments "under the table" such as paying baby-sitters and home health care workers in cash. These are market activities which some estimate to be as much as 13 percent of GDP. However, because of the nature of these activities there are hardly any proponents of incorporating such illegal activities in GDP.

TABLE 3-2 Current Asset and Production Boundaries in the National Accounts

Type of Capital			Category of Service Flows		
ASSET BOUNDARY SHOWN			PRODUCTION BOUNDARY SHOWN		
Marketed	Nonmarketed		Marketed^	Nonmarketed	
Service Flows Used to Determine Asset Value and Depreciation			Service Flows included in GDP		
A. 1	7	13	1	7	13
2	8	14	2	8	14
3	9	15	3	9	15
4	10	16	4	10	16
5	11	17	5	11 *	17
6	12	18	6	12 *	18

SOURCE: Congressional Budget Office

* Major service flows not identifiable

^ Underground market activities are not included in GDP and are not represented.

services. Moreover, no imputed values have been assigned to them as has been done for owner-occupied housing. But the availability of such services does impact GDP through effects on productivity.[2] For this reason, they are included in this representation of the production boundary. Finally, the final services of capital (cells 13-18) are not included in the production boundary and, therefore, are not counted in GDP.

The current asset boundary, demarcated by the thick-lined box on the left in Table 3-2, shows that the accounts only recognize privately owned tangible, reproducible capital (including of capital—publicly owned reproducible, human, and natural capital—whose services appear in cells 2 through 6, 8 through 12, and 14 through 18—are not included in the asset boundary. This means that an asymmetry exists between the current asset and production boundaries since the current production boundary does implicitly or explicitly count the factor services of publicly owned capital, human capital and natural capital. This asymmetry means that the balance sheets do not record investment or depreciation for some kinds of capital stock whose factor services are counted in GDP.

ADDRESSING THE DEFICIENCIES IN THE TREATMENT OF NATURAL RESOURCES AND THE ENVIRONMENT

Three kinds of revisions to the accounts are possible: (1) expanding the asset boundary to record changes in environmental quality and natural resource assets (cells 4-6 and 10-12); (2) expanding the production boundary to include the final services of natural resources and the environment, which are not counted in measures of national income such as GDP (cells 16-18); and (3) reorganizing the production boundary to more clearly identify the input of environmental factor service flows (cells 4 and 10) and the costs of reducing pollution damages counted in GDP.

Expanding the Asset Boundary to Record Changes in Natural Resources and the Environment

Expanding the asset boundary to record changes in natural resources and the environment implies that values for depletion and degradation would be computed for these natural capital assets along with depreciation for tangible reproducible capital. For conventional GDP, the asset boundary would have to be expanded to account for natural capital generating services flows represented in cells 4-6 and 10-12 as shown in Table 3-3. That is, values for depletion and degradation could be estimated for natural resource assets such as forests, mineral reserves, and the quality and quantity of agricultural lands. Values for degradation would also be calculated for the changes in currently available environmental waste disposal services. Available waste

[2] For further explanation see Jan Bojo, et al., *Environment and Development: An Economic Approach*, Dordrecht: Kluwer Academic Publishers, 1992, pp. 40-53.

TABLE 3-3 Expanding the Asset Boundary in the National Accounts to Record Changes in Natural Resources and the Environment for Conventional GDP

Type of Capital

ASSET BOUNDARY SHOWN

Service Flows Used to Determine Asset Value and Depreciation

Marketed	Nonmarketed	
A. 1	7	13
2	8	14
3	9	15
D. 4	10	16
E. 5	11*	17
F. 6	12*	18

Category of Service Flows

PRODUCTION BOUNDARY SHOWN

Service Flows included in GDP

Marketed	Nonmarketed	
1	7	13
2	8	14
3	9	15
4	10	16
5	11 *	17
6	12 *	18

SOURCE: Congressional Budget Office

* Major service flows not identifiable

disposal services depend on limits set by regulation. Of course, changes in the production boundary would imply an expanded set of services for valuing capital assets.

Subtracting depreciation for the expanded set of assets from GDP could be used to produce what might be termed an "environmentally adjusted NDP." That is, NDP would be adjusted for depreciation of tangible capital, depletion of natural resources, and degradation of environmental assets. The balance sheets are the component of the accounts where most of the changes implied by redefining the asset boundary would occur. It is there that changes in assets—whether from use, capital gains and losses, or investment—are recorded.

Expanding the Production Boundary to Include More Services of Natural Resources and the Environment in Measures of National Income

Expanding the production boundary to include more services of natural resources and the environment would mean that expanded definitions of national income could now be calculated. A measure of a "green" GDP, for example, would count the final nonmarketed services of natural resources and the environment. Therefore, the production boundary would have to be expanded to include cells 16-18 as shown in Table 3-4. That is, the value of nonhealth-related services—recreation, biodiversity, aesthetic, and nonuse benefits—as well as pollution damages (treated as negatively valued health-related services) would be included in national income.

Two implications of this kind of change to the accounts deserve mention. One is that the flows in cells 16-18 are among the most difficult nonmarket services to value. Because they are not inputs to the production of marketed goods and services, the choice of techniques for imputing a price for the assets generating these services is much more limited. Second, many of the changes implied by expanding the production boundary would show up in the NIPA component of the accounts where imputed expenditures and rent are recorded. As with other fixes, however, other components of the accounts would be affected to some degree. For example, there may be some depreciation from use of the service flows to households. To be internally consistent, the asset boundary could be extended to measure depreciation (due to use) of assets providing these services.

Reorganizing Items Included in the Production Boundary to More Clearly Identify Environmental Services and the Costs of Reducing the Risks of Pollution

Reorganizing items included in the production boundary to more clearly identify service flows from the environment would recognize the flow of waste disposal services from the environment to businesses as an input into production. As is the case for other kinds of factor services in production, there is an associated return (income). Since waste disposal services are not marketed, a price would have to be imputed based on the productivity of this factor (similar to identifying wages for the services of labor—as flows of human capital). This information could be estimated by sector, recorded in the Input-Output (I-O) tables, and used in analysis of

TABLE 3-4 Expanding the Production Boundary in the National Accounts to Include Final Services of Natural Resources and the Environment that are now Ignored (Measuring a "Green" GDP)

Category of Service Flows PRODUCTION BOUNDARY SHOWN		
Marketed	Nonmarketed	
Service Flows to be Included in the Production Boundary		
1	7	13
2	8	14
3	9	15
4	10	16
5	11 *	17
6	12 *	18

SOURCE: Congressional Budget Office

* Major service flows not identifiable

the impacts of environmental policies. For example, the economic impact on production of an environmental policy to change allowable emission levels, could then be traced on an industry-by-industry level through the I-O tables.

Identifying waste services is described as a reorganization rather than a redefinition of the production boundary since this kind of revision would not have to result in a change in the goods and services included in GDP. It would involve, instead, assigning some of the value added now recorded as profits, wages, rents, etc. to imputed factor payments for the environment. Reorganizing the production boundary would, therefore, result in changes to the I-O table more than to other components of the accounts.

Reorganizing items included in the current production boundary to more clearly identify the costs of reducing the risks of health damages from pollution would mean that some of the expenditures now listed as investment and consumption would be listed as defensive expenditures. These expenditures would include expenses for ameliorating environmentally-related health problems and for abatement equipment. Reclassifying these costs as a part of reorganizing the accounts would also help to identify the benefits and costs of changing emission levels at the industry level. It is called a reorganization because it would not have to result in a change in the measure of national income.[3]

An important problem with carrying out this reorganization will be handling the joint service output of many items. For example, air conditioners may reduce the affects of air pollution on sufferers of respiratory ailments, but they are not purchased for the medicinal purposes alone. The percentage of the total cost of such items to assign to defensive expenditures will have to be determined.

CONCLUSIONS

Incorporating more information on natural resources and the environment into the accounts ("green accounting") will require much conceptual work and data gathering. The principal problems with incorporating more information into the accounts are identifying the most appropriate way of measuring physical changes in environmental quality and natural

[3] Many proponents of changing the accounts axe concerned that gross domestic product is not a good measure of productive activity in the economy because it includes spending on pollution prevention. Some advocate circumventing this anomaly by subtracting out so-called defensive expenditure from GDP. The production boundary would not have to change and yet GDP would decrease.

The problem with this approach is that it also yields a counter-intuitive result. Countries that ignore pollution problems and spend money on other types of goods and services would appear better off relative to countries that spend money on pollution prevention activities. Also by taking out expenditures on environmental protection from GDP, the effects of increased expenditures on jobs and incomes cannot be measured because of the income expenditure identity in the accounts.

resource reserves and identifying reliable and consistent methods of pricing the nonmarket services of these assets.

Estimating changes in the reserves of economically exploitable resources is difficult when market conditions are changing. Measuring net changes in biological resources is difficult because of uncertainties about population growth rates. And aggregate measures of environmental quality mask problems associated with "hot spots" which are well below minimum standards.

Valuing natural resource depletion or environmental degradation depends heavily on techniques to impute prices because many of the services of natural resources and the environment are not sold in markets. The lack of organized markets is especially a problem in valuing service flows associated with the health effects of changes in environmental quality.

If a decision is made to add more information on natural resources and the environment into the accounts, the most immediate concern will be how to proceed with the three types of revisions. The United Nations (UN) and Bureau of Economic Analysis (BEA) have decided to maintain satellite accounts to record measures of the value of natural capital, its depletion, and flow of services, while measurement issues are being resolved. These measures could later be integrated into the main components of the accounts as problems of measurement and data axe resolved.

In addition, initial efforts by the UN and BEA, which are meant to improve their understanding of how best to incorporate natural resources and the environment into the accounts, have relied to a large extent on market data. These initial efforts concentrate on two types of revisions to the accounts: determining the monetary value of environmental asset degradation and resource asset depletion and identifying pollution abatement and control expenditures designed to reduce pollution damages.

The focus of these initial efforts is logical since it is possible to estimate the costs of reducing pollution damages largely from data already collected in compiling the national accounts. Likewise it is possible to estimate environmental degradation and natural resource depletion largely from market data on the costs of maintaining environmental quality and revenues from goods and services from natural resources. In contrast, expanding the production boundary or valuing environmental waste disposal services requires much greater reliance on imputed prices.

Imputed prices are now used in computing aggregate measures such as GDP but are limited to items, such as the value of services of owner-occupied housing, for which much relevant market data exist. Revising the accounts beyond current efforts implies, however, a significantly expanded reliance on imputed prices for valuing services for which there are much less relevant market data. Nevertheless, a gradual process of modifying measures of national economic performance is consistent with our experience since first introducing the national accounts. It is within this context that any effort to incorporate more information on environmental and natural resources into the national accounts should be judged.

4

Sustainable Resource Accounting

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INTRODUCTION

Coinciding with the recent interest in resource and environmental accounting are worldwide concerns over "sustainability." Indeed, some of the interest in resource and environmental accounting may stem from a belief that improved national accounting practices will enhance the chances that a nation's economic growth will be sustainable.

The purpose of this paper is to investigate this proposition and to raise the question: how can resource and environmental accounting contribute to the management of sustainability? I will argue that this contribution depends, first, on how "sustainability" is defined and, secondly, on how one views the accounting process. I will conclude that the benefits of resource and environmental accounting for addressing sustainability issues are greater the more the accounting process is viewed as an information system to support broadly economic (or humanistic) objectives. These benefits diminish the more one focuses on narrow environmental objectives.

To make these arguments, I must first discuss the purposes of accounting and define three terms: "sustainability," "depreciation," and "income." I believe that confusion over the meaning of these terms can lead to disappointment by policymakers who might expect resource and environmental accounting efforts to shed more light on their policy interests than, in fact, will be possible.

ACCOUNTING FUNCTIONS: SCOREKEEPING AND MANAGEMENT

Any accounting activity, whether for a private business or for a nation, serves two distinct purposes. One I call "scorekeeping"—the computation of the "bottom line" (profits and losses) in a business or of one of several indicators of economic performance for a nation: gross domestic product, net domestic product, etc. Knowing the right "score" is of as much policy interest to a business manager and policymaker as it is to a manager of an athletic team. Indeed, the belief that conventional national economic accounting provides a misleading "score"—misleading because of a failure to account for the depletion of natural resources and the quality of the environment—is one of the principal motivations behind some of the more pioneering resource accounting efforts: those of Robert Repetto and his colleagues at the World Resources Institute.[1]

However, the value of good "scorekeeping" depends, of course, on the ability of the manager to use the score to make the appropriate adjustments that will eventually lead to victory. The value of good "scorekeeping" also depends on timeliness: it does the manager little good to first learn the score after the ball game is over. Yet, in practice, accounting scores do come in late. It is not unusual for a business to learn of its "bottom line" more than six months after the close of its accounting year. Even in this circumstance., however, the manager would rarely fire his accountant. In spite of the lateness of the score, the accounting process is serving another important function. It is organizing the basic information—sales, costs, production, inventory-needed to run the business.

This second function of accounting—the "management" function—will justify an accounting effort even if there is an ultimate failure to provide a "score" or, as is more likely with the computation of environmentally-adjusted scores, wide disagreement as to whether the score is accurate. The importance of this observation as it relates to the contribution of resource and environmental accounting to addressing sustainability issues will become apparent later. First, we must define what we mean by "sustainability."

SUSTAINABILITY

John Pezzy, in a World Bank paper, did us all a favor by surveying the many ways authors have been using such words as "sustainable" and "sustainability."[2] I will not attempt to summarize this literature except to note that all the definitions seem to fall into one of three categories: those that refer to sustaining the environment, those that refer to sustaining the economy, and those that refer to sustaining one or the other, subject to one or the other being set at some predetermined level (e.g., sustaining economic growth subject to maintaining the environment at some "clean" level).

It is true that on the part of several authors, their sustainability notions may be mixed. Many have a sincere belief that sustaining the environment is a necessary condition for sustaining the economy while, for others, the opposite view is held: sustaining the economy is a necessary condition for sustaining the environment. I do not wish to enter this debate but only to point out that there is a difference in priorities. Some, when they use the word "sustain-ability," focus on sustaining resources and the environment; others focus on sustaining the economy.

[1] Robert Repetto, William Magrath, Michael Wells, Christine Beer, and Fabrizio Rossini, *Wasting Assets: Natural Resources in the National Income Accounts*, Washington, D.C.: World Resources Institute, 1989.

[2] John Pezzy, *Economic Analysis of Sustainable Growth and Sustainable Development*, Environment Department Working Paper No. 15, Washington, D.C.: The World Bank, March, 1989.

Paralleling this distinction between the two meanings of "sustainability" is a distinction that can be made with respect to an older economic concept: "depreciation."

DEPRECIATION

First, I would like to distinguish between definitions of depreciation and rules-of-thumb for estimating depreciation. There are several ways of measuring depreciation, many of which have been codified in tax laws. I am not especially interested in these measures for this paper. What is of more concern is the concept of depreciation that these measures are attempting to reflect. I believe that there are essentially two concepts of interest: *physical* depreciation and *economic* depreciation.

Physical depreciation refers to the decline in the physical ability of capital to generate useful services. A popular term for physical depreciation is "the wearing out of capital." When applied to the environment and to natural resources, physical depreciation means a physical decline in the ability of these forms of natural wealth to provide services—services ranging from the provision of energy and minerals to the provision of clean air and water.

Economic depreciation, in contrast, refers to the decline in the ability of capital to provide *services of value*. Since the value of a stock of capital is defined in terms of the value of the services generated, an equivalent definition of economic depreciation is the change in the value of capital over time. The important distinction between the two definitions of depreciation is that while physical depreciation can "explain" economic depreciation, it is quite possible that economic depreciation can occur without any physical depreciation at all. For example, a machine that produces large ladies' hats could be so perfectly and strongly constructed that its ability to generate hats remains unchanged over time—it does not physically depreciate. However, if such hats go out of style, the value of the hats produced will decline. As a result, the value of the machine will decline: it experiences economic depreciation. Likewise with the environment or with a stock of natural resources: physical changes in natural wealth may have little to do with its economic depreciation. Thus, with increasing recreational use, a pristine lake may become more polluted physically. Yet, as the number of users increase, its recreation value may not decline and could even increase: it could experience negative economic depreciation or appreciation.

The linkage between the two concepts of sustainability and depreciation should now become clear. Sustaining the environment suggests some actions designed to minimize or, if possible, prevent the physical depreciation of the environment. Sustaining the economy, in contrast, suggests some actions designed to minimize or prevent economic depreciation of the environment or of any other forms of wealth that contribute to economic activity.

To see how all these concepts link to accounting, it is first necessary to link concepts of depreciation with concepts of income.

INCOME AND DEPRECIATION

One of the more controversial issues in economics concerns the appropriate definition of income as a measure of social well-being. Should it be a measure of society's current well-being or potential well-being? Should it be a measure of what has been the case in the past or what could be the case in the future? One particular choice for a definition of income is that of Professor Hicks.[3] He would define income as an amount of goods and services that we could consume without destroying the ability to maintain this consumption in the future. Thus, while it is possible to enjoy a high level of consumption by liquidating all your wealth, this level will only be temporary. A more permanent—a more *sustainable*—definition of income would be the level of potential consumption after incurring such expenses necessary to maintain the income-generating services of your wealth or capital. This definition of income corresponds to the national accounting definition of net income: gross income less depreciation. Net income is sustainable income in the sense that, in principle, its level could be maintained indefinitely. There is, however, no guarantee that a nation's net income will be maintained indefinitely. In the first place, the potential may not be realized because of poor policy choices. In addition, the depreciation estimate, as we shall see, depends on assessments of the future ability of present capital to generate valuable services. Unforeseen events, such as war or world-wide depression, could mean that depreciation was grossly underestimated.

While I would like to avoid being too technical, I shall use a little algebra to make a basic point: that the only concept of depreciation that is consistent with net or Hicksian income is economic depreciation.

The relationship between income and economic depreciation can be shown as follows. A society's capital has value presumably because it generates a stream of goods and services, i.e., income. Let V_0 represent this value at the beginning of the year, and Q_1, Q_2, etc., represent the gross value of these services before any depreciation (that is, "gross income") at the beginning of the next and subsequent years. Thus, Q_1 is gross income in year 1.

The theory of investment relates V_0 to the Q's as follows:

$$V_0 = \frac{Q_1}{(1+i)} + \frac{Q_2}{(1+i)^2} + \ldots + \frac{Q_n}{(1+i)^n} + \ldots, \tag{1}$$

where i is the rate of interest. Since V_1, the value of V_0 at the end of year 1, is simply

[3] J. R. Hicks, "The Valuation of the Social Income," *Economica*, vol. VII, no. 2 (May, 1940) pp. 105-124 and "Maintaining Capital Intact: A Further Suggestion." *Economica*, vol. IX, no. 34 (May, 1942), pp. 174-179.

$$V_0 = \frac{Q_1}{(1+i)} + \frac{V_1}{(1+i)} = \frac{Q_1 + V_1}{(1+i)},$$

equation (1) can also be written:

$$\frac{Q_2}{(1+i)} + \frac{Q_3}{(1+i)^2} + \ldots + \frac{Q_{n+1}}{(1+i)^{n+1}} \ldots, \tag{2}$$

from which it follows that

$$Q_1 = iV_0 + (V_0 - V_1). \tag{3}$$

The term (V_0-V_1), representing the loss in value of the initial capital stock, is, by definition, *economic* depreciation occurring in year one, or D_1. Gross income, Q_1, can also be defined as consumption plus gross investment. By definition, net income equals gross income less depreciation. It follows from (3) that, since Q_1 is gross income, the term iV_0 can be identified with net income. Thus (3) can be rewritten as:

$$Q_1 = C_1 + I_1 + D_1 \tag{4}$$

where C_1 and I_1 are consumption and net investment in year 1. In words,
Gross income = net income plus economic depreciation.
or
Net income = gross income less economic depreciation.

Note that this relationship between gross and net income and depreciation was developed without any reference to the physical destruction of capital. It does not matter why there is economic depreciation. It could be due to physical depreciation or simply due to a change in tastes for the goods or services generated by the capital. The important point is that Hicksian (net) income—or economically *sustainable* income—is consistent only with depreciation defined economically—not physically.

An important implication of this finding is that the physical sustainability of certain kinds of capital—such as natural resource capital—does not, in itself, say very much about economic sustainability. Environmental and natural resource capital has not been "sustained" in a physical sense in the United States nor has it ever been in the nation's history. Yet, by any economic measure, the nation is far better off than it was 200 years ago basically because the total value of national wealth—reproducible capital, human capital, and environmental capital—is far larger than it was 200 years ago.

It has been argued, however, that the use of conventional income measures is misleading. Perhaps if the income were measured in the United States in a way that explicitly accounted for both environmental and economic deterioration, the story of success would have to be modified. Perhaps we are being deceived by the wrong "score." I turn to this argument in the following section.

INTERPRETATION OF ENVIRONMENTALLY-ADJUSTED INCOME

Some of the more well-known work in environmental and resource accounting concerns adjusting conventional income for environmental and resource deterioration—adjustments that supposedly yield a better "score." It is my contention, however, that as important as this work is, its implications for policy have been misunderstood, perhaps even by the authors of the work.

For example, referring to the findings of Repetto et al. for Indonesia, (now) Vice-President Al Gore wrote:

> That nation's net losses of forest resource now exceed timber harvests: so much topsoil has eroded that the net value of the timber crop has been reduced by approximately 40 percent. Yet while this economic tragedy was unfolding and Indonesia was racing toward the precipice, the official economic reports all showed a rosy picture of steady progress.[4]

What the Repetto results did show is that Indonesian GDP, if adjusted for the decline in natural resources, would be lower by an average of about 4 percent over the period investigated. Suppose these estimates were perfectly correct in that the adjusted figure presented a true picture of net domestic product. Then the only implication of the finding would be that Indonesia's Hicksian, sustainable income is perhaps lower than the Indonesians originally believed. Yet the lower income is still sustainable (assuming again that it is a true indication of net income). There is no implication from these findings that Indonesia is heading for a "precipice."

There is another policy implication that has been drawn from these findings. There is the implicit implication that the resources have been "wasted" (thus, the title of the report, *Wasting Assets*). The contention appears to be that had Indonesia not used up their natural resources and thus eliminated the need to adjust their income downward by 4 percent, their (net) income, on average, would have been at least 4 percent greater. This contention might be true if everything else were equal—but everything else is not equal. In particular, it is apparent that the Indonesians converted their forests, minerals, petroleum, and soil resources into other forms of wealth—principally reproducible wealth and human capital. Perhaps this conversion has not been totally efficient. Perhaps some of the assets have been "wasted." However, whether this has been the case cannot be ascertained merely by looking at adjusted net domestic product

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[4] Al Gore, *Earth in the Balance*, New York: Houghton Mifflin, 1992, p. 185.

totals—that is, by looking at corrected "scores." What would be needed to ascertain the existence of waste is a careful simulation of Indonesian income paths with and without the resource exploitation. I believe that resource and environmental accounting would have an important role to play in this analysis.

ACCOUNTING SUPPORT FOR SUSTAINABILITY ANALYSIS

The basic strength of comprehensive accounting systems—whether business or national economic accounting systems—is that they provide a complete picture of all inputs and outputs associated with a complex economic process. Most comprehensive resource and environmental accounting schemes (such as the UN Statistical Department scheme[5] or my own "neo-classical economics" approach[6]) try to *expand* conventional economic accounts by including the nonmarketed input and output services of the natural environment. In spite of this attention to the natural environment, conventional economic inputs and outputs are not forgotten. As a result of this comprehensive focus, the accounting process generates data sets that permit complete analysis of interactions between conventionally measured economic activity and environmental and natural resource activity.

The accounts and supporting databases do not substitute for the requisite analyses but rather provide the empirical information that supports the analyses. Past implementations of resource and environmental accounting systems in the United States have supported comprehensive analyses of such policy issues as how the costs of environmental policies differentially affect the rich and poor, the relative effects on water quality of agricultural and industrial pollution-control policies, and whether the social benefits of various air and water pollution controls are commensurate with their social costs. While all these analyses could have been done without the comprehensive accounting framework, because of the accounts, they were done at very low cost. (Similarly, a business could operate without an accounting system, but at much higher managerial costs.)

Presumably, a comprehensive resource and environmental accounting system could support analyses of "sustainability" in the same way. For example, the accounts could support input-output-type programming models in order to explore the feasibility of future optimal income paths subject to assumed limitations on the availability of resource inputs. In addition, similar input-output models could be used to estimate pressures on resource stocks as assumed

[5] Peter Bartelmus, Carstan Stamer, and Jan van Tongeren. *SNA Framework for Integrated Environmental and Economic Accounting* paper presented to the 21st Conference of the International Association for Research in Income and Wealth, Lahnstein, Germany (August 21, 1989).

[6] Henry M. Peskin, "Alternative Environmental and Resource Accounting Approaches," in Robert Costanza, ed. *Ecological Economics: The Science and Management of Sustainability* New York: Columbia University Press, 1991.

levels and composition of income change. In effect, such models would link concerns for sustaining the environment with concerns for sustaining the economy.

CONCLUSION: THE ECONOMICS POINT OF VIEW

What a system of resource and environmental accounts will not do is identify best management schemes for sustaining the environment per se (other than giving some indication of the economic costs of such schemes). Environmental and resource management design requires much more information than can be expected to be forthcoming from the accounts. It must be remembered that there is a difference between environmental and resource accounts and environmental and resource data systems. The latter contain the physical and scientific data that are essential for the development of resource and environmental policy measures. The former contain the data that support a much broader economic policy framework.

I believe that if environmental policy interests are defined solely by environmentalist concerns for the protection and conservation of the natural environment, the contribution of resource and environmental accounts will be only of peripheral interest. On the other hand, if policymakers have a broader humanistic focus—a focus wherein environmental wealth has an important but not exclusive role to play in the production of human well-being—then I believe that resource and environmental accounting can make a key contribution to the process of policy formation.

5

Transfer Models for "Green Accounting": An Approach to Environmental Policy Analysis for Sustainable Development

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THEME: ARE WE KILLING THE GOLDEN GOOSE?

Efforts to revise national income accounts to incorporate environmental externalities ("green accounting") may help us to better understand how our social, political, and economic actions impact the environment. A primary motivation behind "green accounting" is concern that humankind's activities are creating significant environmental damage which is not captured by conventional accounting techniques. Ascertaining the extent to which humans are consuming nature as contrasted with living upon interest has reached paramount importance. Phrased informally, is our society unknowingly "killing the golden goose?"

There exists an immense range of views on this question. Optimists argue that technological advances will provide substitutes, and claim that there is no need to worry. Pessimists—"cliffologists"—worry that we are destroying irreplaceable resources and creating adverse side-effects at an accelerating pace; they fear that disaster looms.[1]

Regardless of perspective, there seems to be agreement that addressing questions of sustainability requires new tools. We argue here that national income accounts, as commonly constituted, are inadequate to capture some of the most important features of the debate over sustainability. We review the most important of these reasons. From this review we conclude that there are severe methodological issues that cannot as yet be resolved. We propose one approach, which we call the "transfer model" methodology. While this technique shows promise, it is still in an early stage of development.

Our transfer model approach, which emphasizes both stocks and flows, is a framework for giving meaning and context to green accounts. It also focuses upon biogeophysical measures

[1] These differences were clear in the intense discussions at the National Research Council workshop "Valuing Natural Capital in Planning for Sustainable Development," for which this paper was prepared.

which represent direct indicators of particular aspects of sustainability. Such issues were raised in the major report, *World Conservation Strategy* (IUCN, 1980, Section 4.1):

> Sustainable utilization is somewhat analogous to spending the interest while keeping the capital. A society that insists that all utilization of living resources be sustainable ensures that it will benefit from those resources virtually indefinitely.

According to this view, sustainability requires that certain baseline conditions be guaranteed. Because of difficulties associated with monetization (among others), baseline conditions are best specified in biogeophysical terms that take into account both stocks and flows. For instance, biological terms appear the most informative when discussing issues such as the need of species for habitat, healthy food, clean water, adequate range, a minimum viable population, stress resistance, etc. If these and other baseline conditions cannot be provided, species are likely to go extinct.

Because of ambiguities and uncertainties about what constitutes sustainability and whether or not it is being achieved in particular cases, it is not surprising that discussions of sustainability frequently lead to debate. Questions concerning humankind's relationship to the environment, perception of growth, views on the helpfulness or harmfulness of technology, salience of equity issues (both intragenerational and intergenerational), population stress, species and cultural diversity, and the ability of our present socioeconomic-political systems to effectively address these issues are all relevant to this discussion. These issues help us to explore the preconditions for sustainability. Improved natural capital accounts can help us to explore our current state of affairs and hypothesize about how we got here and what the future might hold. Consensus on the range of diverse issues is not necessary for directing policies in a more sustainable direction.

The economist Herman Daly has provided a useful starting point by observing that:

> [f]or the management of renewable resources there are two obvious principles of sustainable development. First that harvest rates should equal [or be lower than] regeneration rates (sustained yield). Second that waste emission rates should equal [or be lower than] the natural assimilative capacities of the ecosystems into which they are emitted. Regenerative and assimilative capacities must be treated as natural capital, and failure to maintain these capacities must be treated as capital consumption, and therefore not sustainable [our interjection] (1990:2).

These two "common sense" principles for the establishment of sustainable policies differ from traditional economic indicators in that they are biogeophysically based. To make such principles operationally useful one must have data on actual stocks and flows. We suggest that when the issue at hand is sustainability, economic valuation techniques are often too decoupled from the biogeophysical world to provide us with the necessary insights. Our approach eliminates the need for developing pseudo-market values for currently nonmarketed goods. The entire issue of assigning monetary values, with its uncertainty, problems of time value, cultural variability, added cost, etc., is effectively side-stepped. Such accounts could serve as biogeochemical satellites to complement the existing monetized national income accounts.

Green accounting cannot focus on renewable resources alone. Complex trade-offs and substitutions may be consistent with sustainability. It is important to recognize that Daly's guidelines are preliminary and not absolute. They are used to illustrate the efficacy of considering a biogeophysically based approach to natural capital accounting.

Daly's notions do not convey that natural capital may be consumed and transformed into other forms that may in turn be sustainable. This may, in fact, be desirable from a development perspective. Harvesting of nonrenewables may, in certain instances, prove to be more "sustainable" than harvesting some resource sustainably. Imagine the case of using a pristine wild river to generate electricity as contrasted with creating solar cells from sand and petrochemicals. Energy from oil may provide a springboard to sustainable photoelectric electricity, while the damming of the river may irreparably destroy ecosystems and native cultures. Static or snapshot analysis is not enough either. A sustainable system should be operated so as to assure resilience against inevitable fluctuations. Determining safe and sustainable harvest levels requires much more information than inventorying natural capital accounts (stock sizes). Careful empirical modeling exercises and field studies are necessary to assess feedbacks, rates of change of stocks, critical cause and effect relationships, hazards, etc.

How to develop these satellite accounts and their associated machinery is far from clear. We believe that the focus on stocks, flows, uncertainties, and their interrelationships that lies at the core of this paper moves in the right direction, but we recognize the difficulty with making direct linkages to existing, monetized national income accounts.

The transfer model approach is designed to explicitly incorporate multiple world views and uncertainty. Accounting systems should reflect a recognition that experts differ, and that in any controversial area there are optimists and pessimists.

For example, the (current) centrist position on the long-term impact of carbon dioxide on climate and thence on agricultural output is optimistic in the sense that potential problems are believed to be addressable at the cost of a few percent of gross national product (GNP). However, some experts are less sanguine. We argue that a successful accounting system should also reflect the views of those (in this example, a minority) whose analysis suggests severe adverse impacts with high social cost.

Discussion at the National Research Council Workshop emphasized the point that all accounting systems necessarily and unavoidably reflect our perception of the world and our perspective on limits. The importance of these "value judgements" (e.g., regarding perspectives of what the future will and should be like; of the roles of technology; of how conceptual frameworks and knowledge bases will change; of how to discount the future; and of equity and the allocation of resources among different groups) becomes amplified when one is dealing with intergenerational issues. For example, the possibility of severe adverse environmental consequences from anthropogenic greenhouse gas emissions has just recently appeared on scientific and political agendas; the implications of these gases for policy has just begun to be seriously discussed.

A successful green accounting framework must be designed so as to make assumptions clear, and to allow a broad band of perspectives to be represented. Our approach, by focusing upon conceptual structures, biogeochemical indicators, and judgements about what is likely to be considered important in the future, directly addresses these considerations. We stress that this is a conceptual paper. As yet there has been only limited work on combining bio geophysical satellite accounts with transfer models and on the use of uncertainty analysis techniques in environmental accounting. Our goal is to suggest directions, and to illustrate the promise of this approach with some oversimplified schematic examples. The framework that we propose links physically based green accounts with "transfer models" to provide the meaning, context, and insight necessary to assess the health of the ultimate "golden goose"—the global life support system.

STRUCTURE OF THE PAPER

The paper is divided into seven textual sections. It also includes eleven figures and references. The core of the paper is the conceptual. Our goal is not to provide answers (a completed green accounting framework), but to correctly frame the appropriate questions, a critical prerequisite for developing successful green accounts. Because there is much controversy over the need for an approach such as ours, we spend much of the paper presenting the background.

We open with a discussion of the need for conceptual frameworks. What kinds of goals should green accounts attempt to meet. Who are the audiences and users? We next examine limitations on optimization techniques for the long-term. We then explore the reasons why goal-setting is so important in contemplating long-term environmental issues. Next we review several technical approaches to long-term issues, indicating their primary strengths and shortcomings.

We conclude with simplified examples focusing on two specific long-term issues— radioactive waste disposal, and global warming and its possible impact on agriculture. We present illustrative graphs that show how a risk analysis approach generates visual aids that can reflect not only the "centrist" conclusions, but which also allow one to understand what might be expected if alternative, less likely, perspectives turn out to be correct. We urge the reader to examine these figures, and to try to form a view as to whether his/her views on global climate change can be comfortably fitted into the framework. We also ask the reader to consider how this approach might influence their perspective on developing appropriate policy. We suggest that capturing a representative range of perspectives, with their estimated likelihood and conceivable impacts, can help us to become better decisionmakers.

WHY CONCEPTUAL FRAMEWORKS MATTER: LIMITS AND EQUITY

> [S]tories generate theories and . . . theories are transformed in the telling, the resultant combinations serving as self-fulfilling prophecies (Apter, 1993).

Environmental accounting, like more traditional national income accounting, cannot exist in a vacuum. Data develops meaning and context by placing it within a conceptual framework that incorporates at least one view of the world. Many issues facing society today qualitatively differ from those of a generation ago. Many types of environmental problems of central importance today were unknown a generation ago. It is no surprise that as new issues emerge, new accounting and evaluation techniques are needed to reflect society's changing insights and concerns. The motivation for "green accounting" emanates from the growing concern over resource degradation and depletion.

To be broadly acceptable, an improved accounting system must be able to cope with the enormous diversity of views on the adaptability of mankind and of the global ecosystem. A wide range of views exist on the feasibility, necessity, and desirability of adaption to a changing environment. The "optimist" view was clearly articulated by a Harvard economist.

> There is absolutely no reason why, on the grounds of the existence of depletable resources, that we ought to conserve for future generations. . .. It is important to remark on the fact that if they have any luck at all . . . they will be a lot richer than we are. . .. If history is any guide, the costs of the materials and energy that are produced even from depletable resources will be cheaper than they are to us in real terms. . .. There is no reason not to use the marketplace . . . there are no externalities of this type that ought to be brought to bear (Jorgenson, 1981).

While such a perspective does not preclude the development of more detailed green accounts, it certainly suggests that technological innovation makes such detailed accounting unnecessary. Investigation into the existence of impending physical limits is precluded by an hypothesis of their nonexistence. Such a view, however, might argue that improved natural capital accounts are necessary to insure that transition to substitutes occurs with minimal adjustment costs.

A slightly less optimistic view was expressed in the Brundtland Commission's Report:

> Humanity has the ability to make development sustainable—to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits—not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities (The World Commission on Environment and Development, 1987:8).

This view posits that sustainability is not a given. It still conveys a strong sense of technological optimism, but it recognizes—albeit grudgingly—the existence of physical limits. While not calling for detailed physical accounts directly, it suggests that more careful accounting will be necessary to insure that we can meet " . . . the needs of the present without compromising the ability of future generations to meet their own needs."

A considerably less optimistic view of limits was put forth in the Report of the World Conservation Strategy.

> A society that insists that all utilization of living resources be sustainable ensures that it will benefit from those resources virtually indefinitely. Unfortunately, most utilization of aquatic animals, of the wild plants and animals of the land, of forests and of grazing lands is not sustainable (UCN-UNEP- WWF, 1980: Section 4.1).

This report expresses a clear distinction between the fruits of technological innovation and those of the natural world. Sustainable resource utilization cannot result from technological innovation alone. The report represents a more direct call for improved physical accounts. It suggests that political will, along with much more careful planning and management, are needed to approach sustainability.

Herman Daly extends the discussion of environmental limits to emphasize that natural capital and man-made capital cannot be viewed as directly fungible.

> It must be clear to anyone who can see beyond paper-and-pencil operations on a neoclassical production function, that material transformed and tools of transformation are compliments, not substitutes. Do extra sawmills substitute for diminishing forests? Do more refineries substitute for depleted oil wells? Do larger nets substitute for declining fish populations? On the contrary, the productivity of sawmills, refineries, and fishing nets (man-made capital) will decline with the decline in forests, oil deposits, and fish. Natural capital as a provider of raw material and energy is complimentary to manmade capital. Natural capital as absorber of waste products is also complimentary to the man-made capital which generates those wastes (Daly, 1990: 3).

Daly's more pessimistic view of the limits of technological innovation can be seen as being in direct contrast to the optimists' view as represented by the Harvard economist, Jorgenson. Daly argues that much more than "luck" is needed to approach sustainability. By focusing upon the complementary nature of natural capital and man-made capital, Daly makes a case for separate, biogeophysically based satellite accounts.

A direct attack of the limits of technological innovation, linking concerns over sustainability directly to ethical issues, was put forth by Rajni Kothari:

> In the absence of an ethical imperative, environmentalism has been reduced to a technological fix, and as with all technological fixes, solutions are seen to lie once more in the hands of manager technocrats. Economic growth, propelled by intensive technology and fueled by an excessive exploitation of nature, was once viewed as a major factor in environmental degradation; it has suddenly been given the central role in solving the environmental crisis (Kothari, 1990:27).

Kothari goes on to argue that there are other perspectives of sustainability that are rooted in ethics, not neoclassical economy:

> Without such striving, sustainability is an empty term, because the current model of development destroys nature's wealth and hence is nonsustainable. And it is ecologically destructive *because* it is ethically vacuous—not impelled by basic values, and not anchored in concepts of rights and responsibilities. Thinking and acting ecologically is basically a matter of ethics, of respecting other beings, both human and nonhuman (Kothari, 1990:27-28).

The ethical concerns of Kothari directly link issues of distribution to sustainability. A definition of sustainable development that explicitly incorporates equity concerns has been put forth by a coalition of about 130 nongovernmental, people's and church organizations actively pursuing sustainable development programs in the Philippines. The "Green Forum" (1991) defines sustainable development as:

> [a] development course that is not prone to interruption by forces of its own creation which push environmental destruction to intolerable limits, exhaust resources, and exacerbate social inequalities to the point of disruptive political conflict.

The philosopher Arne Naess's views on sustainability call for this broader construction of the equity notion to emphasize sustaining human cultural diversity along with ecological diversity. Naess begins with the positive requirement that sustainable development "assures long-range elimination of abject poverty" (1992:307). He also expresses a symmetrical concern over the destructive aspect of excessive wealth engendered by overconsumption. He points to a distinction between "needs" and "vital needs." The Brundtland Report made no such distinction. Naess's broader construction of equity views extra parking spaces and huge estates as "needs" which may be left unsatisfied while maintenance of species diversity is more vital. Naess contends that there can be "ecological sustainability if and only if the richness and diversity of life forms are sustained" (1992:307).

Our purpose in highlighting this wide variety of views on technological innovation and the preconditions of sustainability is to illustrate how one's conception of the world influences the process of framing issues. Environmental science is a social process that entails discourse and debate along with the acquisition and analysis of data (Norgaard, 1992). In this paper we argue that a successful approach to green accounting must represent the range of views expressed above. We feel that three issues in particular should receive careful consideration:

- How do we define the "health" of ecosystems? And relatedly, how do we assess sustainable yields, develop appropriate conservation practices, support species diversity, etc.?
- What is the role of technological innovation and what are the limits of substituting human capital for natural capital?
- How does one deal with "winners" and "losers?" What happens if project proponents are socio-economically better off than the losers (who may also become culturally impoverished), and a proposed project leads to the widening of this gap?

As these questions are applied to different issues, optimists and pessimists are likely to come to very different conclusions as to what factors are relevant. We argue for an approach to analyze these issues that can capture the range of identifiable perspectives, outline "possible" best-and worse-case scenarios, and assess the likelihood of this range of possible scenarios.

GREEN ACCOUNTS

The idea of redefining national accounting systems is itself not new. In fact, conventional national accounting systems were designed to match a theoretical conception of how the economic subsystem works. National Income Accounts are an example. These derive from a conceptual framework developed by John Maynard Keynes. As Anderson states: "Many of the economic statistics collected by governments in the post-war (World War II) period have been designed essentially to produce figures to put into the equations set out in, or which have been derived from the *General Theory.*"

The section on "conceptual frameworks" illustrated how our values and perception of the world influence how we frame issues related to limits and equity. Accounting procedures naturally fare similarly. One expert in international monetary accounting put the matter this way:

> From different ways of accounting follow different ways of information distribution which, in turn, has a strong influence on the distribution of value-added between interested parties. Financial accounting thus becomes a tool in the distribution of income between social groups (Colbe, 1981:179).

As new issues emerge, it is not surprising that older structures must be revised or possibly replaced. Green accounting is properly viewed as a reexamination of the ways in which we think about our relationship to and social responsibility towards the environment and future generations. If we believe that we live in a world with fundamental limits then we need tools that allow us to examine and better understand these limits so that we may learn to live within them.

Greenhouse warming and localized air pollution are illustrative. Absent theoretical constructs (the absorption of solar radiation by atmospheric carbon dioxide), atmospheric carbon dioxide concentrations would be of only minor scientific interest. Over three decades ago when Roger Revelle suggested to Charles D. Keeling that he undertake sustained precision measurements on atmospheric CO_2, almost no one believed these measurements would be of more than minor academic interest. Today they may be among the most important measurements ever taken by earth scientists!

Conceptual focus depends on perspective as well as knowledge of feedbacks and limits. Smog and visibility reduction are major drivers of regional atmospheric analysis, which emphasize atmospheric particulates, hydrocarbons, nitrous oxides, ozone, and sulfates. Technical analyses of local air pollution show that carbon dioxide and methane play essentially no role. This conclusion is explicit in certain regulatory language, which defines hydrocarbons to exclude methane.[2] Such exclusion may be justified when the scale of focus is limited to smog and visibility within an airshed rather than the globe.

[2] Until recently this was the case with the regulations of the San Francisco Bay Area Air Quality Management District

When scientists began to investigate the possibility of adverse effects from global warming, methane assumed significance due to the ability of the methane molecule to efficiently absorb infrared radiation. Thus we have one area of atmospheric investigation (localized air pollution) where CO_2 and methane play no major role and another (greenhouse warming) where they are of major importance. Similarly, stratospheric ozone is beneficial as a limiter of ultraviolet radiation, and deleterious when in urban airsheds.

Until recently global warming was on few agendas. There was no reason whatsoever to investigate incorporating its implications in national accounts. Today, scientific and technical change has altered that situation irrevocably.

Embarking upon the path of developing green accounts requires a concern over the adequacy of existing accounts to represent situations in which both stock and flow variables are important. Emphasis on flow variables tends to favor products that wear out versus those that last a long time. "Representative" stock variables must first be identified and then accurately measured. Both stock variables (resources and savings) and the effects of consumption upon these stocks (productive capacity, regenerative capacity, and waste assimilative capacity) should be considered. Accurate methods are needed for measuring savings, consumption, degradation and reinvestment (restoration, defensive measures, and general improvement/preservation).

Green accounting efforts seek to measure, in an instrumental and anthropocentrically focused fashion, the "value" and status of the goods and services provided by the environment. They extend the range of consideration to include marketed raw materials (natural capital in the traditional interpretation), unmarketed goods, and waste assimilative services. Their purpose is to support modeling efforts and empirical investigations that may help us determine if we are living on interest or capital. If we are living upon capital, these research efforts may help us to make the transition to a more sustainable path.

An acceptable approach to green accounting should incorporate the perspectives of those who believe that "development" means much more than "economic development." It should, within the limits of feasibility, attempt to represent the full set of goods and services that we obtain from the global ecosystem. It should be designed so as to include factors valued by those advocating a multiplicity of notions of sustainability and a variety of conceptions of the notion of externalities. It must reflect the concerns of those who view themselves as being or becoming worse off along with those who see themselves as advantaged.

THE CASE FOR BIOGEOPHYSICAL GREEN ACCOUNTS

Two main issues arise when considering the development of green accounts. The first consists of data structure and organization: what entities should be measured and in what format (e.g., qualitative or quantitative units, etc.) should the data be represented? The second issue, which is intimately related to the first, concerns how the descriptive content of the data is to be employed and given context. We suggest that the data should be available in a format which makes it accessible to a wide range of analytical and modeling approaches for thinking about the future. We refer to these approaches, which give meaning, context, and insight to the data, as "transfer models." They represent "meta-models" which allow us to explore particular environmental science (economic, climatological, agricultural, air pollution, soil conservation, etc.) questions under different conditions and scenarios. Transfer models, by informing us about the effects of particular actions (or inactions), can help us to suggest prescriptive response strategies.

In this section we briefly review intergenerationally relevant aspects of several common accounting approaches. We start with existing national income accounts, which provide much of the data used by other techniques. We then look at several econometric approaches designed to internalize environmental externalities. Finally, we explore the intergenerational discount rate controversy, examine multicriteria techniques, and review biogeophysical approaches. This overview is intended to indicate the types of approaches that have been proposed for collecting and utilizing green accounts and to highlight some of their benefits and drawbacks. We conclude that monetized natural capital accounts, while necessarily derivative of disaggregated biogeophysical data, are limited in their ability to reflect physical changes in the environment. The additional step of monetization reduces data certainty, inhibits application with alternative transfer models, constrains policy insights, and results in significant added cost.

Some Difficulties with Existing Systems of National Accounts

Existing systems of national accounts (SNAs) (e.g., GNP and gross domestic product (GDP) measures) exhibit difficulties when applied to intergenerational environmental planning.[3] Four "failures" appear particularly troublesome to us:

- Failure to separate "goods" and "bads." Medical care resulting from air pollution adds to GNP as do restoration efforts, pollution control equipment, and attempts to preserve species. Similarly, highly efficient or conserving practices with many positive externalities, but a very long payback period, fail to receive adequate consideration. One can imagine a society with an ever-increasing standard of living and an ever-diminishing quality of fife.
- Failure to take account of opportunities foregone, such as the prospective value of species, or wilderness to future generations. The term "option value" was coined by economists to represent this form of valuation, but naming a concept is no substitute for finding a successful approach for including it in an analytical framework. This difficulty becomes particularly important when we consider that a market basket of goods today includes many goods that were previously nonmarketed or nonexistent one hundred years ago.
- Failure to account for goods and services provided outside the marketplace. Current examples include housekeeper services provided by a homemaker, barter, fuel-wood collection, and hunting and gathering. Nonmonetized farm work a century ago was a huge contributor to national well-being. As the structure of society has changed and the number of small farms has dropped, this factor has decreased. On generational time frames even greater shifts could occur.
- Failure to account for the value of time spent on voluntary and leisure activities. Methodologies such as "contingent valuation" attempt to deal with some of these problems, but the methodology appears extremely sensitive to the degree to which a problem is currently

[3] A list of 16 problems is compiled by Anderson (1991:21-32).

popularized. Such techniques also have difficulty with aggregation when a range of alternative projects exist.[4]

Some of these difficulties can undoubtedly be dealt with by incremental improvements to existing accounting procedures. Other problems, such as inherent theoretical inconsistencies and bounded knowledge-synthesis limitations of the economic paradigm (Norgaard, 1990), appear more fundamental. For instance, while global warming may be troublesome to coastal dwellers in temperate regions, it may be seen as a boon to those in northern Siberia.[5] Techniques that aggregate net welfare emphasize the notion of "compensating projects," which may not be appropriate in many situations involving environmental effects. In our view, the sum of the shortcomings makes us dubious of the efficacy of continuing to focus upon monetized accounts for addressing environmental problems, especially those that exist on intergenerational time scales. This is not to say that traditional economic analysis has no role. That role comes after policy goals have been established and after a range of acceptable paths, projects or policies have been identified. Traditional economic analysis is most useful for assessing which of a group of desirable choices or transition paths are most cost-effective.

In the next two sub-sections we discuss two specific difficulties associated with monetized green accounts that directly or indirectly address the four "failures" discussed above.

Intergenerational Discount Rates

Virtually all economic analysis makes use of the concept of the time value of money. From our perspective as scientists, we are dubious about the efficacy of evaluation tools that rely on the concept of the time value of money for assessing problems on multigenerational and highly ambiguous time frames.

The work of Mishan (1975:208-209) is aptly quoted by Cline (1992:239):

> Whenever intergenerational comparisons are involved . . . it is as well to recognize that there is no satisfactory way of determining social worth at different points of time. In such cases, a zero rate of time preference, though arbitrary, is probably more acceptable than the use today of existing individual's rate of time preference or of a rate of interest that would arise in a market solely for consumption loans.

[4] It is common in contingent valuation studies to conclude that people would pay large amounts for preservation of a particular amenity such as a lake or a flyway, but to also find that when one contemplates the result of an array of such studies taken together, the total implied expenditures become enormous. This is just one of many consistency problems that we suspect are intrinsic to the methodology.

[5] Even in Siberia, warming may be a mixed blessing if it is associated with decreases in precipitation or other adverse weather consequences.

Cline observes, "Taken literally, Mishan's admonition would rule out benefit-cost analysis of the greenhouse effect." His review of the literature on long-term discount rates leads to the conclusion that the "social rate of time preference," which corresponds to the intergenerational discount rate, is somewhere in the range of 1-1.5 percent per year (Cline, 1992: Chapter 6). He concludes his discussion of these matters with a clear awareness that economic analysis may, even at its best, leave out considerations of importance to the public.

> [E]conomists will do well to interpret the political reaction to alternative public initiatives as perhaps conveying information otherwise left out of the calculations. . . . Either the public is naive and sentimental and cannot make consistent calculations when it comes to the environment as opposed to other goods and services, or the public may be appropriately attaching some valuation in the environmental case that the economic analysis has failed to measure. . . . It should not be assumed automatically that the former is the case (p. 269).

Norgaard and Howarth explore intergenerational issues from the perspective of choice of intergenerational discount rates (Norgaard and Howarth, 1992; Howarth and Norgaard, 1992). Their fundamental conclusion is that distributional decisions should not be discounted, and that distributional decisions affect discount rates. Accordingly, society necessarily makes choices that impact discount rates, either implicitly or explicitly. Models that assume the same discount rate for all generations represent special cases with no particular claim to validity relative to other choices (see also Norgaard, 1991; and Howarth and Monahan, 1992).

The work of Norgaard and his collaborators provides a clear analytical demonstration that value judgments unavoidably enter into intergenerational economic analysis. The implication of these ideas for green accounting is to reinforce the idea, introduced earlier, that accounting systems must be designed so as to be congenial to many different views of the world, and that monetizing techniques should play a minor role in long-term goal setting relative to biogeophysically based approaches. Once goals are set, monetary techniques are essential aids to determining the economically efficient routes toward these goals.

Analysis Based on Single Numeraires

Most current national income accounts rely on the notion that all factors of importance can be expressed in terms of a single numeraire, usually monetary. The assumption is that a single monetized equation can be written to capture all relevant senses of value. This sum, which consists of "use value," "option value," and "existence value," is referred to as total economic value (TEV = use value + option value + existence value). A critical question for "green accounting" is whether or not to adopt this perspective. Norgaard (1990) argues that the problems that we seek to resolve through developing green accounts are entangled in the issue of monetary valuation itself. He refers to this issue as the "value-aggregation dilemma."

Our discussion of this issue focuses on the work of Pearce, Barbier, Markandya, and Turner. These scholars have been among the most effective advocates for the single numeraire point of view.

Pearce and Turner argue that all relevant multiple senses of value can be incorporated into existing economic tools:

> We have seen that the passing-on of the resource base "intact", i.e. constant natural capital stock K_N, over the next few generations is central to the concept of sustainable economic development. Such a managed growth policy, although directed primarily toward the satisfaction of human needs, would also necessarily ensure the survival of the majority of nonhuman nature and its natural inhabitants. Adequate environmental safeguards are available therefore without the need to adopt any of the radical 'deep ecology' arguments and ethics. In particular it is not necessary to have to accept the notions of intrinsic value in its widest sense, or of equal fights for all species. Our sustainability principle is general enough to encompass the environmental ethical concerns of consequentialist philosophy, as well as meeting the intergenerational equity objective (Pearce and Turner, 1990:238).

The core idea underlying Pearce and Turner's "sustainability principle" is the hypothesis that there exists in principle a scalar quantity, K_N, which completely characterizes the "natural capital stock." They argue that keeping this single numeraire constant will ensure that both human and nonhuman life will thrive. While the symbol is clear enough, the procedure for operationalization is not.

Why should it be assumed that a *single scalar* quantity for measuring natural capital stock should even exist? If it does indeed exist, then in what units, and over what time horizon should it be defined? How is one to include the functional integrity of ecosystems, species diversity, ecosystem health, the economic value of natural resources, and human quality of life in a single optimization equation?

Von Neuman and Morganstern, in their classic work, *Theory of Games and Economic Behavior* (1947), underscored the conceptual and theoretical impossibility of solving such pseudo-maximum problems:

> This [form of optimization problem in the context of a social exchange economy] is certainly no maximum problem, but a peculiar and disconcerting mixture of several conflicting maximum problems. . . . This kind of problem is nowhere dealt with in classical mathematics. We emphasize at the risk of being pedantic that this is no conditional maximum problem, no problem of the calculus of variations, of functional analysis, etc. It arises in full clarity, even in the most "elementary" situations, e.g., when all variables can assume only a finite number of values. (von Neuman and Morganstern, 1947:11).

Von Neuman and Morganstern's admonishment has not been adequately recognized. For example, one need only to refer to the frequent references discussing the desirability of policies leading to "the greatest good for the greatest number"—a clear example of "one too many 'greatests'" (Daly, 1980a:353). The popular misunderstanding motivating attempts to "solve" such pseudo-maximization problems still persists. We must re-emphasize von Neuman and

Morganstern's warning (1947:11) that "[a] guiding principle cannot be formulated by the requirement of maximizing two (or more) functions at once."

Pearce and Barbier, in another paper, adopt a more conservative stance by accepting that many natural resource functions cannot be substituted by man-made capital (Barbier et al., 1990:1260). Nevertheless, they persist in their belief that the cost-benefit analysis (CBA) should be maintained. They argue that alternative objective functions can be chosen which "extend" the CBA framework beyond economic efficiency. Turner and Pearce even argue that "moral" and "cultural" capital can be incorporated into CBA (Turner and Pearce, 1993).

A corollary effect of further theoretical, philosophical, and practical concern is this approach's dependence upon "compensating projects" to mitigate the net negative environmental effects of the collection of projects at the program level. In order to accommodate economic sustainability considerations, they modify the usual economic efficiency (positive net benefits) with an additional constraint that requires zero or negative natural capital depreciation. Pearce and his collaborators posit a "weak sustainability" criterion that aggregates in the time dimension, requiring the sum of individual damages to be zero or negative (i.e., the present value of the sum of environmental damages is constrained to be nonpositive). A "strong sustainability" criterion is also proposed. It constrains the sum of environmental damages to be nonpositive for *each* time period. Thus, rather than achieve global sustainability through extension, by requiring local sustainability, Pearce and his collaborators attempt to integrate sustainability considerations into the CBA through the concept of shadow or environmentally compensating projects (Barbier, et. al., 1990: 1260-1261). This approach, however, still allows whole ecosystems and human cultures to be annihilated as long as the net "natural capital stock" is maintained.

This body of work is still largely conceptual. It remains to be seen whether it can be operationalized in a manner that will find broad acceptance. Nevertheless, we must assert that analytical approaches that presume the existence of compensating projects, when the fungibility between environmental goods and services and man-made capital is largely unknown (and may remain largely unknown), rest upon a shaky footing.

Biogeophysical and Energy-Related Approaches

Many ideas for modifying traditional accounting procedures to better include environmental considerations have been proposed. Some of these are based on modifications of economic accounting techniques (e.g., Cobb, 1989; Ahmad et al. 1989; Anderson, 1991). Other approaches focus on physical accounting, especially energy (IFIAS, 1975; Hannon, 1982; Slesser, 1978).

Pearce et al. (1989) discuss several approaches to revised national income accounts including the French and Norwegian physically based accounts, the monetized Japanese Net National Income approach, and the Indonesian Sustainable Income approach. It is important to realize that any monetized approach is necessarily derivative of disaggregated biogeophysical accounts, which are then monetized at a later time. We emphasize again, because of this fact and because other modeling efforts require nonmonetized data, that revised accounts should be based upon disaggregated, biogeophysically based data. Additional arguments for maintaining biogeophysically based accounts include: information loss, explicit incorporation of uncertainty, difficulties in performing sensitivity analyses, and costs associated with monetizing such data (Hufschmidt, 1983). Most significantly, by inhibiting the application of alternative transfer models, monetized accounts substantially constrain the range of possible policy insights.

An Alternative Transfer Model: Multicriteria Techniques

Approaches for analyzing green accounts that both take von Neuman and Morganstern's admonition to heart and are capable of considering multiple goals, measured with a variety of incommensurable units, already exist. The term "multiple criteria" or "multicriteria decisionmaking" (MCDM) has been given to a general collection of approaches for making decisions in the presence of multiple and often conflicting criteria. A characteristic of these techniques is that there is an effort to recognize explicitly that social decisionmaking has multiple goals, and that attempts to measure all of them using a single scalar are doomed to failure.

A major element of multicriteria approaches is that they aim to capture all relevant foreseeable impacts in their most appropriate and representative units. This is done to accurately reflect and assess the existence of tradeoffs. Multicriteria approaches are characterized by their attempts to systematically structure the various elements of the decision process in a manner that is flexible, clear to the decisionmaker and adaptive to changing circumstances (Nijkamp, 1985). These ideas, we believe, must lie at the foundation of all green accounting.

Four terms—attributes, objectives, goals and criteria—frequently appear in the literature on multicriteria decisionmaking. While there is no clear consensus on their definitions and some overlap exists, it is helpful to both make some distinctions between the terms and use them consistently. We believe that a deeper understanding of these terms can facilitate the conceptual development of green accounts. Our usage incorporates notions from Hwang (1981) and Zeleny (1982).

Attributes: Attributes are descriptive performance parameters and properties of alternatives. Each alternative can be characterized by a set of attributes. While attributes cannot be separated from decisionmakers' values and model of reality, they can be characterized and measured in relative independence from particular decisionmakers' preferences. For example, some attributes currently under consideration for defining sustainable forestry practices include: soil fertility, erosion hazard rating, watershed quality, tree basal area, diameter at breast height, ease of harvest, species diversity, age diversity, fire-hazard potential, etc.

Objectives: After attributes have been characterized and measured, decisionmakers must decide which attributes are desirable to "maximize" or "minimize." When particular desirable values are not (or cannot be) specified in advance and the aim of evaluation is to maximize or minimize (optimize), the most desirable levels of achievement are characterized by objectives. Objectives represent decisionmakers' normative preferences. By incorporating these preferences, by being assigned a particular direction of desirable improvement, attributes are transformed into objectives. For example, a utility company may be concerned with several objectives. It may want to maximize net energy efficiency, minimize pollutant emissions, and minimize production cost. High-level, aggregated objectives, such as "least-cost energy production" and "maximization of environmental improvement" may need to incorporate several attributes and several lower-level sub-objectives.

Goals: Goals represent particular desirable performance values or levels of achievement (targets) that decisionmakers supply in advance of the evaluation process. They are defined in terms of specific attribute values or objectives. Goals are to be achieved, surpassed or not exceeded. They are often referred to as constraints because they serve to limit or restrict an alternative set. Automotive fuel efficiency (CAFE) standards and pollution emissions restrictions represent goals for industry.

Criteria: Criteria represent general measures, rules and standards that help to guide the decisionmaking process. They represent the basis for evaluating alternatives. All three categories, attributes, objectives and goals, can serve as relevant criteria for an actual decision process.

Multiple criteria techniques are divided into two substantial categories: those that are suitable for discrete choice problems and those that address continuous problems. A wide range of solution techniques have been formulated to address each category.

Multiple objective decisionmaking (MODM) is associated with problems where the alternatives are not predetermined or prespecified. An example would be determining the appropriate amount of carbon to be emitted to the atmosphere in various years, subject to competing demand, environmental, population, and cost constraints. The problem is one of continuous evaluation because particular scenarios have not been specified. Extensive discussions of solution techniques appear in Cohon, 1978; Hwang and Masud, 1979; and Goicoechea, 1982).

Multiple attribute decisionmaking (MADM) is distinguished by the existence of a countable small number of predetermined alternatives. An example would be selecting from an array of specific technologies (e.g., solar thermal, photovoltaic, pressurized water reactors, intrinsically safe reactors, fusion reactors). The decision problem involves selecting, prioritizing, or ranking the alternatives in a manner that "best" satisfies a range of objectives. Extensive discussions of solution techniques appear in MacCrimmon, 1968, 1973; Rietveld, 1980; Hwang, 1981; Voogd, 1983; Nijkamp, 1990; and Chen, 1992.

Multicriteria techniques have been applied to a wide variety of urban and regional planning problems, including land reclamation (Nijkamp, 1974), evaluation of forest road investment projects (Gomes, 1975), analysis of airport location issues (Palinck, 1977), evaluation of landscape plan alternatives (Xiang et al., 1987), and evaluation of urban transportation system alternatives (Gomes, 1989), to name a just a few of the myriad of applications. While further development and application is needed, this approach holds great promise for quantitative and qualitative analyses of sustainability considerations.

EXAMPLES OF ALTERNATIVE TRANSFER MODELS: RADIOACTIVE WASTE AND GREENHOUSE WARMING

Radioactive waste disposal and greenhouse warming both operate on and must be analyzed using intergenerational time scales. We treat the first example, radioactive waste, descriptively. The second example, the impact of anthropogenic carbon dioxide on agriculture, is used to illustrate explicitly the "transfer model" concept which we believe has much promise as an integrative tool for reflecting divergent points of view and uncertainties in data.

Radioactive Waste

While controversy over specifics remains intense, there is broad consensus that storage techniques for radioactive waste can only be considered acceptable if they hold the promise for sequestration over time spans of millennia. US-EPA guidelines for high-level radioactive waste storage must "meet radioactive release limits . . . that would result in less than 1000 deaths in 10,000 years" (NRC, 1990). This is one area where the public perceives a real risk to future generations and is willing to invest heavily in remedial measures. The discussion is couched in terms of social goals and human health, and most particularly in terms of a desire to leave an inhabitable world for our descendants.

Operationalizing the 10,000-year goal has proven difficult. Public opposition to specific proposals has been relentless. Credibility of institutions grappling with the problem is low (Slovic, 1990; 1991). Expenditures for planning and analysis continue to be enormous.

In an increasingly diverse society, issues relating to trust in institutions loom increasingly large. Methodologies for valuing the environment should be sensitive to the existence of a multiplicity of value systems. A review of public confidence in radioactive waste management by a Department of Energy (DOE) Committee emphasized the centrality of trust to the policy process (DOE Energy Advisory Board, 1992:9):

> In the realm of radioactive waste management problem-solving, public trust and confidence is especially salient because of the high degree of technical expertise required for understanding, participation, and sound decisionmaking. In validating alternatives, there must be trust that uncertainties are resolved in an unbiased fashion. . . . IT]here must be trust that the full range of values and alternatives has been taken into consideration and that the interests of all have been recognized even if they are not accommodated.

Policy suggestions relevant to global climate change appear in the NRC report "Rethinking High-Level Radioactive Waste Disposal" (NRC, 1990). These suggestions make the point that while it may be possible to recognize a serious long-term problem, it may not be possible to make detailed plans for addressing it. Rather, it is better to try to identify worst case outcomes and design to minimize the chance that they will occur, while simultaneously recognizing that even the very best of plans will need modification as experience is gained. The NRC report made these points:

- Realize that surprises are bound to occur (planners must "expect the unexpected").
- Pursue an empirical exploratory approach: one that emphasizes fairness in the process while seeking outcomes that the affected populations judge to be equitable in the light of their own values.

- Start with the simplest description of what is known, so that the largest and most significant uncertainties can be identified early.
- Meet problems as they emerge, instead of trying to anticipate in advance all the complexities.
- Define the goal broadly in ultimate performance terms, rather than immediate requirements.

These guidelines place emphasis on careful attention to obtaining all relevant information, and then using judgment to form policy. A wide variety of indicators are involved, many of which must necessarily be weighed judgmentally, not by formula. Because of the complexity of the phenomena, the "simplest description of what is known" tends to be quite complex, as well as full of lacunae.

What might one ask of a "green accounting" system that would provide insight into the implications of radioactive waste systems? Estimates of containment and leakage involve technological and geological extrapolations into regions where, in many cases, information is limited. Costs of control technologies have a long history of underestimation. Uncertainties about time frames for construction as well as time frames and probabilities for leaks to the environment make it difficult to estimate future costs, and make use of economic discounting techniques extraordinarily problematic. In practice, the public debate over nuclear waste has largely been framed in terms of perceived risk and confidence rather than economic benefit-cost analysis.

Radioactive waste management thus provides a major challenge to any new accounting methodology. Most technical analysis appears to show that the probability of truly disastrous accidents is small in all time frames. On the other hand, worst-case analysis gives rise to enormous social impacts. Public concern focuses on worst-case analysis, and public perception is strongly influenced by many examples of false assurance by both government and industry in the U.S. as exemplified by Hanford, Rocky Flats, and Three Mile Island, and by Chernobyl and Chelyabinsk in the Former Soviet Union. An accounting methodology that looks only at center line expert opinion will be no more credible than one that focuses on worst cases.

This overview provides convincing (to us) evidence that any green accounting system for radioactive waste that uses either single numeraires (point estimates) or monetary measures alone has no possibility of wide acceptance. Approaches more likely to win acceptance will emphasize probabilistic statements of a variety of outcomes, and will be structured so that the views of all major involved groups are accurately reflected in the spectrum. Accomplishing this goal will not be easy. We illustrate one way to proceed by presenting an illustrative, risk-based transfer model focusing on the impact on agricultural output of global warming.

Global Warming

Greenhouse warming is the most discussed aspect of long-term global climate change. "Greenhouse," in this context, refers to the prospect of global warming driven by substances introduced into the atmosphere by human activities. Greenhouse warming itself is not scientifically controversial. Absent radiation trapping, the average temperature at the earth's surface would be about 250K rather than the actual 290K, and far too cold for life as we know it. Anthropogenic carbon dioxide, chlorofluorocarbons, and other greenhouse gases may be producing rapid warming with potentially serious consequences for virtually all life forms.

Typical current projections are for a rise in global temperature of from about 1°C to as much as 5°C within the next century. This is a rate of change far greater than has been seen historically. Figure 5-1 shows historical data, and several forecasts of what the next century might hold in store (Organization for Economic Cooperation and Development (OECD), 1991).

Whether such warming is occurring is not as yet proven. Correlations between carbon dioxide and global average temperature in this century are not especially striking. There is general agreement that about one degree Centigrade warming has occurred in the post-industrial revolution period. However, some data contradicts this—for example, tree ring results from South America (Lara and Villalba, 1993). Anticipated effects of anthropogenic gases on climate include large geographical variations, increased fluctuations of all sorts, and shifts in rainfall.

Major analyses have been conducted by many groups, including the U. S. Office of Technology Assessment (OTA, 1991), the Intergovernmental Panel On Climate Change (IPCC, 1991); the NAS (NAS, 1991); and the Dutch Government (Krause, 1988; 1989). A variety of perspectives may be found in Singer (1989). "Integrated Assessments" and models are among the analytical approaches in use (Dowlatabadi and Morgan, 1993; Rotmans, 1990). Methodological issues of the risk assessment approach may be found in Morgan and Henrion (1990). Qualifications to the risk assessment methodology (primarily in the context of near-term issues) are discussed generically in Shrader-Frechette (1991) and Hornstein (1992). A practitioner's perspective is given by Lash (1992). The U.S. government has set up a Carbon Dioxide Information Center (ORNL, 1991), which is one of dozens of relevant databases that will serve as the source for the information to be used in new accounting systems.

Dramatic as some predictions of adverse effects are, it is important to remember that they depend extensively on a worldwide database and large-scale computer models, both of which have severe limitations.

It is also useful to recognize that the scientific community has been anything but consistent in its collective attitude toward anthropogenic climate change. One of the discoverers of greenhouse warming, S. Arrhenius (SCEP, 1970), reportedly hoped the effect would make his native Sweden warmer and more comfortable. As recently as 1977 the meteorologist Reid Bryson prefaced a book "Climates of Hunger" as follows:

> In 1973 an international group of scientists wrote to the President of the United States about a matter of grave concern. They were specialists in the history of ice ages, and they could see from the rhythm of past ice ages the possibility of another ice age within centuries, and almost positively within a few millennia (Bryson and Murray, 1977: ix).

At about this time careful work to explore global warming was beginning with the SMIC and SCEP studies pioneered by Carroll Wilson (SCEP, 1970; SMIC, 1971). These opened the modem era of climate study.

Today, interest in ice ages has virtually vanished (e.g., California Energy Commission, 1989), yet the memory of the scientific community changing its mind persists. As understanding of the effects of the proposed greenhouse warming increases, we can expect that, due to unanticipated effects, revisions in both directions will occur. Indeed, recent estimates show that

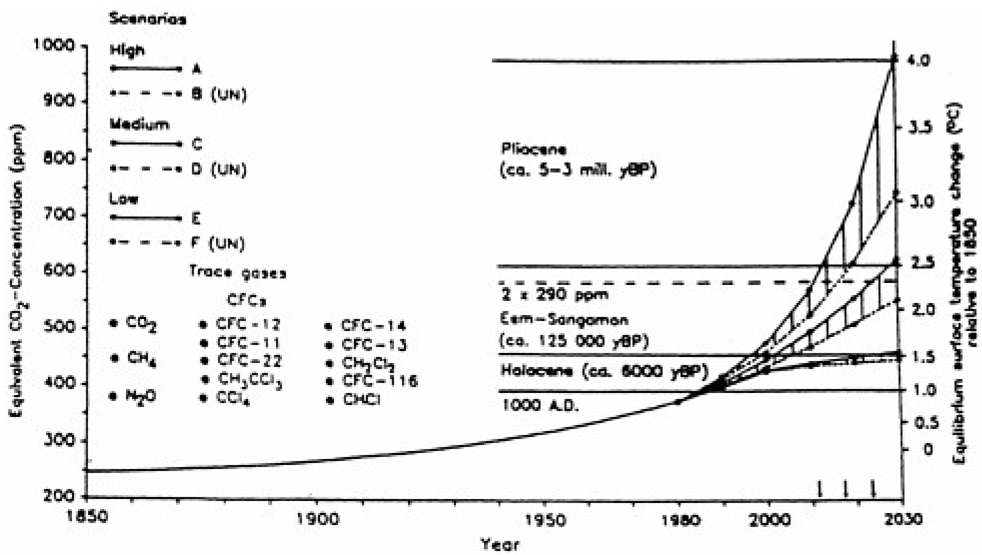

FIGURE 5-1 Estimates of the possible impact of anthropogenic carbon on globally averaged temperature. SOURCE: Krause, 1988.

sulfate aerosols may cool, biosphere CO_2 uptake may increase as CO_2 levels increase, and ozone depletion may decrease radiation forcing (IPCC, 1992).

Greenhouse warming may well be a major threat to our society. The "Precautionary Principle" suggests that the mere possibility of its existence should motivate us to reconsider those actions which may be exacerbating such a phenomena. We ourselves believe that the weight of scientific evidence and the fact that cost-effective responses exist are sufficient to warrant placing the matter high on our social agenda. It is important, however, to recognize that the uncertainties remain great, and that there remain individuals of stature—though ever fewer of them—who argue that the evidence is not yet compelling. This view, in fact, was at the core of the Bush Administration global climate change policy agenda. Their "no regrets" strategy was based on the idea that the nation should make no investments in mitigation that might later on turn out to have been unnecessary.

"No regrets" policies stand in contrast to "insurance policy" strategies, known in this context as the "Precautionary Principle." Emphasis is placed on taking those precautions that make sense today, in anticipation of change in the future. Thus, for example, it is now policy in the Netherlands to build new off-shore oil drilling rigs and new dikes about 1 meter higher than previously planned just in case sea-level rise occurs. The argument is that it costs little to add one meter in new construction, but would cost far more to modify an existing structure later, should the need arise.

Human activities are certainly producing increases in atmospheric carbon and other anthropogenic gases. Changes in the global ozone system are being driven by anthropogenic chlorofluorocarbons. Yet experimental observation of effects on ecosystems due to increases in greenhouse gases is as yet problematic. There is consensus within the global scientific community on a significant possibility that warming of several degrees Centigrade could occur within the next century. However, the magnitude of the effect must be estimated using large-scale models, and there remains great concern as to the validity of these models, both in forecasting average temperature responses and, especially, in forecasting regional responses. Understanding of fluctuation phenomena, including weather of all types, which is likely to be of immense importance to biological systems, is at a far more rudimentary level.

Response of biological systems (including both natural ecosystems and human agricultural systems) to temperature change and to weather fluctuations is poorly understood. We find no consensus, except that responses might turn out to be large and nonlinear, and that systems with long internal response times are likely to be particularly vulnerable. Forests are probably the most important case in point. Forests grow slowly, and a change of a few degrees over a century could lead to die-out in some regions and inadequate time for new growth in others. They could either contribute to stabilization, or amplify threats of global warming (Rosenfeld and Botkin, 1989), with the possibility of catastrophic collapse.

One consideration that makes plausible inclusion of "collapse" possibilities in global climate change analysis is that we have evidence for such effects in the past. Examples include the Mayans and Incas in Central and South America; cities in the cradle of civilization such as Petra, Baalbek, Persepolis; and the American desert culture of the Anasazi. In every case there is debate about the origins of the collapse, but overextension of the agricultural base is invariably one of the most discussed possibilities, sometimes driven or abetted by extended periods of drought (Carter and Dale, 1974). Developing nations are especially vulnerable.

Cohesion within the international scientific community is clearest in the reports and deliberations of the newly formed Intergovernmental Panel on Climate Change (IPCC, 1992). Scientific members of the IPCC axe close to and trusted by their governments, and their concerns are reflected in governmental attitudes. There is also a great deal of nongovernmental interest in global climate change, which also contributes to driving the policy process.

Thus far there is rather little policy in place relating directly to global climate change. The Montreal Protocol, an international agreement that is leading to the phasing out of one set of anthropogenic greenhouse gas, chlorofluorocarbons (CFCs), is one example.

Econometric Approaches for Examining the Impacts of Global Climate Change

Several efforts have been made to use econometric tools to examine the impact of global warming. The work of Cline (1992), Nordhaus (1991), and OECD (1992) is particularly interesting. Cline and Nordhaus seek to estimate the economic impact of doubling of greenhouse gases. The two studies have been compared by Howarth and Monahan (1992), who have summarized the assumptions and have made some corrections in order to place them on comparable footing. The key results are that Cline's annual cost to the U.S. of a doubling of greenhouse gases is estimated as 1.25 percent of 1981 income, while Nordhaus' estimate is 0.26 percent of 1981 income.

An OECD study (1992) finds the estimated annual damage from global warming to the U.Ss economy to be \$61.6 billion (1990 dollars) for a doubling of CO_2 leading to 2.5°C temperature increase, and \$338.6 billion (1990 dollars) for long-term warming of 10°C.

These annual costs of global warming are relatively small percentages of GNP. The uncertainty in growth rate of total GNP is far greater. Accordingly, given the discussions of the prospect of ecological or biological collapse it is not surprising that these results are sometimes described, especially by Cassandras, as missing the point. Given the uncertainties, they are consistent with no adverse effect upon economic growth.

From an ecological perspective, any work that leads to a primary conclusion that greenhouse warming a century hence is probably only a few percent of GNP seems problematic. The issue is basically one of how one analyzes uncertainty and risk. It may well be that the current "best" estimate of loss is modest. If, however, there is a significant chance that actual losses will be much greater then there axe very different policy implications. At issue is whether society wants to make its planning decisions on the basis of averages, worst-case analysis, or other planning rules. We argue that, to be acceptable, accounting systems must support the acknowledgement of both optimistic and pessimistic minority positions.

An Alternative Transfer Model Approach for Examining the Agricultural Impacts of Global Climate Change

We illustrate our concept of transfer models using a highly simplified conceptual example. We consider just three categories: greenhouse gas emissions due to carbon dioxide, warming and fluctuations due to these emissions, and response of the agricultural system to warming.

We focus on the agricultural sector since a major problem in that sector would be critical to every society. It is important to recognize that in industrial nations, the economic contribution of on-farm activities to total GNP is quite small. Since food is critical to any society, it is clear that if global warming has severe adverse impacts on this sector, then there would be major repercussions throughout the society. Green accounts should be sensitive to this issue.

In practice, many more categories would be required to adequately represent the level of complexity and range of feedbacks involved. The task of determining how many categories are necessary, and how to keep the number of categories from growing too large to be manageable remains an issue for research.

The links we consider are:

Carbon input **= > temperature and temperature fluctuations**

= > agricultural and ecological system impacts

- **a)** **Greenhouse gas emission**s. A proper accounting scheme should include all substances that might contribute significantly to the greenhouse effect. We consider carbon as a surrogate quantity.
- **b)** **Warming**. A proper accounting scheme will include the differential impact of various substances, the local climatic impacts, and fluctuation phenomena (which some believe may prove far more important than shifts in means). We aggregate to a single functional relationship between greenhouse gases and global temperature.
- **c)** **Agricultural and ecological impacts**. The impacts of warming and temperature fluctuations can affect many aspects of society. We restrict discussion to one impact—the globally averaged impact on agricultural output. Detailed accounting will require geographic disaggregation.

These three elements form a causal sequence (with feedback). Examination of feedbacks is, however, not our goal. We are interested in providing an example that explicitly includes multiple perspectives and uncertainty. The methodology has the capability to include a multitude of expert views, integrated via statements about the statistical properties of the views of experts.

Carbon emissions are believed to be causally related to global temperature. Specification of this relationship in detail requires large-scale models. For simplicity we let average global temperature vary linearly with delayed cumulative global carbon input. More realistic delay mechanisms could be included. A practical version of the methodology might use expert judgment to provide estimates of temperature as a function of both time and greenhouse gas input, using a particular model of analysis.

Agricultural output is assumed to decrease logistically with global temperature increase. Parameters depend on temperature, temperature fluctuations, technological optimism (e.g., about bioengineering), etc. The relation between anthropogenic global climate change (warming and temperature fluctuations) and agricultural output has been studied only very little, so this part of the transfer model is likely to be the most uncertain (e.g., Knox and Scheuring, 1991). On the other hand, if anthropogenic gases do impact agriculture significantly, this part of the model could well be determinative. The model we use here is discussed in more detail in the appendix at the end of the paper (p. 107).

Figure 5-2 shows an illustrative baseline growth in human carbon production. Figure 5-3 shows the baseline illustration of temperature increase and the baseline agricultural output decline due to temperature increase.

At this stage probabilities are introduced. Experts (and others) contribute opinions on parameters that drive the system responses. These views are assembled into probability distributions. The implications of the probability distributions are propagated through the model so as to provide a clear picture of how much consensus exists, and of how lack of consensus in one area impacts other areas.

Expert opinions are only loosely related to probability. Surprises occur. With time and new information expert views will change. The process is, in essence, collecting Bayseian priors. New information and concepts can lead either to changes in the probability distributions (maintaining the structure of the system fixed) or to changes in system structure.

For illustrative purposes we include uncertainty as follows. Growth of carbon (and other greenhouse gases) is assumed to follow an exponential path. The coefficient of the exponent in the base case, is distributed by a normal probability distribution. The relation between carbon emissions (a surrogate for all greenhouse gases) and temperature is also distributed normally. Finally, the parameter in the logistic function is normally distributed.[6]

Figures 5-4 through 5-6 (for carbon, temperature, and agricultural output) illustrate the spreads of values obtained when probability distributions are introduced. The means are required to be identical to those in Figures 5-2 and 5-3. The bands show the 10 percent and 90 percent probability zones.

A primary goal of the approach is to allow ready discussion of the implications of different views of the causal relation between atmospheric carbon and its impact on the biosphere. A good way to make the implications clear is to look at the probability distributions for a particular year. Figure 5-7 shows the distribution of temperature in year 2085. The "raggedness" of the data results from the sampling procedure.

The example shows how statistical distributions give rise to a most likely shift of 3°C (as it must), a significant chance of 2°C and 4°C shifts, and a very small probability of a shift of 6°C. Figure 5-8 shows the distribution of agricultural productivity in 2085.

Risk and Uncertainty Made Explicit

The relation between cumulative global carbon and temperature is controversial. Suppose there are two theoretical constructs leading to two rather different relationships. Does this

[6] We used "@Risk" from Palisade Corporation (1992).

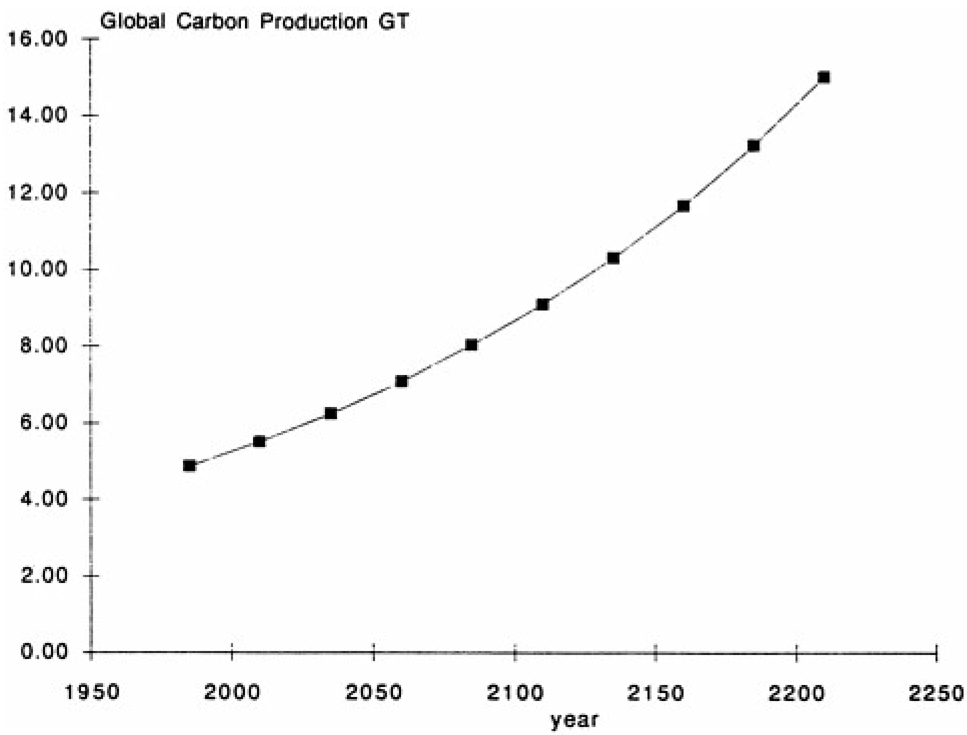

FIGURE 5-2 One scenario for the future growth of anthropogenic atmospheric carbon.

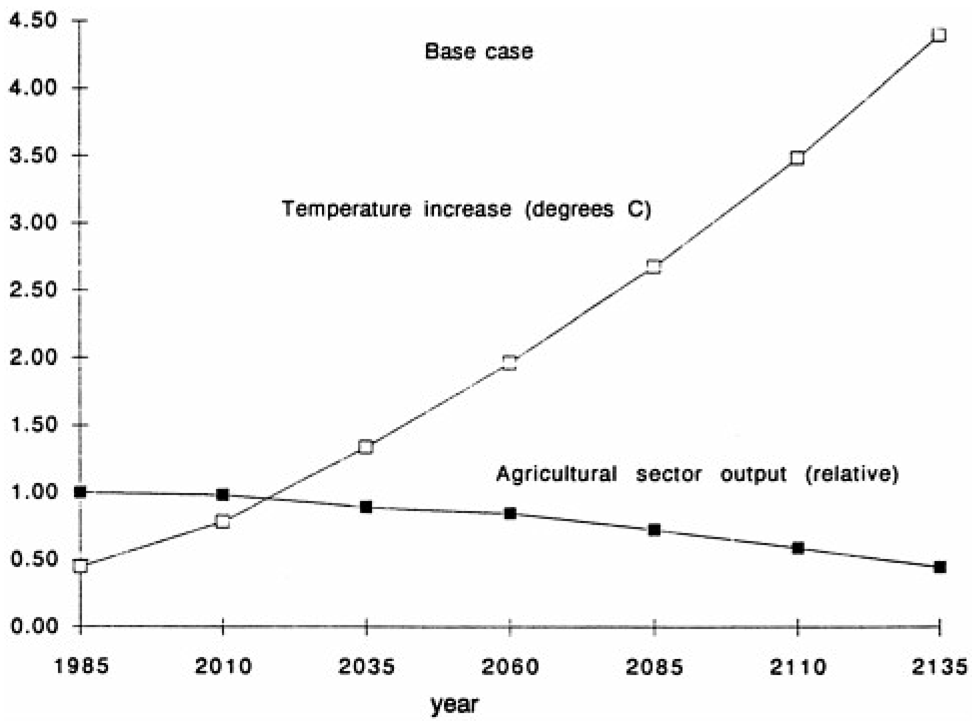

FIGURE 5-3 Possible impact of anthropogenic carbon on globally averaged temperature and on agriculture.

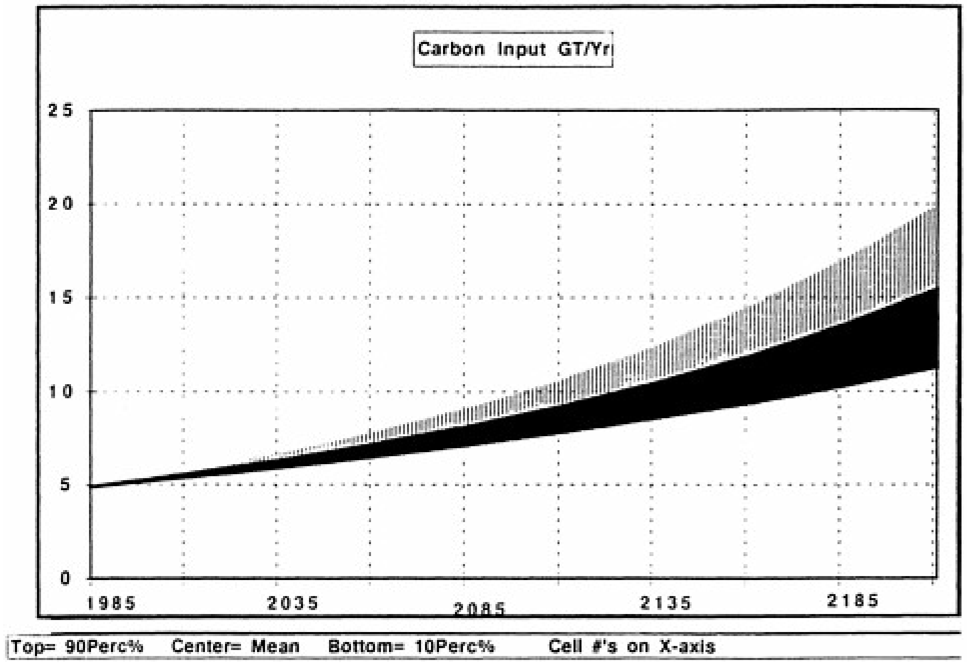

FIGURE 5-4 Inclusion of uncertainty changes the point calculations in Figure 5-2 to uncertainty bands.

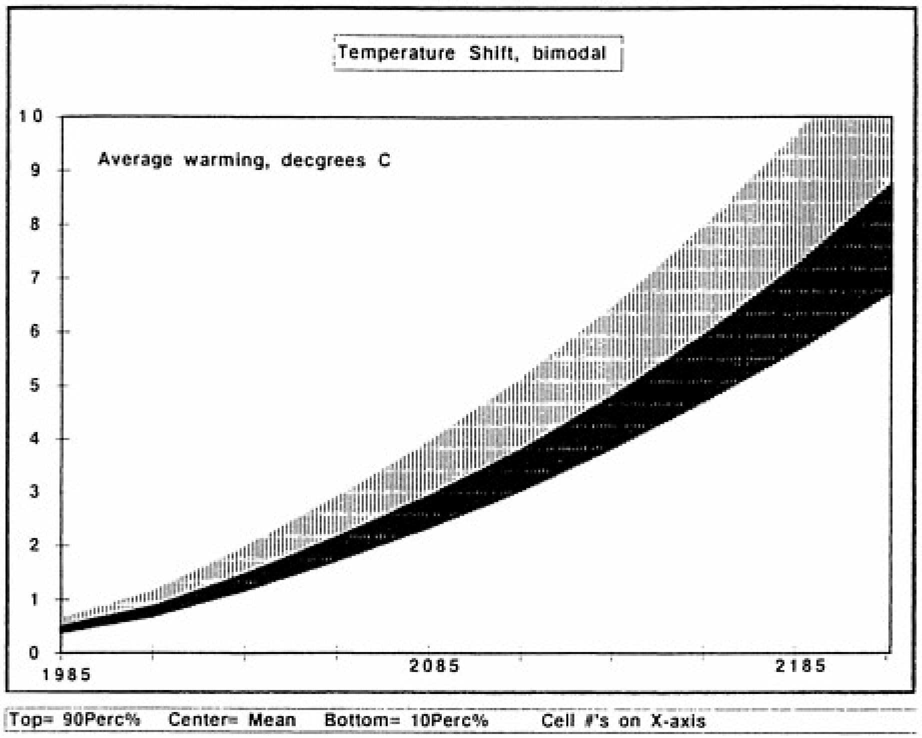

FIGURE 5-5 Inclusion of uncertainty changes the point calculations in Figure 5-3 to uncertainty bands.

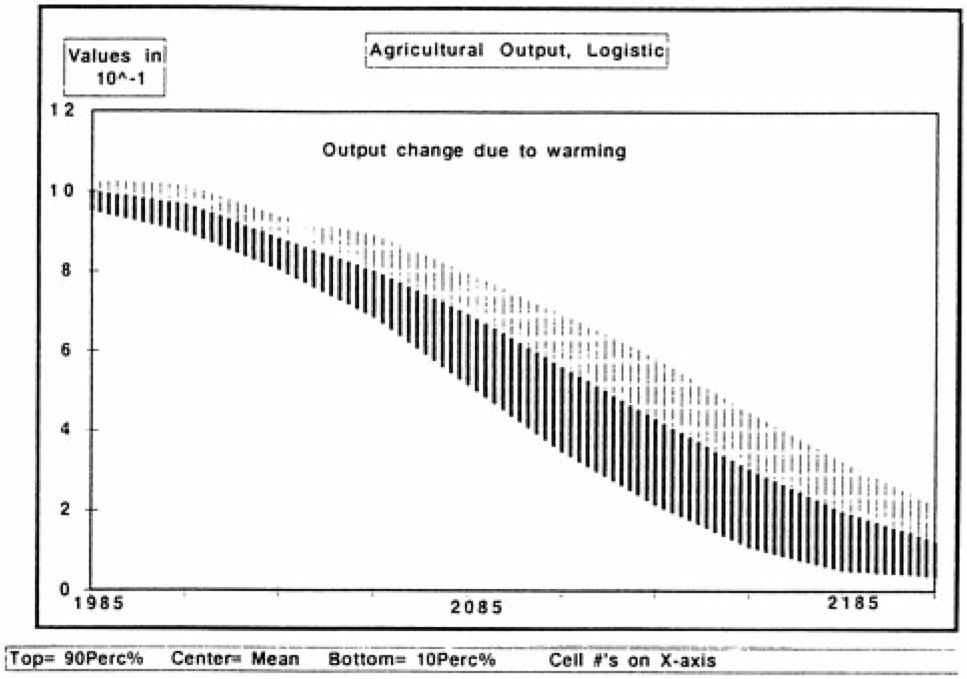

FIGURE 5-6 Inclusion of uncertainty changes the point calculations in Figure 5-3 to uncertainty bands.

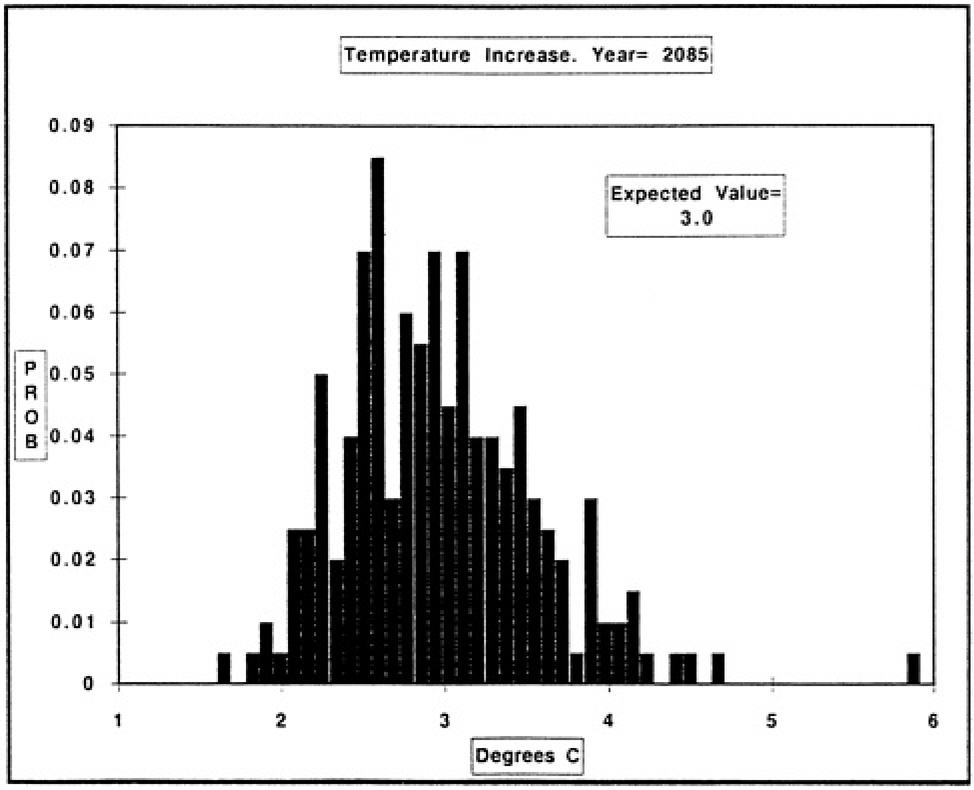

FIGURE 5-7 Uncertainty leads to a probability distribution of temperature in 2085. Normal probability distributions are used (see text). Five hundred simulations were run using the Latin Hypercube technique.

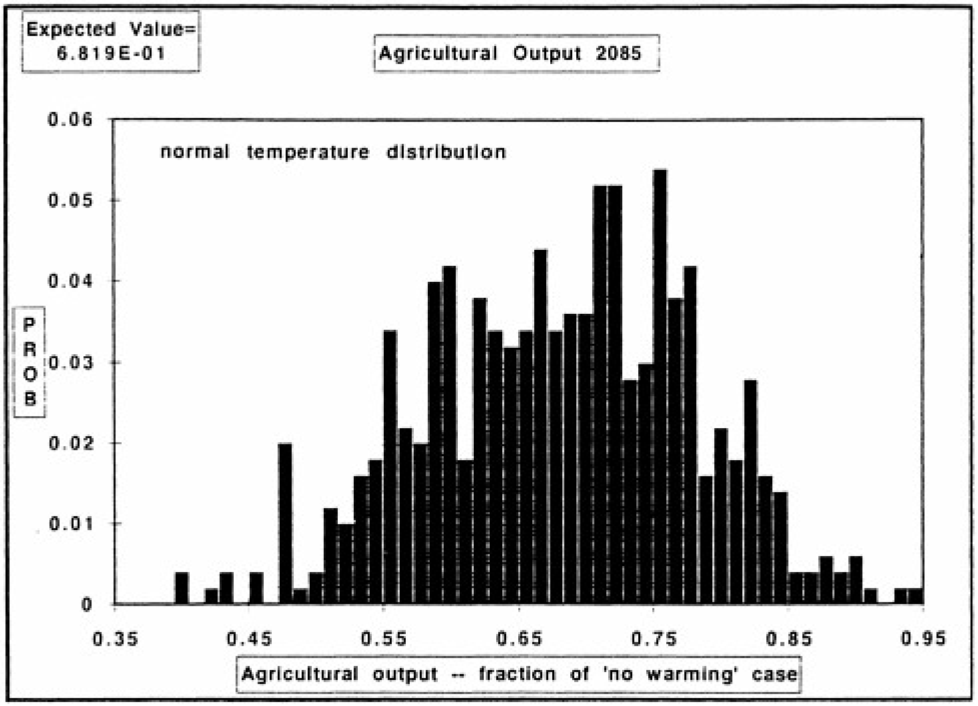

FIGURE 5-8 Probability distribution of agricultural output in 2085. Normal distribution for relation of greenhouse gases to warming.

matter? In this example the focus is the impact on agriculture, which also entails uncertainty. We describe disagreement among experts by using two normal probability distributions. One of these leads to a most likely temperature increase of 2.5°C in the year 2085, the other to a most likely increase of 4°C in 2085. The two distributions are weighted at 80 percent and 20 percent respectively, so the most likely warming in 2085 remains 3°C. When this probability is folded with the distribution on greenhouse gas emissions, the result for 2085 is bimodal but blurred (Figure 5-9).

However, when one examines the agricultural output (Figure 5-10), the bimodal temperature distribution is no longer visible. Instead, one finds an asymmetrical agricultural output distribution peaking a bit at about 72 percent of the base output, with an expected value of 68 percent of the base, and with a significant probability of only 45 percent of base case output. The uncertainties among experts in relating warming to temperature are large enough that they barely affect the final estimates of agricultural output.

This is an example of how a probabilistic approach can help focus discussion on where better information may make a difference, and where improved data may be necessary. Such analysis can help focus research programs on areas where acquisition of new or improved data matters most. Most important, the probabilistic aspects of this particular transfer model approach provide a way to explore implications of minority views, to examine the sensitivity of certain planning paths to different assumptions, and to include the concerns of optimists, pessimists, and the range in between.

DIRECTIONS

We argued that green accounting for the long-term is inextricably intertwined with goal setting and social values. Our images of desirable futures serve as the basis for such goal setting. These images must be explored, scrutinized, and discussed. Carefully constructed green accounts have the potential of helping us to analyze a selection of feasible transition paths for realizing desirable future states.

There are many views of the future. To some, technological ingenuity and "progress" will provide future generations with undreamed of opportunities and few adverse side effects. This is the optimists' view. To others, the pessimists, our generation is depleting irreplaceable resources. We are impoverishing our descendants and the rest of the world's inhabitants. Such differences in world view, while unlikely to be resolved, can be discussed beneficially. A green accounting system must be capable of representing the views of optimists, pessimists, and the wide range in between. It should also take into account the possibility that if technological optimists turn out to be wrong we may be left with an impoverished world. One of the main goals of green accounting should be to help us reduce the likelihood of realizing such an undesirable scenario.

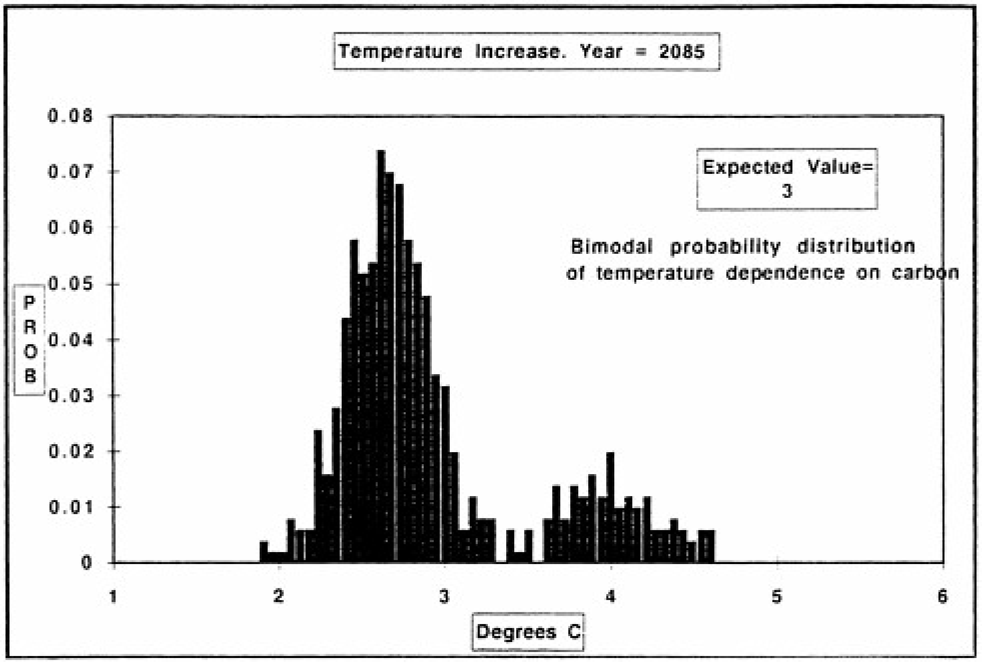

FIGURE 5-9 Temperature distribution when experts disagree. Two normal distributions are used, resulting from differing views of the impact of anthropocentric atmospheric gases on temperature.

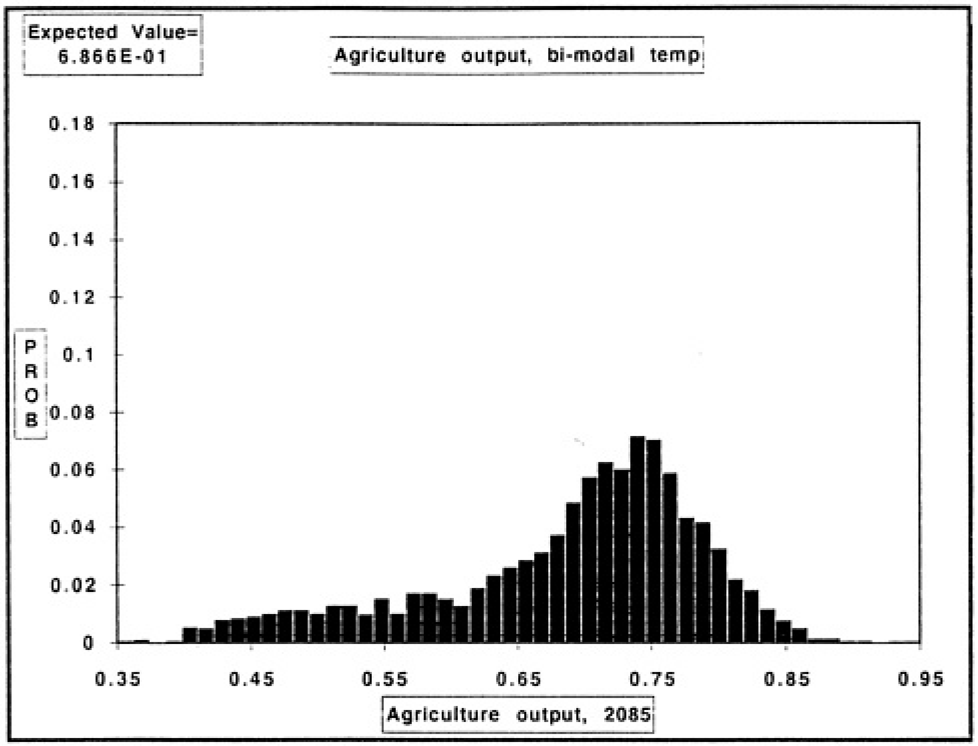

FIGURE 5-10 Probability distribution of agricultural output in 2085 using the bimodal temperature distribution. The uncertainty in the impact of temperature on agriculture is so large that the differing views of experts on temperature washed out.

These considerations lead to several general observations:

- The structure of existing accounting systems contains biases. Among the most important of these are biases in favor of quantities that enter into commerce, in favor of flow quantities, and against stocks.
- Innovation has created "resources" where none previously existed, but has also lead to new types of side effects. Improved procedures are needed for anticipating side effects, especially those which may be uncertain in character and delayed in time.
- The concept of limits is not made explicit in most prevailing accounting systems. Limits may be reached so rapidly that there is inadequate time to develop alternatives. In addition, the mere fact of approaching limits may result in bifurcations and irreversibilities (e.g., indirect species extinction resulting from loss of critical habitat).

These broad principles lead to a general recommendation which is in the spirit of Ann Harrison's final recommendation presented at a UNEP-World Bank Symposium (Harrison, 1989):

> Accounting systems should be structured so that they "show for all capital—man-made, natural and human—the ratio of stock at the end of the period to that at the beginning."

This broad guideline is open and flexible, but implementing it is difficult. We make several observations directed towards facilitating implementation:

- Many kinds of measurement units should be included in a green accounting system. When long-range and multicriteria problems are involved, biogeophysical and equity indicators must figure prominently. Econometric techniques become most important after goals have been set and near-term policy decisions are required.
- Green accounting systems should be fashioned so that very different types of indicators, with different spatial and temporal scales, can be constructed. Some of these will be highly aggregated; others will focus on highly specialized questions (e.g., the number and health of particular species in a given region).
- Uncertainty is intrinsic and must be made explicit. Approaches for analyzing green accounts must admit minority views, thereby recognizing that, not infrequently, today's minority position is tomorrow's reigning paradigm.
- Green accounting systems should be dynamic and flexible. They should be structured so that their internal organization can be updated as new indicators and information become available.
- Green accounting systems must be linked to specific conceptual models of economy-environment interaction. Massive amounts of data cannot be comprehended except in the context of logical structures. Databases need to be constructed so that they are accessible to a wide range of transfer models. An example is the connection between anthropogenic carbon emission and climate. Lacking a conceptual framework (in this case, climate models), data in this area would be incomprehensible.

- When considering the results of transfer model analyses, the role of "best" answers or "optimized solutions" should be scrutinized carefully.

Fine-tuning of existing national income accounts—valuable as such exercises may be—will necessarily be inadequate to the goal of robust assessment of economy-environment interaction. The problems are far too complex. For now, what is needed is a variety of different approaches for developing green accounts. These must be subjected to debate and tested by asking a variety of users whether transfer models which they consider important can easily make use of this data. A minimum precondition for assessing a viable approach to green accounting is that users are able to frame and analyze their most significant questions.

This review process should focus on identifying those major conceptual models that are today found useful for characterizing the environment. Because of the extreme complexity of this problem and the changing nature of theoretical understanding, this must be viewed as a dynamic and ongoing process rather than a one-time activity.

The second step in developing a green accounting system should focus on articulating and integrating the conceptual frameworks in each topical area where threats to sustainability are believed to exist (e.g., agriculture, forestry, fisheries, climate, species diversity, air, water, and land quality, etc.). This process would be initiated by asking individuals and researchers knowledgeable in particular subfields to identify the normative assumptions and key conceptual frameworks of their field. The process should include practitioners as well as researchers. In the field of agriculture, for example, there should be involvement from family farmers, organic farmers (both large- and small-scale), corporate farmers, genetic engineers, and consumers. Those with long practice in sustainable agriculture (e.g., Amish farmers), should also be involved. Each person might be asked to describe how he/she assesses soil quality and soil deterioration. Each would be asked to consider near-term and long-term threats to sustainability. This type of process would be replicated for each topical area.

This process should place emphasis on developing a broad spectrum of indicators. An enormous variety of these have been developed (Bernard, 1990; House, 1990; Huffman, 1990; Kuik, 1991; and Rapport). Maps of ozone holes dramatize change. Many indicators of environmental quality have been proposed, for example, in the 1970s by the Council on Environmental Quality (1981), and more recently by the World Resources Institute (1992) (see also OECD, 1991; Brown et al., 1993).

The final stage would be to develop transfer models to relate key concepts and data, and to include ambiguity and uncertainty. This army of databases and indicators should be constructed so as to be useful for addressing issues on a wide variety of spatial and temporal scales, ranging from local to global. Long-term indicators will be predominantly biogeophysical. Nearer-term indicators may be more heavily weighted toward economics. With an extended set of indicators, decisionmaking processes can be more soundly based (incorporating both scientific knowledge and "traditional knowledge," see Agarwal, 1989) and planning can include a broad spectrum of attitudes toward goals, aspirations, risk, progress, and limits.

Accomplishing the goals outlined above will require much research. We are a long way from having any satisfactory green accounting system. We have tried to characterize the primary problems associated with extending existing national income accounts to incorporate sustainability considerations. We have also sketched an alternative approach to green accounting that outlines critical prerequisites for developing such accounts. We emphasize the importance of considering a wide range of possible images of the future, then developing representative biogeophysical and equity indicators, and finally using these indicators with transfer models (e.g., economics, multicriteria techniques, risk analysis, etc.) to assess policies and perform resource allocation.

APPENDIX: CATASTROPHE: FAILURE IN THE AGRICULTURAL SECTOR COULD IMPACT THE ENTIRE ECONOMY

Even though agriculture is a small part of the economy, serious losses there could propagate throughout the society and prove catastrophic. We illustrate this with a very simple model. Agricultural output (on-farm production) is the product of a technical factor (agricultural output per capita) times the number of agricultural workers, which is a fraction of the working population; nonagricultural sector output is the product of another technical factor times the number of nonfarm workers; agricultural output per capita is assumed to decrease as a result of greenhouse warming.

In order to maintain total agricultural output, increasing numbers of persons must be shifted to the agricultural sector. This leads to decline in nonagricultural output. For illustrative purposes, we consider the agricultural output per capita to decline logistically as a function of warming. The logistic function provides a slow initial decline, then a rapid decline as temperature approaches a critical value (which we take as 3°C warming), and finally decline slows as experience is gained. The kind of result that emerges from such a structure are shown in Figure 5-11.

Such a model illustrates the idea that major loss in agricultural productivity could have severe repercussions throughout the entire society. This is an example of instability. There are many others. Population growth is one of the most discussed (e.g., Ehrlich and Ehrlich, 1990). Instability due to resource depletion is the focus of the "Limits to Growth" school, which lead to considerable debate in the early 1970s, and has recently been reintroduced (Meadows, 1992).

Impact of loss of agricultural productivity on consumer output.

Agricultural Productivity = AgProductivity PerCapita*(f*N)

N = working population

f = fraction of working population involved in agriculture = 0.03 at (T1-T) = 0

T = average global temperature

T1 = temperature at which major change occurs = 3C

T-T1 = temperature increase from reference point, C

NonAgOutput = Consumer Output PerCapita*(1-f)*N

AgOutputper Capita = L(T) = logistic = 1/[1+exp(a*(T-T1))]

a = 1 provides a reasonable response band.

Solve equations for NonAgOutput as a function of temperature shift (T-T1).

The same kind of result is illustrated in economic language by Howarth and Monahan (1992).

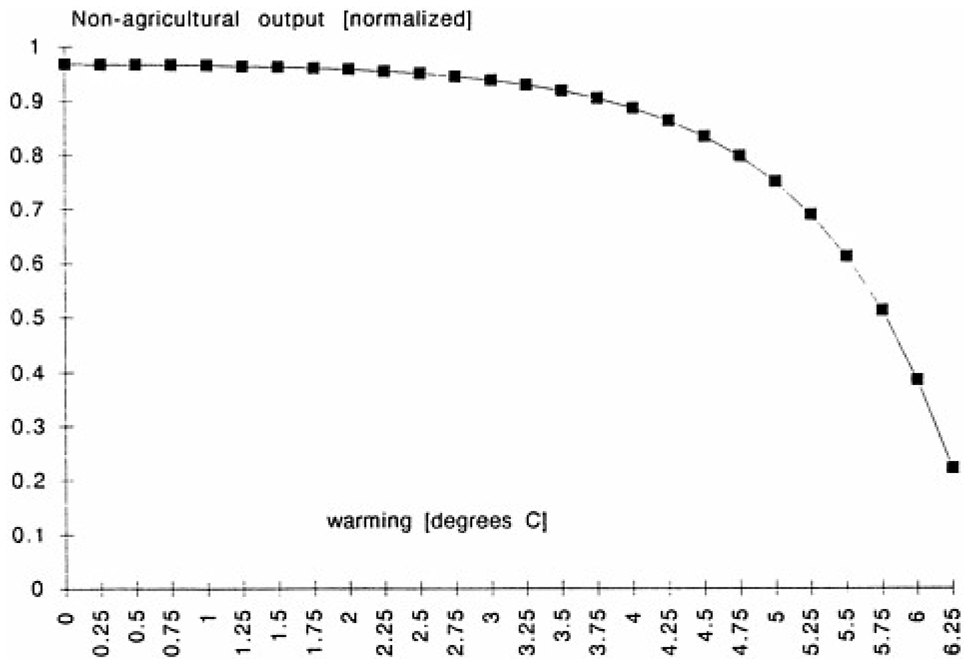

FIGURE 5-11 Illustration of nonlinear feedback. Schematic of decline in nonagricultural sector output decline driven by climate-change-induced loss of agricultural sector output.

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6

Natural Resource and Environmental Accounting in U.S. Agriculture[1]

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ISSUES IN ASSESSING AGRICULTURAL PERFORMANCE

Introduction

Between 1950 and the early 1990s U.S. agriculture had impressive success in reducing the economic costs of production—measured by declining real prices of farm commodities— despite an almost two-fold increase in crop and animal production. The combination of lower prices and expanded output conveyed substantial economic benefits to consumers of American farm output, both at home and abroad. The high productivity of the nation's agricultural land, greatly increased use of water for irrigation, and major advances in agricultural science and technology and in the managerial skills of farm people were the key elements in U.S. agriculture's strong economic performance.

But over the last decade or so, questions increasingly have been asked about the adequacy of this assessment. The questioning has run along two lines. One asks whether farm commodity prices fully reflect the on-farm costs of long-term depletion of the land and water resources used in agricultural production. Erosion-induced losses of soil productivity are of special concern; but the "mining" of groundwater for irrigation—withdrawing more water than is replenished by infiltration from the land surface—also excites unease.

The other line of questioning reflects recognition that U.S. agriculture generates a variety of costs and benefits which are not reflected in the prices of farm output because they occur off the farm. The scenic amenity values of a well-tended agricultural landscape provide an example of an off-farm agricultural benefit. The values are enjoyed by farmers and nonfarmers alike, but they are not reflected in farm commodity prices. On the other side of this coin, losses of scenic amenity values when farmers sell their land for conversion to urban sprawl are an example of an off-farm cost not reflected in commodity prices.

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The wildlife habitat values of farm woodlands and wetlands are another example of typically off-farm benefits. That is, habitat values are enjoyed by hunters, birdwatchers, and even by people who get pleasure from the mere knowledge that wildlife are provided habitat for their continued existence. But the values are not reflected in farm commodity prices, and only partially captured in agricultural land prices.[2] Symmetrically, the costs of losing habitat values when the land is cleared and drained for crop production are not reflected in commodity prices.

The off-farm benefits and costs of agriculture are not always symmetrically balanced, as in these examples. The benefits of resources which increase the productivity of farm operations, such as pesticides and fertilizers, are reflected in lower prices of food and fiber. But use of these resources may also impose a variety of off-farm costs, for example, damages to human health from ingestion of contaminated groundwater, to wildlife (from pesticides) and to aquatic ecosystems (from pesticides and fertilizers). Similarly, sediment eroded from farmland and deposited in floodplains and river deltas can increase soil productivity, and hence may generate benefits reflected in lower farm commodity prices. But sediment may also impose off-farm costs in the form of losses of recreational values because of murky water in streams, lakes and reservoirs, damages to fish spawning areas covered by silt, and higher costs of cleaning the water for residential and industrial uses.

Clearly, a full assessment of the performance of U.S. agriculture must take account not only of on-farm economic costs and benefits but the off-farm costs and benefits as well. In such an assessment, Crosson (1992) concluded that the off-farm costs of U.S. agriculture rose relative to the off-farm benefits from the end of World War II to the early 1990s. The implication is that off-farm costs rose also relative to on-farm economic costs (since the latter, reflected in farm commodity prices, declined). But because of the lack of reliable data for off-farm costs and benefits, Crosson (1992) made no judgment of whether these costs rose enough to offset the decline in on-farm economic costs.

Sustainability Issues

Consideration of the on-farm and off-farm costs of U.S. agricultural production raises the issue of the sustainability of the production system. Sustainable agriculture is the subject of intense discussion and increasing research in the agricultural and environmental communities, not only in the U.S. but also in other countries and in international agencies such as the World Bank. Definitions of sustainable agriculture vary widely, but the key element in all of them, implicit if not explicit, is concern about the long-term social costs of agricultural production. The most hard-bitten environmentalist would join with the most hard-nosed agriculturalist in agreement that the U.S. agricultural system is sustainable if each were satisfied that the system could indefinitely accommodate demands for food and fiber at satisfactory social costs.

[2] Many farmers charge fees to hunters and bird watchers for access to their land, and the resulting net income must be reflected in land values, at least to some extent. But not all farmers do this, and they have no way of capturing the existence value of habitat on their land.

Where the participants in the sustainability discussion part company, therefore, is not about the key importance of costs but about criteria for judging whether costs are, or are likely to be, satisfactory into the indefinite future. This is not the place to discuss differences with respect to these criteria. It seems clear, however, that many of the differences reflect differences in deeply held values, e.g., about more equal income distribution or the intrinsic worth of wildlife relative to low-priced food. But many of the differences must also reflect lack of information about the relative importance of the various costs, now and in the future. That is, it likely would be easier to narrow present differences about the sustainability of the U.S. agricultural system if we had more quantitative information about the magnitude of the various on-farm and off-farm costs, now and in the future. For example, it likely would be easier to get agreement between environmentalists and agriculturalists about the importance of protecting on-farm wildlife habitat relative to increasing crop production if we had reliable estimates that on a national scale the annual social costs of habitat loss because of clearing and drainage are × percent of crop production costs, plus or minus 20 percent.

The objective of this paper is to indicate how a system of accounts for agriculture could be developed to display quantitative estimates of the effects of agricultural production on natural resource capital used in agriculture and on environmental costs and benefits. Over time, such a system of accounts should help to reduce differences between agriculturalists and environmentalists concerning the sustainability of U.S. agriculture.

AN ACCOUNTING FRAMEWORK FOR AGRICULTURE

Introduction

It was asserted above that environmentalists and agriculturalists could agree that the U.S. agricultural system is sustainable if each, in their respective judgments, believed that the system is capable of satisfying long-term demands for food and fiber (the benefits of the system) at acceptable on-farm and off-farm costs. The advantage of an accounting framework for agriculture is that it provides a mechanism for systematic tracking of the production system's benefits and costs, thus promoting better-informed judgments about the sustainability of the system. This section discusses issues in constructing such an accounting framework.

Net Income as an Indicator of Sustainability

The net social income provided by the agricultural production system is the difference between the value of gross production and the on-farm and off-farm production costs. Net social income, therefore, is a key indicator of the sustainability of the production system. If over time production costs rise relative to the value of total production, net social income will fall, arousing doubts about sustainability. If the proportion of costs to production remains the same or declines, net income will be maintained or increased, indicating that the system is on a sustainable path.

Maintaining a constant or rising stream of net social income—achieving sustainability— depends on the capacity of the production system to transform inputs into outputs desired by people at social costs which do not increase in proportion to production. The capacity of the system, in turn, depends on the quantity and productivity of the resources employed in production—the land, the water, the people, the fertilizers, farm machinery and so on.[3] Should the quantity of these resources decline and their productivity (output per unit of resources) remain the same, then the capacity of the system to maintain the stream of net social income would be reduced. Similarly, a decline in resource productivity would reduce capacity unless there were an offsetting increase in the quantity of resources.

The distinction between the quantity and productivity of resources is recognized, albeit implicitly, in the literature on accounting, whether for a firm (e.g., a farm), a sector (e.g., agriculture) or for an entire regional or national economy. All modern accounting systems are based on the principle of double-entry bookkeeping. The principle is that for any production unit the quantity of resources employed (the inputs), measured in dollars, must be precisely equal to the quantity of outputs produced, also measured in dollars. This is to say that the bookkeeping system "accounts for" all the inputs by insisting that the sum of them must equal the sum of the outputs.

Changes over time in the productivity of resources typically are measured by changes in the ratio of total output to total resource inputs.[4] This measure of productivity change cannot be derived from double-entry accounting systems, however, because, as just noted, in such systems the quantity of resources employed, measured in dollars, is always equal to outputs produced, i.e., the ratio of outputs to inputs is always and necessarily equal to one.

Changes over time in the resource productivity of a production unit nonetheless can be inferred from examination of the unit's accounts with respect to net income. In the accounts net income is the residual difference between the value of resources employed and the value of outputs produced. Thus resources and outputs will always be equal, but net income may rise or fall, depending on an increase or decline in resource productivity.

[3] We deal here with resources directly employed on the farm and with off-farm resources directly affected by farm operations, e.g., streams used as a dump for sediment or agricultural chemicals from farmers' fields. However, agricultural production draws also on a much larger and more heterogenous set of resources such as the transport and communications infrastructure; the social, legal, and political institutions which shape attitudes toward farming and define and enforce agricultural property rights; and stocks of accumulated social knowledge about how to make the economic system, of which agriculture is an integral part, work effectively. We make no effort to capture the role of this very broad but less agriculture-specific set of resources in shaping agricultural performance. For a discussion of these resources and the problems of reflecting them properly in a set of national income accounts, see Juster et al., 1979.

[4] The U.S. Department of Agriculture, for example, measures changes in the total productivity of American agriculture as changes in the ratio of an index of total farm output to an index of total farm input (USDA, 1991).

To understand this, consider an example. Suppose that over time soil erosion reduces the productivity of the land by removing nutrients, but that production does not fall because farmers exactly compensate by increasing applications of fertilizer. Since the value of total output by assumption remains the same, the value of total input must also be unchanged. However, the composition of inputs has changed. Inputs of fertilizers have increased, reducing, by exactly the same amount, the proceeds available as net income. The decline in net farm income—equal to the increased outlays for fertilizer—measures the cost of the erosion-induced decline in soil productivity.

In this example farm productivity, measured by net income, declines because erosion increases on-farm production costs in the form of higher outlays for fertilizer. However, increased off-farm costs also reduce the productivity of the system, measured by social (farm plus off-farm) net income. Suppose that the erosion posited above does not affect soil productivity, but that the soil moved is carried to streams and lakes where it reduces water quality, imposing losses in recreational values of the water. Total marketed farm output is unchanged, so inputs also necessarily are unchanged. Net *farm* income, therefore, also is unchanged; but net *social* income is reduced by the cost of sediment damages to recreational uses of surface water. With total on-farm costs unchanged and off-farm costs higher, the net social income from farm operations necessarily is reduced, measuring a decline in the productivity of the system.

Conceptually, the effects of off-farm costs and on-farm costs on the productivity of the agricultural system are the same; and a properly constructed accounting framework will incorporate both kinds of costs. From the standpoint of farmers, however, the two kinds of costs are quite different. Farmers pay on-farm costs. They do not pay off-farm costs, absent policies or institutions which require or induce them to do so. This difference in the two kinds of costs is critically important in understanding and assessing the performance of the agricultural system. It also is critically important for policies to ensure the sustainability of the system. In this paper, however, we deal only with an accounting framework to incorporate the two kinds of costs.

Limitations of Existing Accounting Systems

Table 6-1 shows data for gross and net farm income in the U.S. for selected 3-year periods since the late 1940s-early 1950s. Gross income is the value farmers received from selling the crops, animals, and other services they produced, the value of their consumption of farm produce, the change in value of farm-held inventories of crops and animals, and payments from the federal government under various price and income support programs.

Production expenses are the amounts farmers paid to purchase fertilizers, pesticides, seed, and a whole range of marketed inputs used in production; to hire labor; as interest on debt and on farmer-owned equipment and buildings; plus an amount representing depreciation of the farmer's human-made capital: principally equipment such as tractors, cultivators, combines and so on, and barns, fences, silos, and other built structures.

TABLE 6-1 Average Annual Farm Income, Various Periods (Billions nominal and 1987 dollars)

Time Period	Gross[a]					Net			
	Total	Gov't payments	Gov't percent of total	Production expenses[b]	Total[c]	Ex-gov't payments	Gov't Percent of Total	Net in Total	1987 dollars Ex-Gov't.
1949/1951	34.1	.252	0.7	19.9	14.2	13.9	1.8	64.9	63.7
1959/1961	39.0	.968	2.5	27.7	11.3	10.3	8.6	43.5	39.8
1969/1971	59.1	3.549	6.0	44.6	14.5	11.0	24.4	41.5	31.4
1979/1981	155.4	1.531	1.0	131.9	23.5	22.0	7.0	32.8	30.5
1988/1991	186.6	11.600	6.2	139.5	47.1	35.5	24.6	43.4	32.7

[a] Sales of crops and livestock, value of produce consumed on the farm, government payments, and changes in the value of farm-held inventories.

[b] All purchases of goods and services used in production, wages of hired farm labor, interest on real estate and non-real estate debt, non-income taxes, and depreciation and other consumption of farm capital. Depreciation is the money needed to replace the capital used up in production annually. Depreciation of natural resource capital is *not* included.

[c] The difference between gross income and production expenses.

SOURCES: Gross and net income, government payments, and production expenses: 1949-57 -USDA (1960); 1959-61, 1969-71 -USDA (1974); 1979-81, 1988-90 -USDA (1991b).

Net income in 1987 dollars: Office of the President (1992). Nominal net income was deflated by the price deflator for gross domestic product, 1987 = 100.

The depreciation charge against gross farm income does not include consumption of natural resource capital incurred by the production process, e.g., losses of soil productivity because of soil erosion. Nor does gross farm income include the off-farm benefits of farming or production expenses of the off-farm costs of environmental damage.

Net income is the difference between gross income and production expenses. We argued above that movements of net farm income over time could be taken as an indicator of the sustainability of the agricultural system. However, this interpretation is ambiguous in Table 6-1 because of the role of government payments in net farm income. These payments are made under various federal government programs designed to protect farm income against the negative effects of market forces. As a percent of net farm income government payments rose from 1.8 percent in 1949/51 to 8.6 percent in 1959/61, to 24.4 percent in 1969/71, fell to 7.0 percent in 1979/81, reflecting the relative farm prosperity of the 1970s, then rose sharply to 24.6 percent in 1988/90 as U.S. export markets and crop prices fell in the 1980s.

One interpretation of government payments is that they reflect efforts to compensate for weaknesses in the agricultural system, the higher the payments, the greater the weaknesses. Because of the weaknesses, farmers are insufficiently competitive in agricultural markets to earn satisfactory incomes. Under this interpretation, the rise in government payments as a percent of net farm income over the last 40 years would raise questions about the sustainability of the system.

Another interpretation of government payments, however, is that they reflect a politically determined decision that the benefits bestowed by agriculture on American society are not fully captured by market processes. In this view the payments reward farmers for this otherwise uncompensated contribution to the general welfare.

We do not discuss the merits of these two interpretations, but we believe that net income exclusive of government payments is the better indicator of performance. This is based on the assumption that a sustainable system for agriculture (or for any economic sector) is one which over the long-term can "earn its own way," that is that it can earn a socially satisfactory income for the people engaged in the system without the help of government payments. As noted, other interpretations of government payments are possible; but we believe the one adopted here is closest to what most people have in mind when they think about sustainable agriculture.

By this criterion, net income exclusive of government payments is the best indicator of agricultural performance. Specifically, this indicator adjusted for inflation (the last column in Table 6-1) is most relevant. In the 20 years from 1949/51 to 1969/71 this measure of agricultural performance fell from $63.7 billion (in 1987 dollars) to $31.4 billion, then remained about the same over the next 19 years. Over three-fourths of the $31 billion decline from 1949/51 to 1988/90 had occurred by 1959/61.

The decline in real net farm income after 1949/51 was accompanied by—indeed reflected—a massive shift of people out of farming. Between 1950 and 1989 the total farm population decreased about 75 percent. Although the amount of land in farms declined some 15 percent, the total number of farms fell 60 percent.[5] Consequently, real net farm income *per*

[5] The 60 percent decline in farm numbers is overstated because in 1975 the definition of a farm changed to eliminate approximately 10 percent of the rural operations previously classified as farms.

farm, exclusive of government payments, was roughly 25 percent higher in 1988/90 than in 1949/51, and about 50 percent higher than in 1959/61.[6]

There is a widely held view, which most Americans probably share without bothering themselves about its philosophical underpinnings, that if farmers are better off—and not at the expense of nonfarmers—then society generally is better off. The view is based on the philosophy of utilitarianism, first developed by British philosophers in the 18th century and still alive and well at the end of the 20th century. Crudely, but not inaccurately put, utilitarians argue that the welfare of society is the sum of the welfare of the individuals in the society. It follows that if the welfare of some members of the society—e.g., farmers—increases without detriment to the welfare of other members, then the welfare of society as a whole is increased. If one holds this view, and is willing to accept net income as measured in Table 6-1 as a satisfactory, if very rough, measure of welfare, then one could conclude that over the last 40 years fanning in America has enhanced the welfare not only of farmers but of society generally.[7]

But whether or not one is a utilitarian one may, and many do, object to the estimates of net income in Table 6-1 as measures of "true" net farm income. There are two reasons: (1) the measures of production costs may underestimate on-farm costs because as noted, they do not include the draw-down—the consumption—of natural resource capital, principally land and water, used in production; (2) the estimates of gross farm income and production costs do not include the off-farm benefits and costs of farming.

These are serious issues. If consumption of natural resource capital is significant, then agriculture has not done as well in generating net income for farmers as Table 6-1 indicates. Indeed, if in fact there was a significant, but unmeasured, loss of natural resource capital, then American farming may be on an unsustainable course. If off-farm costs are significant, then net farmer income, as measured in Table 6-1, has been sustained in part by the imposition of costs on nonfarmers. In this case, net income in Table 6-1 *overstates* the contribution of farming to the general social welfare. If off-farm benefits are significant, then to that extent the Table 6-1 estimates of net income *understate* farming's welfare contribution. The rest of this part is devoted to discussion of how to deal in an income accounting sense with these issues of natural resource depletion and off-farm costs and benefits.

The Consumption of Natural Resource Capital

The value of any capital asset is the sum of the discounted stream of net income yielded by the asset over time. The income stream may be measured in any increments of time, but for convenience here we assume annual increments. Given the costs of producing the output of the

[6] The numbers in this paragraph on farm population and number of farms are from various issues of USDA's *Agricultural Statistics*.

[7] The increase in farm output and decline in farm commodity prices, noted in the Introduction, provide a more direct indicator of the contribution of farming to the general welfare over the last 40 years.

asset, the size of the net income stream depends on the annual quantities of goods or services produced by the asset, times the prices of these outputs over however many years the asset remains in service. Consequently, given the life of an asset, its value can change because the quantity of its output changes, or the prices of the output changes, or the discount rate changes, or some combination of these.

Capital is consumed, or "used up" whenever the discounted stream of its net income declines. Apart from increases in the discount rate, this can happen because the quantity of output of the capital declines, reflecting, perhaps wear and tear, as on a machine which experiences more downtime for repairs. The decline in capital value may also occur because the prices of the capital's output decline, or because newer, more productive machines are developed which economically displace the older machine.

If in the process of production capital is consumed—the net income stream of the capital declines—then sustainability requires that investments be made in new capital that generates enough value of output to replace the loss of net income. This required amount of investment is called a capital consumption allowance because it is the amount needed to replace the capital consumed.

Perhaps paradoxically, the value of an asset can increase even if the quantitative output of the asset declines. This will happen if the price of the output increases proportionally more than the decline in the quantity of output, (holding the discount rate constant). For example, if the demand for food were rising faster than the supply, forcing food prices up relative to the general price level, then the real net income stream to the land, hence real land values, would rise even if the *quantity* of food production were declining because of severe soil erosion. The physical productivity of the land would fall but its economic productivity would rise. In such cases the capital value of assets is not "consumed" or "used up." On the contrary it is increasing and the increase is counted as income to asset owners.

This consequence is entirely consistent with the concept of capital and with understanding of how real capital values change over time *for any given sector of the economy*. But the situation depicted cannot apply to capital values in the economy as a whole. In the example cited, in which we are dealing with inflation adjusted prices, if the real price of food goes up, then the real prices of some other goods and services must come down. The real value of the capital employed in producing those goods and services would also decline. This is another way of expressing the common sense notion that the real income of the economy as a whole cannot rise, or even stay even, if the physical productivity of all the capital assets in the economy are declining.

The discussion indicates that in principle there would not necessarily be anything paradoxical in rising real prices of agricultural land in the U.S. combined with declining physical productivity of the land. In such a case, the notion of a capital consumption charge against the land would seem to make little sense since the *economic* capacity of the land is not consumed but in fact is rising.

Yet if the question concerns the long-term sustainability of the U.S. agricultural system, this conclusion excites unease. Should, in fact, U.S. agriculture combine rising economic value of the land with diminishing physical productivity it almost surely would be because of rising foreign demand for U.S. agricultural output. Foreign demand currently takes 25-30 percent of the value of U.S. output, and most of the changes in demand over the last couple of decades have been in foreign demand. This is expected to continue in the future (Crosson, 1992). In the situation depicted, therefore, U.S. consumers would be confronted by an increase in real prices of food, *not of their making*, simultaneously with a decline in the physical productivity of the nation's agricultural land. Would such a situation be perceived as consistent with U.S. concerns about the sustainability of agriculture? I believe that it would not. Consequently, I regard the situation as in principle a possibility (although no such situation has occurred in U.S. agriculture for at least the last 60 years), but one that, should it occur, would be considered inconsistent with agricultural sustainability and would prompt public action to control erosion-induced losses of soil productivity.

I return, then, to the assertion that sustainability requires that losses of the physical productivity of natural resources should be reflected in a capital consumption charge against gross output; and that the charge should equal the amount of investment needed to restore the net income stream of the capital to its previous level.

Notice, however, that the money spent to replace capital consumed does not have to be spent on the same assets that are consumed. It is the *total* capital of the enterprise (or of the sector, or of the nation) which must be maintained, not the capital represented by any particular asset. Thus a farmer may decide to use the capital consumption allowances for a moldboard plow to purchase the equipment needed to shift to some form of conservation tillage system. In a more extreme case, the farmer may cut back sharply over time On his investment in crop production, using the capital consumption allowances for crop production capital to expand his investment in animal production. The important point is that the capital consumption allowances charged against gross farm income must be sufficient to maintain the *total* farm capital, and hence the stream of net farm income over time. Given this condition, the precise form the capital takes is not important.

Clearly, the consumption of capital is a cost of production. Since net income is the difference between gross income and production costs, consumption of capital must be taken into account if net income is to be properly measured. All modern accounting systems recognize this. However, the systems of national income accounts used by the United States and other nations do not include an allowance for consumption of natural resource capital. There are a variety of arguments for this exclusion. One of the most important is that natural resources are free gifts of nature so consumption of them is costless. This argument misses the point that although natural resource capital may be "free," it generates social value which may be diminished through use of the resource. Another argument is that estimates of natural resource capital are subject to large short-term fluctuations, reflecting sudden shifts in market conditions. For example, the capital value of global oil reserves rose steeply in 1973 and 1974 when the Organization of Petroleum Exporting Countries raised its prices, then declined for several years, then rose steeply again in 1979, only to decline again in the 1980s. Changes in capital value are part of national (and global) income, so inclusion of the value of oil reserves in national income accounts would result in large, and so far at least, temporary swings in national income estimates. This would "distort" long-run trends in national income, runs the argument for excluding natural resources from national income accounting.

There is a substantial literature on the conceptual and measurement problems of including natural resource capital in national income accounts. (A sampling of this literature is cited below in footnote 8). Suffice it to say here that among the experts in national income account ing, there now is agreement in principle that consumption of natural resource capital should be counted as a cost of production, just as is consumption of human-made capital. By this principle, the estimates of farm production costs in Table 6-1, which are part of the U.S. national income accounts, are underestimated—and net farm income is overestimated by the same amount—to the extent that, over the period shown, the capital value of land and water resources was in fact diminished by use of them.

Off-Farm Costs and Benefits

The systems of national accounts are designed to measure the production, cost, income and expenditure consequences of transactions in markets. This quantifies the consequences in dollars and permits size comparisons among sectors of the economy and measurement of trends over time, both by sector and for the economy as a whole. But many transactions involving the use of resources are not registered in markets. Hence they are unpriced and are not reflected in the national income accounts. Unpriced uses of "environmental" resources are a major but not the only category of these excluded transactions. Unpriced use of the land for wildlife habitat, of surface water as a dump for runoff from farmers' fields, and of the atmosphere as a sink for methane emitted by farm animals are examples from agriculture of unpriced transactions in environmental resources. These unpriced transactions make up a major pan of what, in this paper, I call off-farm benefits and costs of agricultural production.

As noted above, there is an extensive and growing literature on the failure of systems of national income accounts to incorporate natural resource depletion and unpriced transactions in environmental resources; on the consequences of this failure for assessment of performance over time by individual sectors and for the economy as a whole; and on measures to remedy the failure. It is not necessary for our purposes here to review this literature.[8] Instead we draw on a portion of the literature to illustrate how natural resource depletion and off-farm costs and benefits could be included in an agricultural sector system of accounts which would be appropriate for the farm level as well as for agriculture as a whole. The system also would be consistent with national accounts as they might be revised to include natural resource depletion and unpriced transactions in environmental resources.

A Schematic Accounting Framework

Table 6-2 displays an accounting framework consistent with currently used national income accounting practices, but which incorporates both consumption of natural resource capital

[8] For a representative sampling of this literature see the following: Ward (1982); Levine (1991); Peskin with E. Lutz (1990); Norgaard (1989); Repetto et al. (1989); Repetto (1992); Faeth et al. (1991). Also the following chapters in Ahmad, E1 Serafy and Lutz (eds., 1989): Peskin (1989a and 1989b); El Serafy and Lutz (1989); Daly (1989); El Serafy (1989); Harrison (1989); Hueting (1989); Blades (1989); Bartelmus (1989); Lutz and El Serafy (1989).

and environmental costs and benefits. The framework—taken with a slight modification from Peskin (1989b in Ahmad et al., 1989)—is designed to represent the inputs and outputs of a private sector firm as they would be displayed for use in the national accounts. In this discussion we assume that the firm is a farm.

In this, as in any accounting system based on double-entry bookkeeping, the inputs must equal the outputs. Specifically, everything the farm sector produces (the output side) must be accounted for somewhere on the input side of the ledger. Before adjustment for environmental damages, the output side of the farm sector is readily understood. Everything farmers produce is sold to industry (e.g., wheat for milling to flour), to households (e.g., fresh vegetables purchased from a farmers' market), for export (e.g., grain to Japan), to government (e.g., under farm price support programs) and for gross investment which, in the case of agriculture, would be mostly changes in inventories of crops and animals. The corresponding output entries in Table 6-2 are 12a, b, and c; 13 and 14.

The entries on the input side require more explanation. Note that profits, item 3, are calculated *after* subtracting capital consumption, item 9. Subsidies, item 8, are entered negatively because they are a free good. They can be thought of as a balancing item. If the subsidies are for purchases of inputs, say fertilizer, then the price of the inputs will not be fully reflected in the prices of commodities farmers sell. Consequently, the value of inputs purchased will exceed the value of outputs sold unless the subsidy is subtracted from the input side.

In American agriculture, however, subsidies show up as government payments added to net farm income (Table 6-1). In Table 6-2 these subsidies are included in item 3. However, the subsidies are not reflected on the output side of the farm ledger, that is they are not attributable to the goods and services farmers produce and sell. Consequently, the farm income subsidies must be subtracted from the input side to assure balance between the inputs and outputs.

The inclusion of a charge for consumption of natural resource capital (item 9b) assures that this cost of farm output is reflected on the input side just as is the consumption of human-made capital. Recall that profit (item 3) is calculated after accounting for capital consumption. To the extent that farming "consumes" natural resource capital, farm profit is reduced, as it should be.[9]

Items 10 and 15 respectively are the environmental inputs and outputs of the farm enterprise. The environmental inputs (item 10) are entered negatively because they are free to the farmer, that is, they are a subsidy to farm production. For example, the unimpeded use of

[9] In fact, consumption of natural resource capital may also show up as reduced rental income to the farm (item 2). For present purposes it does not matter whether profits or rental income is charged with consumption of natural resource capital so long as the charge is fully reflected on the input side of the ledger.

TABLE 6-2 An Accounting Framework for the Farm Sector

Inputs	Outputs
Gross farm input before adjustment for environmental inputs	**Gross farm output before adjustment for environmental outputs**
1. Purchases from other sectors	12. Current account sales to the private sector
2. Compensation of employees and proprietors, including rental income	a. to industry
	b. to households
3. Profits after inventory evaluation and capital consumption adjustment	c. for export abroad
	13. Sales to government
4. Net interest paid	14. Sales for gross investment
5. Imports	
6. Transfer payments	
7. Indirect taxes	
8. Subsidies received (-)	
9. Capital consumption adjustment	
a. Human-made capital	
b. Natural resource capital	
Gross farm input adjusted for the environment	**Gross farm output adjusted for the environment**
10. Environmental inputs (-)	15. Environmental outputs
a. Land	a. Land
b. Water	b. Water
c. Air	c. Air
11. Net environmental benefit (15-10)	

SOURCE: Adapted from Peskin (1989b in Ahmad et al., 1989).

streams by farmers as dumps for sediment and chemicals in runoff is a free service. The value of the service is the loss of income to farmers if they had to eliminate these discharges.

Environmental outputs, item 15, may be either negative or positive. For example, the value of reduction in recreational uses of streams because of sediment and agricultural chemicals is a negative environmental output (a "bad" of farming). The aesthetic value of a well-tended farm landscape is a positive environmental output (a "good").

Item 11, a balancing entry, is the absolute difference between items 15 and 10. For convenience it is called a measure of net environmental benefit, meaning of course that it may be positive, negative, or zero.

An example will help to explain the environmental entries in the farm product account. Suppose that the sums of gross farm inputs (items 1-9) and outputs (items 12-14) before adjustment for environmental inputs and outputs are each equal to $1 million. Now suppose that the value of environmental inputs to farms (e.g., the savings from being able to dump sediment in streams free-of-charge) is $10,000, and that this is the only environmental service received by farmers. Item 10b in Table 6-2 would therefore have a value of-$10,000, as would item 10 as a whole. Gross farm input adjusted for the environment then would be $990,000. Suppose also that the sediment reduces recreational benefits of the receiving streams by $15,000 and that the scenic amenities of the farm landscape generates benefits of $10,000. Item 15a would then show an entry of $10,000 and item 15b an entry of-$15,000. Total environmental outputs then would be-$5000, and total gross farm output adjusted for the environment would be $995,000. Net environmental benefits, the absolute difference between items 10 and 15, would be $5000, raising total gross farm input also to $995,000. (Table 6-3 presents these hypothetical numbers.)

The interpretation of this way of handling the environmental account runs along the following lines. The $10,000 of free inputs provided by streams receiving sediment is a benefit either to farmers (profits are higher) or to society (commodity prices are lower), or to both farmers and consumers. In either case, the $10,000 in environmental benefits is shown in the input account, and subtracted to avoid double counting.

On the output side the positive $10,000 in scenic amenities are added to the negative $15,000 sediment-induced losses of recreational values to give a $5000 loss of environmental outputs. Net environmental benefits, therefore, the absolute difference between environmental inputs and outputs, are $5000, and total gross farm input and output, adjusted for environmental transactions, is $995,000.

Notice that the adjustment for environmental inputs does not change total gross input. It merely reallocates the inputs to make explicit the contribution of the environment. To see this, suppose that before adjustment the $10,000 in free environmental inputs is reflected in some combination of higher profits (item 3 in Table 6-2) and in lower prices to purchasers of farm output (items 12-14 in Table 6-2). The $10,000 in environmental benefits thus is buried in both the unadjusted input and output accounts, each of which total $1 million. Suppose also, to keep things simple, that there are no environmental outputs (item 15 in Table 6-2 is zero). This implies that the quality of the water in the streams receiving the sediment from farms is not seriously impaired for users of the water. So item 10 in Table 6-1 is-$10,000, item 15 is zero, net environmental benefits (item 11), the absolute difference between items 10 and 15, are $10,000 and gross farm input and output is $1 million, as it was before the environmental adjustment. The adjustment nevertheless is important because it shows the $10,000 where it properly belongs, in the environmental input account, not hidden in the profit account or in lower prices of farm output.

TABLE 6-3 A Hypothetical Account of Gross Farm Product

Gross farm input before adjustment for environmental inputs:		Gross farm output before adjustment for environmental outputs:	
	$1,000,000		$1,000,000
Environmental input (-)		Environmental output	
Land	- 0 -	Land[b]	+$10,000
Water[a]	-$10,000	Water[c]	-$15,000
Air	- 0 -	Air	- 0 -
	Total-$10,000		Total-$5,000
Gross input minus environmental inputs	$990,000		
Net environmental benefit	$5,000		
Adjusted gross farm input	$995,000	Adjusted gross farm output	$995,000

NOTES: [a] To dispose of sediment; b Scenic amenities; c Loss of recreational values because of sediment damage to water quality. SOURCE: See text.

The implication of this argument is that if the adjustment for environmental transactions changes the estimate of gross farm input and output, the change will show up in the environmental output account (item 15 in Table 2). This is evident in Table 6-3. Scenic amenities increase output by $10,000, but damages to water quality reduce it by $15,000. Gross adjusted output thus falls by $5000 to $995,000, as does gross adjusted input.

That adjustments for environmental transactions which affect gross input and output should show up in the environmental output account makes sense. We are accustomed to thinking that agricultural production generates a set of both good and bad environmental outputs. If the bads—damages or costs—exceed the goods—benefits—then the adjustment for environmental transactions should reduce the value of gross farm output. And vice versa if the goods exceed the bads.

This interpretation of the role of environmental outputs in adjusting the gross farm product account probably will raise few eyebrows. The argument that inputs of environmental services—item 10 in Table 6-2—generate benefits may not be so readily accepted. The idea that when farmers use the environment (e.g., neighboring streams) to freely dispose of farm effluents (e.g., sediment in runoff) they generate private and social benefits goes against the grain. Yet unbiased reflection indicates that these benefits are real, showing up, as indicated above, either in higher net farm income or in lower farm commodity prices, or in some combination of both.

There are two points to keep in mind when considering the treatment of inputs of environmental services as benefits. One is a point made above: this treatment does not *increase* gross farm input; it merely reallocates it to make explicit the contribution of environmental services. The second point is that the benefits of environmental inputs are not necessarily net. The free use of the inputs may well generate environmental costs which exceed the benefits. For example, the recreational values lost because of sediment damages to water quality may be greater than the benefits of the inputs to farmers. This is the situation represented in Table 6-3. Indeed, the marginal social costs of this use of streams almost surely will exceed the marginal benefits except in the unlikely case that the social value of the water is insensitive to sediment damage. The reason is that farmers have incentive to use the water as a sediment dump to the point where the marginal benefit received by them is zero. This is because the marginal cost of the water to the farmer is zero. If the marginal value of the water in other uses, for example recreation, is greater than zero, then the marginal net social benefits of the farmers' use are negative and the pattern of use is socially inefficient. That is, the marginal social cost of the sediment damage is greater than the marginal benefits to farmers of using the stream to dispose of sediment. The pattern of resource use may also be inequitable if the water available to downstream users formerly had been unpolluted by sediment.

Thus the treatment of the free services of the environment to farmers as a benefit on the input side is designed to give an accurate account of one aspect of the role of the environment in farming. The treatment does not imply that the benefits are greater than the costs (measured on the output side), and it is quite consistent with the argument that the free use of environmental services by farmers (or anyone else) is socially inefficient and possibly inequitable as well.

In summary, the accounting framework presented in Table 6-2 offers a way of dealing with the two principal limitations of current representations of the farm sector in the national income accounts: (1) it specifically includes an item for consumption of on-the-farm natural resource capital; (2) it specifically accounts for the inputs of environmental services to farm production and for the outputs of environmental benefits and costs. The inclusion of consumption of natural resource capital assures, in principle, a more complete accounting of on-farm costs; and the inclusion of the environmental inputs and outputs does the same for off-farm costs and benefits. Adoption and implementation of the accounting framework, therefore, would provide more complete information than the existing system for assessing the sustainability of current agricultural practices.

CONSUMPTION OF NATURAL RESOURCE CAPITAL: HOW TO REPRESENT IT[10]

Recall the definition of capital consumption: it is the amount of money which must be withdrawn from annual[11] gross income and reinvested to replace the capital used up in production. The reinvestment, however, need not be in the "used up" assets. If the capital consumption allowance is not reinvested but is spent for consumption, then the capital of the enterprise (or the sector, or the nation) will not be maintained and productivity, measured by net income of the activity, will decline.

In agriculture the natural capital of principal interest is the nation's stocks of land and water resources used in production.[12] Soil degradation, mainly by wind and water erosion, is the principal threat to the productivity of the nation's agricultural land resource. The "mining" of aquifers and impaired surface water quality, primarily from rising salt loadings in irrigation return flows, are the main threats to the water resource. The data available for analyzing erosion-induced declines in the productivity of the soil resource are much more ample than those for analyzing the comparable threat to the water resource. And the principles for incorporating these threats in a farm income accounting system are the same for water as for land. For these reasons the discussion here deals with the' land resource.

It is clear that if soil erosion reduces the productivity of the soil resource, proper measurement of farm net income requires that the productivity decline be reflected on the input side of the farm, and farm sector, income and product accounts. In terms of Table 6-2, the money required to compensate for the loss of soil productivity must be entered in one of the input-side accounts and subtracted from item 3, the profit account.

[10] In a longer version of this paper I deal also with measurement of environmental costs and benefits of agricultural production. Space limitations preclude dealing with those issues here.

[11] .As noted earlier, I assume here that the accounting period is annual. This is a convention. The period could be more or less than a year.

[12] The plant and animal gene pool and the climate also are important parts of the natural capital employed in agriculture. And their productivity could be degraded in the course of agricultural production. For example, the development of a few high yielding crops may result in neglect, and eventual loss, of some of the genetic variety represented by wild, lower yielding representatives of the favored crops. The evidence does not suggest that this has, in fact, happened in the U.S. But the example illustrates a form of possible consumption of agricultural natural capital. Methane emissions from farm animals contribute to global warming, hence to possible depreciation of the climate resource available to agriculture. However, U.S. agriculture is a minor contributor to global warming (Council for Agricultural Science and Technology, 1992).

But ambiguities arise with respect to where on the input side the soil productivity decline should be represented because farmers have several alternatives for dealing with the effects of erosion on soil productivity.

(1) They can adopt tillage practices or crop rotations which reduce erosion enough to eliminate the productivity effects of erosion and over time restore soil productivity by building up soil organic matter.
(2) They can invest in the building of terraces, grass waterways, strip cropping or other "structural" approaches to controlling erosion and restoring soil productivity.
(3) If the productivity effect of erosion is to reduce soil nutrients farmers can respond by putting on enough fertilizer to compensate.
(4) Farmers may decide not to control erosion but to use the capital consumption allowance to invest in new technology, e.g., higher yielding crop varieties, to compensate for the loss of soil productivity. This response typically would also require increased outlays for fertilizer.
(5) Farmers may decide to gradually withdraw some or all of their capital from agriculture, investing the allowance for consumption of soil capital in the stock market or some other nonfarm enterprise. In this case the capital, and stream of net income, of the farmer is maintained, but the capital invested in the soil resources of the farm declines, as does net income from farming.

All of these alternatives are open to farmers. All of them reflect the negative effects of erosion-induced losses of soil productivity on net farm income. Presumably farmers choose among the alternatives, or among some mix of them, to minimize the loss of net farmer income. But how would the alternatives best be represented in a farm accounting framework such as that displayed in Table 6-2? Recall that capital inputs are represented in the table solely in the capital consumption account, items 9a and 9b. Outlays for new machinery and equipment are not included, only the necessary annual consumption charges against these assets. But all of the alternatives likely would involve some measure of current account expenses, all of which must be included on the input side of Table 6-2. The first alternative, for example, likely would require more labor than the erosion-inducing practices it would replace. These labor expenditures would be included in item 2 of Table 6-2. Alternatives 3 (more fertilizer) and 4 (higher yielding seed varieties) would require increased expenditures in item 1. Only alternative 2 would appear to involve predominantly, although not exclusively, capital outlays, to be accounted for in item 9a, consumption of human-made capital.

The question is this: if the capital consumption allowance for the erosion-induced decline in soil productivity is spent on current account inputs (e.g., item 1 in Table 6-2), should the same amount also be charged against the capital consumption account for natural capital, item 9b? The answer would seem to be "no" because to do so would involve double-counting of the productivity effect of soil erosion. I am assuming that the outlays, under alternatives 1-4, exactly compensate the net income effect of erosion.[13] The output side of Table 6-2, therefore,

[13] I do not further consider alternative 5 because I am interested only in situations in which farm capital is maintained.

is unaffected by erosion, which means, of course, that *total* input also is unaffected. The increase in current account outlays in, for example, item 1 must, therefore, be matched against an equal decline in some other input account, probably item 3, profits (although it could be in item 5, imports). If the capital consumption account, 9b, also is charged, this too would be reflected in item 3, profits. In this case profits would be charged twice for the erosion-induced decline in soil capital, which seems incorrect.

The way out of this conundrum is to follow this principle: if the alternative, or combination of alternatives, chosen to deal with the effect of erosion on soil productivity would indefinitely maintain the same level of output, then no capital consumption charge should be levied against soil capital. However, if in time additional expenditures to deal with erosion-induced losses of productivity would be needed beyond those required by the chosen alternative, then a capital consumption charge sufficient to accumulate the additional funds by the time they are needed must be entered in the natural capital consumption account (item 9b in Table 6-2). For example, suppose that the economically optimum choice for the farmer "today" is alternative 3—additional fertilizer to offset erosion-induced losses of soil nutrients. Suppose also, however, that after 10 more years of erosion, topsoil depth will have been reduced enough to significantly diminish soil water-holding capacity. Much research indicates that when this happens, additional fertilizer will no longer suffice to offset erosion-induced productivity losses. To avoid these losses the farmer will have to shift to erosion-control practices (perhaps alternatives 1 or 2) before soil water-holding capacity has been diminished to the critical point. To accumulate the funds needed to finance the shift to erosion control practices when that becomes necessary (10 years in this example), an annual charge should be entered against the capital consumption account for natural resources, beginning "now," and subtracted from farm profits (item 3 in Table 6-2).

This way of dealing with consumption of natural capital will assure that the costs of consumption are always reflected in the farm, and farm sector, income and product accounts, either in the capital consumption account for the natural capital itself or in one of the operating cost accounts. Accordingly, net farm income (or profit) will always be less by the amount of the costs of capital consumption, as it should be. The current failure of the national agricultural accounts to reflect consumption of natural resource capital thus would be corrected.

CONCLUSION

The sustainability of U.S. agriculture can be judged by whether over time the net social income per unit of resources employed by the system is maintained. In making the judgment it is essential that all of the outputs generated by the system, both on and off the farm, and all the inputs employed by the system, also both on and off the farm, be counted. The various outputs and inputs can be represented in a system of accounts, as in Table 6-2 for example. Such an accounting system has the virtue of representing both the marketed outputs and inputs of agriculture, as in the present system of accounts, but also the unmarketed outputs and inputs now left out of the present system.

In this paper the focus is on how to represent on-the-farm inputs of natural capital in a revised system of farm sector accounts. The discussion dealt with this issue with respect to agricultural land. There can be no doubt that if the productivity of the land is reduced by soil erosion or any other form of land degradation, the effect of this must be reflected in the farm sector and national accounts to assure that the contribution of agriculture to social income is accurately measured. How best to represent the productivity decline in the accounts, however, is not so clear. Much depends on how farmers respond to the erosion-induced loss of productivity. If they do nothing, the output side of the accounts will decline and a corresponding capital consumption charge must be made on the input side and subtracted from farm income. The negative income effect of the loss of soil productivity thus will be properly reflected in the accounts. But farmers may take a variety of measures to counter the erosion effect, for example, by adding more fertilizer to maintain production. The output side of the accounts, therefore, remains the same but net farm income nonetheless falls, as it should, by the amount of the increased outlays for fertilizer. In this circumstance to also enter a capital consumption charge against the natural resources account and subtract it from net income would seem to double count the income effect of the erosion-induced loss of productivity of the land.

The principle is clear: judgments about the sustainability of the agricultural production system require that any negative (or positive) effects of the system on the productivity of the natural resource base must be represented in the farm sector accounts. How best to represent those effects, however, depends on how farmers respond to them—or so it seems to me.

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7

Natural Resource Accounting for the Forestry Sector: Valuation Techniques And Policy Implications in Thailand

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SUMMARY AND OVERVIEW

In standard calculations of national income there is a dichotomy in the treatment of natural and man-made capital assets. The differences in accounting procedures effectively overestimate the income generated by natural-resource-based production relative to the income produced using man-made capital, creating market signals that recommend increases in resource exploitation without regard for their full costs. The United Nations has presented preliminary natural resource accounting (NRA) guidelines to modify the current System of National Accounts (SNA), from which national income is compiled, with regard to the treatment of natural resource-related activities. As yet, however, no consensus has been reached concerning a standard technique for valuing natural resources and environmental services in the revised SNA.

The importance of specifying valuation methodologies is highlighted in this paper by a comparison of the policy implications arising from different NRA valuation techniques. Specifically, the "user cost" and "depreciation" approaches were used to modify Thailand's forestry sector income between 1970 and 1995. The two methodologies differed in their implicit evaluation of Thailand's 1989 forest logging ban. While user-cost-adjusted income projections showed the ban to yield net economic gains, the depreciation approach captured changes in wood volume which demonstrated that stricter control of commercial wood removals was required to economically balance forgone forestry income under a logging ban. Thus, while a user cost analysis recommended the ban as economically beneficial, the depreciation analysis suggested that it was not.

The divergence in policy recommendations, however, was not so much a result of differences in the theories themselves, but rather a result of the specific units of measure used to value the resource. The logging ban was found to slow forest area loss, the criterion upon which forest depletion penalties were calculated in the user cost analysis, by 86 percent. The rate at which the volume of commercial wood was removed from the forests, however, slowed only 26 percent; commercial wood volume losses were used as the basis for calculating depreciation adjustments. A continuous decline in the density of Thailand's forests, and dispro

portionate clearing of denser and more commercially valuable forest areas, gave rise to considerably different rates of forest area and commercial wood volume losses. The fact that the two valuation techniques were applied using these two differing rates of forest loss decline, in turn, led to differences in the methodologies' policy recommendations.

NATURAL RESOURCE ACCOUNTING

National income indicators, by which policymakers often judge their countries' economic performance, abstract the costs of natural resource depletion and environmental degradation. By abstracting these costs, national income indicators mislead policymakers, presenting the depletion of environmental assets as income generation. In the case of natural resource extractive activities such as forest logging, income will be recorded as total revenues less extraction costs. No costs are deducted either for the inherent value of the resource or for any damage associated with its removal. Failing to subtract these costs inflates the true value added generated by the activity and presents the sale of an asset as production.

Capital depreciation provides another example of the asymmetrical treatment of natural and man-made capital in the SNA. Depreciation is not an economic transaction but an imputation capturing the decline in income-generating potential of assets over time. Yet depreciation is imputed and deducted only for wear and tear on reproducible, man-made capital. When natural assets are depleted, no analogous depreciation is recorded. The exploitation of resources and degradation of the environment undoubtedly lessen an economy's productive capacity, particularly those developing economies which rely heavily on resource-extracting industries. This being the case, it is clearly inconsistent and misleading to deduct depreciation for productive man-made capital, while ignoring the analogous depreciation of productive natural capital.

Various modifications to the national accounts have been proposed. The different methodologies focus on specific shortcomings in the current income calculations and differ in their valuation of the services provided by the environment.

No standard valuation technique for natural resource accounting has yet been established. Opinion remains divided among market values, opportunity or replacement costs, and discounted future revenues as bases for valuation of the physical units. To remain consistent within the SNA, which was constructed to measure formal market activity, it is generally accepted that only the commercially salable value of forest timber would be included in the valuation of forest resources. Significant nonmarket values and externalities are not captured by these resource depletion adjustments. In this sense, most natural resource accounting adjustments are extremely conservative, reflecting only a small portion of the true social costs of deforestation.

There are two commonly discussed NRA approaches that address resource depletion and degradation in the national income accounts; they are the "user cost" (see El Serafy in Ahmad et al., 1989), and the "depreciation" methodologies (see Repetto et al., 1989). The two methodologies attempt to address a basic asymmetry in the way the SNA treats natural and man-made capital. They differ, however, in the valuation of natural resource depletion.

User Cost

To separate the cost of resource depletion from value added, the user cost approach explicitly calculates and subtracts a capital consumption component from the standard stream of recorded income. The premise of this approach is that revenues from resource-based activities include a component which represents the final sale of a natural asset, a component that is not value added, but rather disinvestment. El Serafy argues that if the owner of a natural asset is to consume only his true income, he must lend or invest a portion of his current revenues that would be capable of generating income to compensate the loss of revenues from his wasting asset in the future.[1] The sale of nonrenewable resources, or the unsustainable exploitation of renewable resources, is similar to the sale of an asset. It contains both a capital component or user cost, and a value added or income component.

In the case of renewable resources such as forests, El Serafy claims that an appropriate maintenance or reforestation cost, the cost required to sustain the productivity of natural capital, should be charged against the gross revenues of those activities which deplete or degrade the asset. If the asset is not, in fact, sufficiently maintained, the costs which would have been incurred in doing so should be charged against income.[2]

Calculations of user cost will necessarily differ by resource, and difficulties are certain to arise in defining maintenance. To maintain forest resources, for example, should the area of forest or the volume of wood be the appropriate criterion by which to measure depletion and, hence, replacement? Furthermore, if numerous technically acceptable means of maintenance exist, with widely varying costs and benefits, what criteria should be used to choose among them? In most cases, data availability will be the practical arbiter of such questions, but standardization and comparability will be comprised as a consequence.

The Depreciation Approach

The depreciation approach emphasizes actual natural resource depreciation, in contrast to the user cost approach which focuses on losses in future income resulting from the decline in natural resource productivity.

Standard calculations of national income impute and subtract the depreciation of man-made capital from gross domestic product (GDP) to arrive at the net domestic product (NDP). The rationale behind imputing depreciation is that the wear and tear of capital usage today will decrease the productivity of this capital in the future, and that this decreased future

[1] Whether investment actually occurs is irrelevant. The methodology is designed to isolate the portion of revenues which could be consumed without decreasing future income. Limiting consumption to this level is therefore necessary, though not sufficient, to insure non-declining income.

[2] El Serafy, 1989.

productivity should be reflected in net national income. The depreciation approach argues that this same logic applies to the degradation of natural assets, yet in the case of natural resources, no decrease in productivity, or depreciation, is reflected in the accounts.

Stocks of natural assets therefore ought to be compiled and depreciated in the manner of man-made capital, to more accurately reflect the country's declining productive capacity. Specifically, the value of the net change in natural resource stocks over each accounting period should be calculated as depreciation. This natural resource depreciation would then be subtracted from GDP, in addition to the depreciation calculated for man-made capital, to arrive at a resource depletion-adjusted NDP.

A Case Study from Thailand

Thailand's ban on forest logging provides an illustrative backdrop to examine the policy implications of natural resource accounting methodologies. Here, both the user cost and depreciation valuation techniques were applied to adjust forestry sector income in Thailand.

Thailand's Forest Logging Ban

Despite a long history of forest management, deforestation has been significant in Thailand. In the beginning of the twentieth century, over 75 percent of the kingdom was covered with forest. Since 1960, the forest has shrunk at an average annual rate of roughly 2.5 percent, peaking at over 3.3 percent in the 1970s. Official estimates claim that less than 27 percent forest cover remains. Unofficial estimates suggest the actual figure may be closer to 18 percent.

In the fall of 1988 Thailand suffered floods and mud slides which killed more than 370 people. The intensity of the floods was blamed on the area's severely deforested surroundings and watershed. A nationwide logging ban was issued in 1989 in response to the floods and growing public concern for Thailand's forests. The ban itself is not totally restrictive. It allows, for example, the felling and sale of trees in privately operated forest plantations, harvests of designated species and trees which have been damaged by age or natural disasters, and the clearing of forests for infrastructure projects.

Official data reported by the Royal Forest Department (RFD) showed a significant decline in forest area losses following the ban. The rate of deforestation fell from 1.7 percent in the 1980s before the ban, to less than 0.3 percent after 1989—a decline of nearly 86 percent below projected trend levels.[3] The success of the ban, however, is not as clear as these numbers make

[3] In the absence of a logging ban, deforestation is projected to continue at a declining rate. The effects of the ban must therefore be considered as the actual decline in deforestation, less the decline expected in the absence of a ban. For details of the forest area and volume calculations reported here, see Natural Resource Accounting: A Case Study of Thailand's Forest Management, (1992).

it appear. Each year since the establishment of the ban, an average of over 300 square kilometers of forest has been cleared. In addition, the ban has been considerably less successful in slowing the volume of commercial wood removed from the forests.

The estimated annual volume of commercial wood losses has fallen just 26 percent from projected trend levels since the ban. The forests that have been illegally logged since the 1989 ban must therefore be significantly more dense and/or support a higher percentage of commercial species than those previously logged. In other words, forest loss has been successfully slowed only in those areas where it is least profitable.

Moreover, if the government-awarded concessions had been optimally managed to maximize wood extraction and minimize environmental damage, then this shift from previous patterns must imply a more ecologically harmful system of forest logging.

Illegal logging is not a new phenomenon in Thailand. A ban on legal logging could only serve to increase the well-established demand for illegally procured logs. In 1980 the total illegal harvest was estimated to be twice the magnitude of the legal cut,[4] and in 1991 it was believed to be more than six times as high.[5] In some villages where government officials exercise their full authority, and where powerful political and business interests are absent or uninvolved, the ban has been successful in halting deforestation. In many areas, however, losses of legitimate logging employment and rising log prices have led to actual increases in cutting.[6]

Enforcement of Thailand's logging ban is likely to become even more difficult in the future. In order to insulate Thailand's wood-related industries from the adverse effects of a restricted domestic log supply, policies to facilitate regional timber imports were adopted in concert with the logging ban. Certification requirements were lifted, customs procedures were expedited, and duties fell to negligible levels. Thailand's log imports grew more than four-fold in the first two years following the ban and are causing a sizable spill-over effect of deforestation and environmental damage in the region. It has become increasingly apparent that while Thailand's forests may be spared by the logging ban, Thai import demand has contributed to widespread and relatively uncontrolled logging in the forests of its trading partners. The isolated national ban is simply shifting deforestation across borders. In response, however, the Southeast Asian nations have begun to tighten regulations and control the flood of logs into Thailand. The upward pressure this will exert on the market price of logs will in turn bolster the demand for, and profitability of, illegally procured logs.

Income growth in the wood-based industries has not been significantly affected by restrictions on the domestic log supply. Since the 1970s Thailand has encouraged the production of higher value added processed wood products. As a consequence, the total income earned by

[4] Bangkok Bank Monthly Review, June 1980.

[5] Thai Forestry Sector Master Plan, Markets for Industrial Forest Products and Roundwood in Thailand, (Bangkok: Royal Forest Department, 1991), p. 11.

[6] MIDAS Agronomics Company, Limited, Study of Conservation Forest Area Demarcation, Protection, and Occupancy in Thailand. (Bangkok: MIDAS Agronomics Company, Limited, 1991).

wood-based industries exceeded that of forestry in 1977, and by 1990 it was nearly five times as high. Wood-based industries include paper and paper products,[7] furniture, and processed wood products, all of which have continued to grow since the ban. The construction sector, which accounts for the use of roughly 90 percent of domestic logs and 65 percent of imported logs,[8] has been one of the strongest performers in the economy, showing strong uninterrupted growth following the 1989 ban.

Natural Resource Accounting Analyses

The adoption of legislation to preserve natural forests presupposes that those forests embody social value. Current calculations of national income, however, assign no value to standing forests. Standard economic indicators are thus inappropriate tools for analyzing the economic effects of such policies because they would tally only the costs, and assign no value to the benefits, of forest preservation. Natural resource accounting can be used to impute and incorporate a value for standing forests so that the economic success of forest protection can be more comprehensively assessed.

User Cost

The user cost of forest exploitation in Thailand was calculated to adjust forestry sector income before and after the 1989 logging ban. User cost, following El Serafy, was defined as the expense incurred in replanting the forest area cleared each year, and minimally maintaining it to a harvestable age. The calculation of this charge requires specification of the timing, costs and extent of reforestation.

The timing of forest replacement will affect both the total area and cost per unit area reforested. Here, reforestation was calculated for the net area cleared of forests at the end of each accounting period. Yet, as will be discussed below, a considerable decline in the density of forested areas has occurred as well. Charging the costs of reforestation only when an area is fully cleared postpones the penalty to an accounting period in which most, though not all, of the forest loss occurs.

Before an area is cleared, however, it still retains great natural regenerative capacity. Because it is the loss of this productive capacity that is measured by user cost, it would be inappropriate to apply the penalty to an area in which natural rehabilitation was not significantly compromised. Even if a practicable definition could be found to identify the point at which forests no longer can effectively renew themselves, the lack of forest volume data in Thailand

[7] The Thai pulp and paper industry is also insulated by its reliance on waste paper and non-wood pulp for fiber inputs.

[8] Thai Forestry Sector Master Plan, "Markets for Industrial Forest Products and Roundwood in Thailand," (Bangkok: Royal Forest Department, 1991).

makes it impossible to distinguish declining forest density until the forest's crown disappears from LANDSAT images altogether, and the area is recorded as non-forest.

Furthermore, past experience replanting forests as they are thinned, rather than after they are cleared, suggests this method of reforestation is prohibitively expensive and complex in Thailand. Unsuccessful replanting of selectively logged forests led to calls for forest clear-cutting in the mid-1980s; a practice which was then officially agreed to on an experimental basis, but which had always been the de facto system of logging. The only "technically acceptable criterion" for reforestation in Thailand would therefore appear to be total replanting of cleared forest areas.

The second issue to be clarified in defining user cost, is whether forests should be maintained in terms of land area or wood volume. If a wood volume approach were adopted, larger tracts of natural forest cover could be replaced with smaller, higher-density, monoculture plantations. Wood, however, is only one of many forest products. Many nonmarket forest functions would in fact be hampered by high volume monoculture plantations. Plantations of this type crowd out undergrowth, limiting the diversity of flora and hence fauna supportable in the secondary forests. Widespread public protests have occurred regarding the harmful effects of commercial plantations, particularly eucalyptus which has been found to significantly draw-down the water table of surrounding agricultural lands.

Moreover, there is a clearly articulated social preference in Thailand to maintain significant, specified areas of forest cover. Each of Thailand's seven National Economic and Social Development Plans (1961-1996) have called for a target of at least 37 percent forest cover in the country, though in nearly all periods actual forest area has fallen well below the target level. These repeated calls for ecological balance suggest that conservation of forest area in itself is a priority for Thai society.

Deforestation was therefore defined as the net forest area cleared each year. Forest losses by region over the period were calculated by interpolation of periodic aerial photography and LANDSAT survey data published by the RFD.

The cost of reforestation was calculated as the sum of the present discounted costs of establishing a forest plantation, and maintaining it until a harvestable age. This would be the amount necessary to set aside in the year deforestation occurred in order to fund complete forest renewal.

Reforestation is by nature a labor-intensive operation. The cost of reforestation is thus driven by the cost of labor. Calculations of reforestation costs over time were therefore derived primarily from labor requirements and regional wages. A conservative estimate of the cost of labor was calculated at the prevailing legal minimum wage.[9] Labor requirements for

[9] The wages commonly paid to workers are often below the legal minimum, in which case actual labor costs might be inflated. The assumption of legal minimum wage for labor involved in replanting, however, could also be expected to understate total labor costs by not explicitly differentiating supervisory from unskilled labor wage rates, excluding any labor contracting costs which are common to the region, and ignoring any upward pressure in localized wages which might be created by replanting schemes.

reforestation were drawn from a study of the employment effects of forest plantations by Tingsabadh, and based on a ten-year profile for the establishment and maintenance of a mixed forest plantation.[10] A mixed plantation standard was used on the assumption that, though monoculture plantations have somewhat lower maintenance costs, mixed forests present closer ecological approximations of natural forests. Similarly, while fast-growing tree species such as eucalyptus have shorter maturation periods, these foreign species are less acceptable substitutes for Thailand's natural forests, and their use has met with stiff local resistance. Costs over the ten-year cycle were discounted back to the year deforestation occurred in order to arrive at the present value of reforestation per rai by region in each year.

The series of present value regional labor costs was then weighted by the proportion of terrestrial deforestation, and hence required reforestation, in each region during the relevant period. To this, capital costs were added. Capital requirements, which account for roughly ten percent of total costs, are relatively small and unchanging. Capital inputs were therefore assumed to be a constant ten percent of labor cost in each period. The time series of reforestation costs calculated under these assumptions fell well within the range of published cost estimates for plantations of various types. Finally, total costs were deflated to create a time series of total, real reforestation costs per rai. The resulting series was multiplied by net deforestation in each period to arrive at the real user cost penalty for that period. This forest depletion penalty was then subtracted from forestry sector income to determine the user cost-adjusted forestry income in each period.

Depreciation

A similar series of resource depletion-adjusted forestry income was calculated following the depreciation approach. Depreciation was defined as the net change in value of the forest asset. It was calculated as the volume of commercially valuable wood removed from the forest annually, priced according to its stumpage value. This represents the opportunity cost of wood still standing in the forest.

This methodology captures only the commercial timber loss resulting from deforestation. It is an understatement of the true loss to society because it excludes the value of environmental services, nonmarket forest production, and non-commercial timber species. Restricting adjustments to commercial timber, however, will maintain the consistency of the SNA, a system which is designed to reflect only market transactions and their clear proxies.

The physical volume of the forest stock will depend on both forest area and density. Forest area estimates were derived from published and secondary RFD data sources, and broken down into four types in four regions using intermittent RFD surveys. Proportions of the forest types for each region were interpolated between the two survey years, and elsewhere assumed

[10] In this study a mixed dipterocarp plantation was used as a model, though the choice of species actually planted would not be limited by this assumption. The ten-year cycle of planting and maintenance could be applied to most indigenous forest species in Thailand.

constant. The constructed forest area time series reflects the net changes in each period, by forest type and region. These area estimates are the same as those used to calculate the user cost penalties.

No current or time series forest density data exist for Thailand. The First and Second National Forest Density Inventories performed in Thailand between 1969 and 1973, and 1975 to 1979, are still considered the best available density measures. A considerable decrease in density, approximately six percent annually, was seen between the two surveys, suggesting that forests were being thinned as well as cleared over time. A straight application of the late 1970s densities would thus almost certainly overstate actual forest volume by failing to account for such thinning. On the other hand, a projection assuming a continuation of the rate of decline in density seen between the two inventory periods might well understate actual densities, because the period in which the measurements were made was a time at which forest clearing was at its peak.

The relationship between the rate of change in forest area and the rate of change in forest density was found to be statistically significant at the 95 percent confidence level for each of the forest categories over the period between the two national inventory surveys. A simple model was therefore constructed using deforestation rates as a proxy for pressure on the forests to estimate the change in forest densities by type and region.

This derived density function was used to project changes in density from a base-year measurement of the second national forest inventory in 1977. The density model permitted both increasing and decreasing forest densities, capturing natural regeneration in previously thinned forest areas where decreased pressure on the forest allowed for net growth. Where this relationship projected an increase in forest density that exceeded the forest type's natural growth rate, the natural growth rate was used to project density changes. The estimated density series,[11] as expected, fell markedly over time, but did so at a declining rate after the late 1970s.

The total volume of the forest stock over time was calculated by applying forest densities by type and region, to the corresponding forest areas. These calculations, like those performed in the user cost analysis, capture only the wood loss resulting from total forest clearing; declining densities in remaining forest areas are not reflected by these measurements.

Changes in the physical volume of the forest stock must be quantified in monetary terms if they are to be incorporated into a national income accounting framework. The market price of wood products, however, is not an appropriate value to attach to the wood inherent in a standing forest. A stumpage value, the value of wood still on the stump, must therefore be calculated.

Stumpage values are calculated from the market prices of wood products by subtracting the costs and profits associated with their production. These costs generally include extraction,

[11] Density measures were given in hoppus volume cubic meters per hectare. Hoppus volume is a measure of useable wood, roughly equal to 80 percent of total log volume, and 50-70 percent of total stem volume. Only those trees over 100 centimeters in girth at breast height (gbh) were included in the volume inventories.

transport and processing. Here, world average export log prices were used as a starting point for the calculation, as they reflect the economy's opportunity cost of wood.

Extraction costs were estimated from benchmark year reports on the cost of forest log felling and removal. Transport costs were calculated in two parts. Estimates were first made for the cost of transporting logs from their roadside felling sites to sawmills. The rates charged for these transfers were higher than the standard transport rates because they travelled more remote and less well kept road networks. Average distances between felling sites and sawmills were used for each region.[12] The second component of transportation cost was the transfer of logs from sawmills to Bangkok. Stumpage values calculated from freight-on-board prices must include all of the costs required to deliver logs to the location at which export prices would apply, in this case Bangkok. Regional distances were determined by weighting the distance from provincial capitals to Bangkok, by each province's sawmilling capacity. Cost rates for standard highway trucking were then applied to find the cost of transfer from mills to Bangkok.

Regional stumpage values were applied to that portion of wood volume loss that could reasonably have been expected to arrive at market. Wood that either lacks commercial value or is effectively irretrievable has no opportunity cost. Volume was therefore adjusted to include only commercial species in each region. Percentages of commercial species by region were taken from a study by Thammincha[13] and were assumed to remain constant. Adjustments were also made to allow for the volume of timber normally damaged in the logging process, an amount which would contribute to net forest loss, but which could not be expected to reach market. A ratio of 1.71[14] was used to reflect the total volume of wood felled or damaged for every cubic meter marketed.

This stumpage value, applied to the adjusted volume of wood loss over each accounting period, represents the depreciation of Thailand's forest assets.

Findings and Policy Implications

Following both the user cost and depreciation[15] methodologies, depletion-adjusted forestry sector income between 1971 and 1982 were actually negative. A reversal in the sign of adjusted forestry income results from the fact that climbing rates of deforestation in the 1970s were not matched by corresponding increases in the sale of timber. Standard measures of

[12] Average Costs and distances were taken from Wuthipol Hoamuangkaew and Prakong Intrachandra, The Structure of Sawmilling Industry (Bangkok: Royal Forest Department, 1991).

[13] Songkram Thammincha, Thailand's Forest Resources Data. (Bangkok: FAO, 1982).

[14] This ratio was taken from *Accounts Overdue: Natural Resource Depreciation in Costa Rica* (1991) and corroborated by informal estimates of logging damage in Thailand.

[15] For purposes of comparison between the methodologies, the depreciation penalty is subtracted from GDP rather than NDP in this section.

forestry GDP over the period remained quite steady while depletion penalties rose, leading to negative depletion-adjusted incomes. An implication of this is that deforestation in the period was not effectively driven by commercial logging operations but was more the result of agricultural expansion and forest encroachment.

The magnitude of the forest depletion adjustments calculated using the depreciation approach were generally larger than the comparable figures produced following the user cost approach, particularly before 1979. Differences arise from the fact that the user cost approach, in this study, was calculated on a forest area basis, while the depreciation approach was based on the volume of commercial wood lost.[16] A continuous decline in forest density made these differences more pronounced in the earlier years, when changes in forest area led to proportionately larger changes in wood volume.

Resource depletion adjustments indicate that the failure to account for the cost of deforestation in standard measures of GDP, has led to consistently overstated levels of national income in Thailand. Following the user cost approach, GDP adjustments for forest loss between 1970 and 1990 yielded an average annual income 1.45 percent lower than the figures derived by standard calculations. The depreciation approach called for an average downward adjustment of 2.17 percent.

At the same time, the adjustments indicate that the rate of Thailand's GDP growth is actually understated. Standard GDP calculations found 7.29 percent real average annual growth between 1970 and 1990. Over the same period the user cost-adjusted incomes grew at a rate of 7.38 percent, while depreciation adjustments resulted in a real growth rate of 7.61 percent. The upward adjustment in income growth was a result of the declining rate of deforestation, and hence the declining magnitude of resource depletion adjustments since the 1970s.

To examine policy implications of the two NRA accounting analyses, two different logging scenarios were projected to the year 1995—assuming continuation of the current ban and assuming that the ban had never been imposed.

The two approaches differed in their implicit evaluation of the logging ban. The ban severely restricts recorded forestry income, regardless of its effectiveness in terms of forest protection. Resource depletion penalties, however, are calculated in proportion to actual forest savings. The magnitude of foregone forestry income relative to savings in terms of forest resource depletion penalties will dictate whether the policy yields net economic benefits. User cost calculations in this case showed forest area savings to be of greater value than foregone forestry income, hence, the positive user cost-adjusted incomes. Forest savings in terms of commercial wood volume, the measure by which depreciation penalties are calculated, were considerably lower and did not outweigh foregone income. Depreciation-adjusted incomes were therefore negative.

[16] The choice of "area" rather than "volume" as a measure of forest loss in the user cost analysis gives rise to the major differences seen here between the two methodologies. These results reflect the specific assumptions made by the author and do not suggest the theoretical superiority of either approach.

Results of the user cost adjustments to forestry income recommend continuation of the current logging ban. The ban led to considerable decreases in forest area loss, and therefore decreases in user cost depletion penalties. The value of these forest area savings outweighed losses in recorded forestry GDP, making a continued logging ban the highest income scenario. An enforcement level of 80 percent, in forest area terms, was required to achieve net economic gains following the user cost approach.[17] The current ban has decreased forest area losses by 86 percent, hence its recommendation by the user cost analysis.

The depreciation-adjusted income projections, however, recommend a different policy ranking. While the ban has produced environmental gains, enforcement must be tightened to yield economic benefits as well. An enforcement level of 50 percent, measured by commercial wood volume losses, was required to balance forgone forestry income and produce positive depreciation-adjusted incomes. The current ban, however, achieved only a 26 percent decline in commercial wood volume removals, thus creating net economic losses when depreciation adjustments were made.

The explicit accounting of commercial wood volume changes in the depreciation methodology called attention to important facts concerning the sufficiency of the logging ban's enforcement; facts which failed to be reflected in the user cost analysis. It is clear that effective forest protection in Thailand has been extended only to those areas in which logging is least profitable. Continued illegal logging in Thailand's most dense, commercially valuable forests has led to unintended and unnecessary economic and ecological damages. It should be noted, however, that in this instance the difference in illustrative power of the two methodologies is largely a result of the variables chosen in their application, rather than a consequence of the two techniques' theoretical underpinnings.

CONCLUSIONS

Recognizing the costs and consequences of its forest use policies, the Thai government banned commercial forest logging in 1989 to protect the country's forests and restructure its management system. The logging ban was originally expected to be an economic sacrifice for environmental gains; ironically, it has resulted in little of either. The economy has been largely insulated from the ban's anticipated negative effects, while deforestation continues in Thailand's most pristine and commercially productive forests and grows rapidly in neighboring countries.

On a national level, the economic and forest area losses that have been incurred under the ban are not inevitable consequences of the legislation, but rather the result of failed enforcement. When calculated in terms of forest area, the rate of deforestation declined by 86

[17] Simulations were performed to find the threshold level of enforcement at which net economic gains could be achieved under a logging ban. Scenarios were constructed assuming varying levels of ban enforcement, where the level of effective enforcement was judged to be the percent decline in deforestation below its expected trend.

percent following the logging ban. The loss of commercial wood volume, however, declined by only 26 percent. If the ban were more strictly enforced, and commercial wood volume losses were curtailed by 50 percent, the logging ban could achieve both net economic gains[18] and forest preservation in Thailand.

Both the user cost and depreciation methodologies suggested that standard GDP calculations overstated Thailand's national income as a consequence of failing to account for forest depletion. The user cost methodology suggested that real GDP was overstated by an average of 1.45 percent annually, while the depreciation adjustments found GDP inflated an average of 2.17 percent. Gross capital formation was found to be 6.4 and 9.5 percent inflated, following the user cost and depreciation methodologies respectively.

A natural resource accounting analysis of Thailand's forest logging ban pointed to the differences between the two approaches. The user cost analysis found the ban to be both ecologically and economically beneficial, while depreciation adjustments suggested that forest protection was not sufficient to reap net economic gains. This divergence, however, is not so much a result of differences in the theories themselves, but rather of data choices in their application.

If the costs and benefits of resource use policies can be prescribed by the choice of valuation technique, then natural resource accounting without a standardized valuation methodology cannot provide a consistent analytical framework for the economic evaluation of resource management.

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[18] Economic gains are defined here in terms of user cost and depreciation adjusted forestry sector income.

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8

Soil Quality in Relation to Value and Sustainable Management

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INTRODUCTION

Soil is a vital natural resource, whose quality is inextricably linked to the human quality of life. Processes that affect the soil resource base impact the quality of life, either directly by affecting food and fibre production or indirectly by affecting other natural resources such as air, water and wildlife. The link to human quality of life gives soil *value*. My assigned task is to address how soils are valued, with specific emphasis on the "weaknesses in conventional measures of crop yields from a soil science perspective." It is my intention in this discussion paper to raise issues related to soil value in terms of the capacity of soil to produce food and fibre tempered by the need to account for impacts of land use on the quality of life, e.g., "green accounting," over the long-term.

I am suggesting in this paper that, in order to better reflect the depletion of the soil resource base and environmental damage associated with its use, crop yield alone must be considered inadequate as a measure of soil productivity, that the concept of maximum economic yield (MEY) of the 1970s and 1980s be replaced by maximum sustainable yield (MSY), and that deliberate efforts must be made to design management systems that are inherently sustainable and establish standards for soil quality as a measure of that sustainability.

SOIL PRODUCTIVITY AND CROP YIELDS

Point I. Crop yield alone is not a good measure of soil productivity because (1) long-term yield data by soil type are limited, and (2) maximum yield is not a sufficient measure of productivity because it does not reflect all costs of production, including environmental costs.

From an agricultural perspective, the value of soil has traditionally been measured in terms of its productivity, defined as the capacity of a soil to produce a plant or sequence of plants under a physically defined set of management practices (Soil Survey Staff, 1951). Soil productivity, then, includes two aspects: the inherent productivity of soil and its response to managed inputs. Crop yield has been considered the best indicator of soil productivity as it integrates the inherent and managed components of soil productivity. However, using crop yields as a measure of soil productivity is difficult since yield data are limited, are spatially and temporally variable, and depend on the management and level of technology used (Pierce, 1991). Well-documented yield records are scarce and usually available only from farmers' long-term records, crop yield surveys, and plot experiments. Farmers' yield records are field-based, which actually represent averages of a number of soil map units and combined fields with varying management histories. As fields continue to increase in size, field yields increasingly average across management units, making identification of specific soil yield potentials more difficult. Even when available, a well-documented yield history will not necessarily be indicative of future effects of soil degradation processes. Therefore, alternatives to evaluate land and soil productivity have been intensively pursued.

Land evaluation systems and soil productivity ratings have been developed in lieu of crop yields as a measure of potential productivity (Huddleston, 1984; Olson, 1974; Riquier, 1974; Stewart, 1968; Wagenet et al., 1991). Nix (1968) recognized three approaches. The most common is the analogue or transfer-by-analogy approach and is based on land and soil classifications. A second approach, the site-factor approach; seeks to relate key parameters to biological productivity within a given environment where yield is described by a multiple regression equation. A third approach, called the system-analysis-and-simulation approach, is concerned with resolution of a complex system into simple component processes that are synthesized into a mathematical model of the whole system. The simulation of crop yields utilizing soil databases is gaining in use in land evaluation (Wagenet et al., 1991) and productivity assessment (Williams and Renard, 1985). Each of these approaches has been used not only to assess soil productivity but also the effects of soil degradation, most commonly by accelerated soil erosion, on soil productivity (see Pierce, 1991, for a review). These evaluation techniques will become increasingly important in the design and evaluation of sustainable management systems, as discussed later.

Regardless of the approach, however, land evaluation procedures or indices relate to the potential of land (soil) to produce food and fibre, and hence must correlate to crop yield. This must take into consideration, however, that weather and inputs are major contributors to crop yield, in addition to soil. Farmers consider the most productive and, therefore, valuable soils to be those that produce the consistently highest yields. While important in the equation, crop yields alone are no longer sufficient as a measure of productivity since the costs of production (economic, social, and environmental) increasingly alter the value of production.

SHIFTING FROM MAXIMUM CROP YIELDS TO MAXIMUM SUSTAINABLE YIELDS

Point II. Concerns over resource degradation and environmental damage from agriculture require a shift from crop and economic yields to sustainable yields.

Crop yield as the measure of *soil value* is inappropriate because it "simplifies" the soil by treating it as a closed system in which an array of managed inputs produces a single output, crop yield (Figure 8-1a). This closed system view of soils was exemplified by the "maximum yield" (MY) concept of the 1960s in which large quantities of inputs were used to achieve increases in crop yield, often realizing only incremental increases at high levels of input. Agricultural production systems were characterized by high productivity with huge energy and material subsidies of labor, fossil fuels, pesticides, fertilizers, and irrigation. The tendency was to simplify the agricultural ecosystem by creating monocultures with minimal diversity beyond what was needed to produce maximum yields—a very short-term perspective. Continuous monocultures, particularly corn, tend to require larger subsidies of materials and energy. Such simple ecosystems tend to be ecologically unstable in their characteristic patterns of energy flow, nutrient cycling, and structural change (in terms of species composition, biomass, and spatial organization) (Cox and Atkins, 1979). During the period of MY, soil erosion was a major national problem. The resulting nonpoint source pollution and soil productivity decline associated with soil erosion stimulated the enabling legislation for the protection of soil and water resources, which began with the Water Pollution Control Act of 1965.

It was the energy crisis of the 1970s that moved agriculture to the "maximum economic yield" (MEY) concept in which inputs are limited to those that produce an economic crop yield response. Given typical input yield response curves, MEY would be less than MY. Higher production costs associated with increased energy costs and inflated land values resulted in increased interest in and use of conservation tillage, efficient nutrient management, and Integrated Pest Management (IPM). The shift from MY to MEY was relatively easy for farmers because it was value based at the farm level. The farmer needed to improve his profitability in the face of increased production costs and lower prices for his crops. Therefore, maximizing economic return was essential for those who would successfully compete.

It was clearly demonstrated both by research and on-farm demonstration that decreased inputs could improve farm profitability. It was also clear, however, that agriculture did not buy into MEY completely since farmers continued to apply more inputs than necessary, in part, perhaps, due to their perception of risks involved. For example, yield goal is the key parameter in determining the optimum rate of fertilizer addition. However, farmers apply fertilizers even when soil tests indicate more than adequate levels of these nutrients are available in soil, a sort of insurance application. Some, in fact, ignore soil testing completely. The same is true of nitrogen (N) applications. Farmers will often overestimate their yield goal, apply more than the optimum rate, and/or inadequately account for N supplied from the soil or previous crop in their determination of N fertilizer needs. Schepers et al. (1986) reported that farmers in Hall County, Nebraska, overestimated their yield goal by 40 bushels per acre, resulting in an over application of 40 pounds of N per acre. The extent to which farmers adhered to the MEY concept probably relates to their perception of risks associated with the MEY management practices.

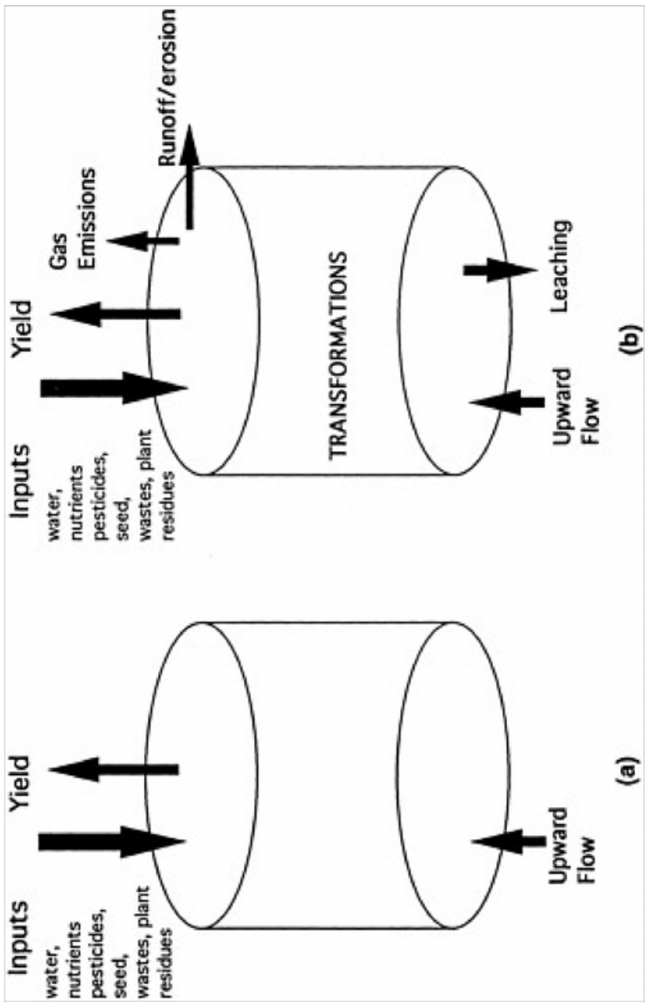

FIGURE 8-1 (a) An illustration of soil as a closed system in which crop yield is the sole output. (b) An illustration of soil as an open system with all its component inputs, outputs, and transformations.

While farmers have undoubtably shifted to the MEY approach, there is little evidence that national accounting systems have moved away from the MY concepts. The focus is still on yield potential without regard to efficiencies of production. This must certainly be regarded as a weakness in the conventional measure of crop yield.

The concept of MEY was directed primarily at the economics of crop production over the short-term. The principles of MEY, however, also had implications for environmental issues which intensified during the 1970s and 1980s and proved useful in providing a basis for the development of best management practices (BMPs). BMPs refer to a variety of agronomic practices and structural practices that are designed to reduce the transport of sediment, nutrients, and toxics to water resources, while sustaining producer profitability. Currently, BMPs are voluntary and, therefore, must be economical if they are to be adopted. Therefore, some BMPs require financial subsidy to offset their costs, such as waterway structures. The point is that the management practices that accomplish MEY also improve water quality. Bock and Hergert's (1991) statement that high N-use efficiency is the main goal of a "best management practice" conforms completely to the MEY concept. However, the relevant question concerning MEY is whether it is sufficient for sustainability? For some soils and cropping systems, MEY may be sufficient; for others, it will not suffice.

Although not formalized, the search for an optimum yield as a *value* for soil is headed towards what I will call maximum sustainable yield (MSY). The concept of MSY embraces the concerns of green accounting without abandoning the traditional view of soil productivity as a capacity to produce crop yield. What changes is the physical set of management practices under which that capacity is defined. Under MSY, the soil is treated as an open system of inputs, outputs, and transformations in which more emphasis is placed on transformations than external inputs to create desirable outputs of crop yield and minimal environmental impacts (Figure 8-1b). The reliance on transformations will require more biological diversity within the soil and thereby increase the complexity within the agroecosystem, resulting in increased stability and resiliency. Where managed inputs are required, they will be tailored to the location specific needs within a field and applied at the time and in a manner conducive to maximum use efficiency or efficacy. Thus, the MSY concept will incorporate the qualities of MEY and at the same time accommodate the goals of green accounting. The next step is to define MSY management systems and what standards will be used to evaluate them.

The sustainable management systems that are emerging in the United States depend more on internal transformations within the soil and less on external inputs. Pierce and Lal (1991) envision the incorporation of ecological principles from natural ecosystems into agroecosystems as the key to developing sustainable soil management systems. They proposed a broad management principle to achieve sustainable management: "managing soils in space and time." Within this framework, they offer three specific management principles.

The first is **farming by soilscapes** in which management practices are matched to specific soil and landscape characteristics within a field. Farmers farm fields which contain a range of soils and landforms that differ in inherent productivity and susceptibility to undesirable material flows, such as erosion and leaching. Technology exists to vary managed inputs as machinery moves across the field so that inputs can be matched to location-specific needs within the field and applied with precision. The net result will be to increase profitability for farmers and reduce soil and environmental deterioration (Robert et al., 1993). The second aspect of farming by soilscapes deals with the notion that controls to a problem occurring within agricultural fields are often located outside the field boundaries. Soil erosion extends beyond field and political boundaries and is best managed on a watershed basis.

The second management principle is to **manage zones within a field**. This is not a new concept, as USDA has used it in the design of water and erosion control measures since the 1930s. New applications of this principle fit MSY as illustrated in the use of trap crops for insect control. Figure 8-2 illustrates the use of strips of potatoes and eggplant as trap crops to manage Colorado beetles in tomatoes. The trap crops attract the beetle, since they are a preferred host plant. Control is made easier when the beetles are concentrated in small strips near field borders. This avoids beetle damage on the tomato plants while minimizing the use of chemicals over the entire field. Alley cropping is another more recent example of managing zones within a field by combining ligneous species with field crops arranged spatially and temporally to provide food and fibre while preserving the soil resource base.

The third management principle is **managing the noncrop period**. During the cropping period, soils are managed intensively. Outside the cropping period, little is done to manage the soil in spite of the fact that the major degradation processes, such as erosion, leaching, and compaction, are often most intense during the noncrop period. The noncrop period affords an opportunity for sustainable management practices that enhance MSY. A prime example is the use of cover crops during the noncrop period which provides for erosion control, weed suppression and fixation of atmospheric nitrogen for use in the succeeding crop, all beneficial to MSY.

I would expect the nature of MSY to be quite diverse and variable but its yield level close to MEY, if the management system were properly designed and the actual management conformed to that design. The perspective of MSY is long-term and unlike either MY or MEY, it is predicated on what happens to the resource base, not just short-term gains.

DESIGN AND EVALUATION OF SUSTAINABLE MANAGEMENT SYSTEMS

Point III. Deliberate efforts must be made to design management systems that are inherently sustainable and establish standards for soil quality as a measure of that sustainability.

Pierce and Larson (1993) recognize that a deliberate effort is required to design management systems that are inherently sustainable and ensure, through quality control measures, that the system processes conform to the design. In an analogy to statistical quality control in manufacturing, they suggest that quality must be built into both the design and the system processes in order to achieve the desired food or resource quality. The overall process of assessing sod quality and evaluating management systems is illustrated in Figure 8-3. A brief discussion of soil quality and statistical quality control is necessary to understand these concepts (based on Larson and Pierce, 1991, 1993; Pierce and Larson, 1993).

The term "soil quality" is relatively new. Soils vary in quality and quality changes in response to its use and management. The changes in quality can be either positive (aggradation)

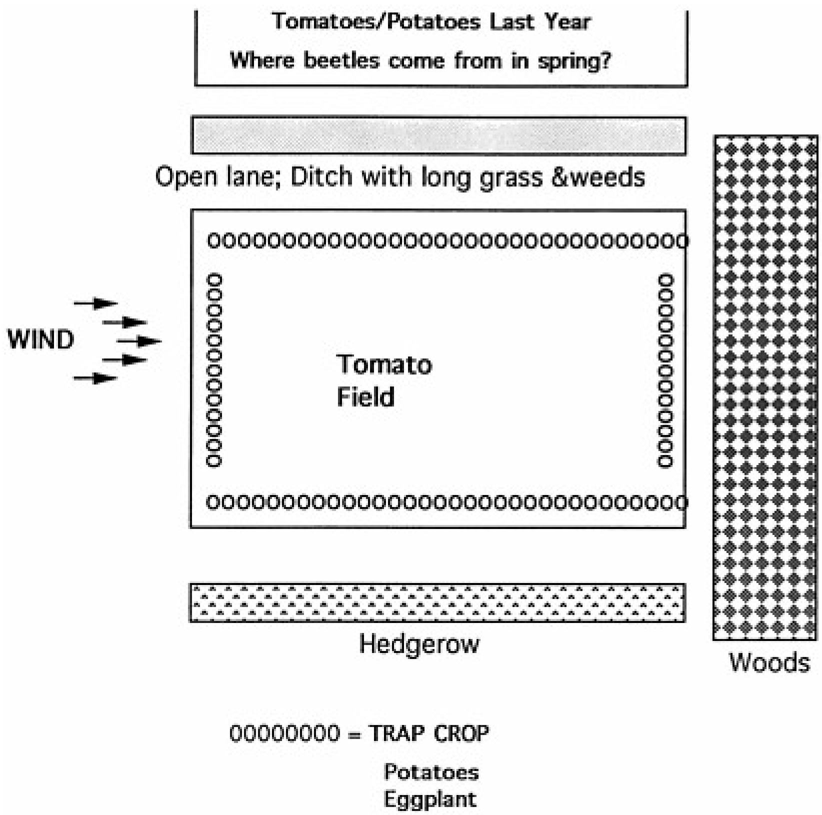

FIGURE 8-2 Illustration of the concept of trap crops for the control of Colorado potato beetle in tomatoes. Source: Redrawn from Janice Elmhirst, O.M.A.F., Ontario, Canada.

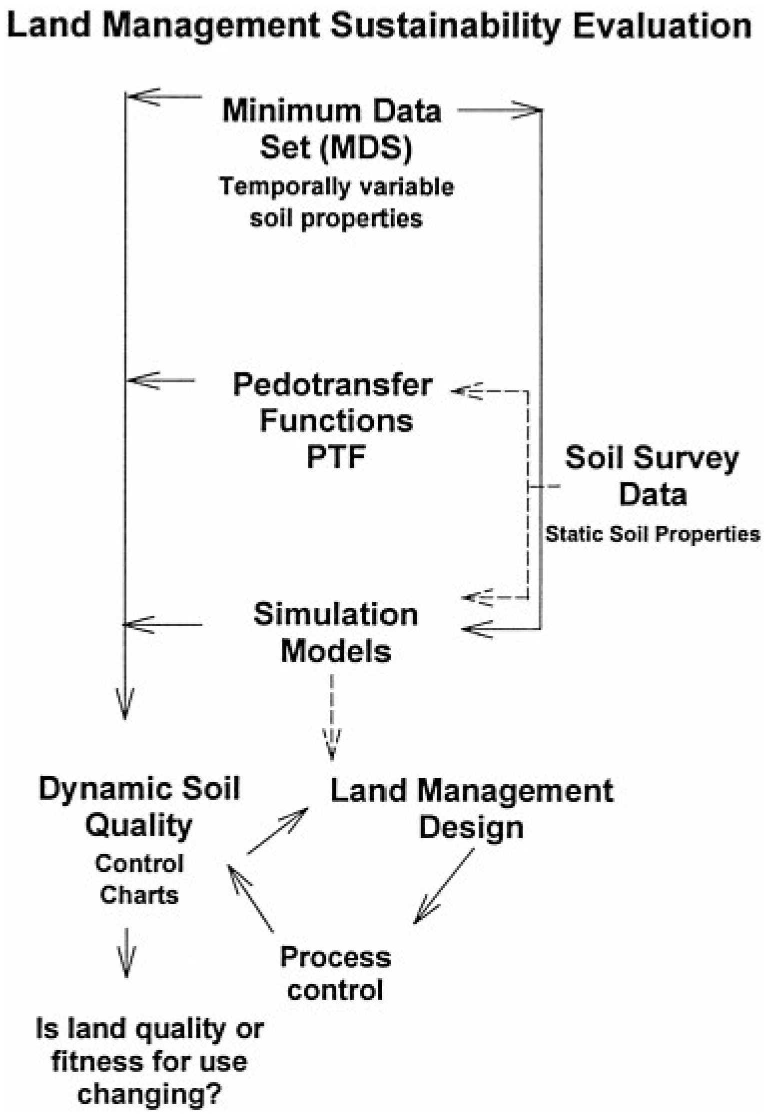

FIGURE 8-3 A flow diagram illustrating a procedure for evaluating the sustainability of land management systems. Source: From Pierce and Larson, 1993.

or negative (degradation). If sustainable systems must maintain or improve soil quality, then a quantitative assessment of soil quality provides a measure of sustainable management. Thus, the performance of a management system can be determined by measuring the change in soil quality parameters.

Larson and Pierce (1991) defined soil quality as the capacity of a soil to function, both within its ecosystem boundaries (e.g., soil map unit boundaries) and with the environment external to that ecosystem (particularly relative to air and water quality). Soil quality relates specifically to the ability of soil to function as a medium for plant growth (productivity), in the partitioning and regulation of water flow in the environment, and as an environmental buffer. As a simple operational definition, soil quality means "fitness for use" (Pierce and Larson, 1993). In this concept, crop yield is not the sole value of soil.

Larson and Pierce (1991) define soil quality, Q, as the state of existence of a soil relative to a standard or in terms of a degree of excellence. It is expressed as a function of attributes of soil quality, q_i, defined as:

$$Q = f(q_{1...n}) \tag{1}$$

While Q is important in land evaluation, sustainable management requires knowledge about changes in soil quality, dQ/dt, defined as:

$$\frac{dQ}{dt} \quad f\left[\frac{\dfrac{(q_{it} - q_{it0})}{q_{it0}} \; . \; . \; . \; \dfrac{(q_{nt} - q_{nt0})}{q_{nt0}}}{dt}\right] \tag{2}$$

An aggrading soil would have a positive dQ/dt and a degrading soil would have a negative dQ/dt.

The functional relationship in Equation (2) is difficult to define and it is impossible to describe Q in terms of all soil attributes. Therefore, Larson and Pierce (1991) proposed that a minimum data set (MDS), in combination with pedotransfer functions (PTF's), be designed to monitor changes in soil quality. An important aspect of an MDS is that it must include soil attributes in which quantitative attributes can be measured in a short time span in order to be useful in land use or management decisions. The components of an MDS are selected on the basis of their ease of measurement, reproducibility, and to what extent they represent key variables that control soil quality. It is important to note that any MDS represents a *minimum* set of attributes to be measured to assess soil quality. Other attributes may be part of an extended data set intended for certain investigations. An example of a minimum data set was described by Larson and Pierce (1991) and a summary is given in Table 8-1. Note that both the type of measurement and a measurement procedure should be standardized, at least within a geographic region. In addition, there are soil parameters that are too costly or difficult to measure that would be desirable in a MDS for soil quality. Fortunately, soil properties are interrelated and can be predicted from other properties using pedotransfer functions (PTFs). A

PTF is described by Bouma (1989) as a mathematical function that relates soil characteristics and properties with one another for use in the evaluation of soil quality (Larson and Pierce, 1991). Therefore, PTFs can be used to extend the utility of the MDS to monitor soil quality. Many PTFs occur in the literature and are statistical or empirical in nature. Selected PTFs were discussed by Larson and Pierce (1991) and are given in Table 8-2. There is no consensus on what a MDS for soil quality should contain. The MDS and PTFs given by Larson and Pierce (1991) represent a starting point. The soil quality MDS is measured over time to assess the dynamics of soil quality. There are two ways of assessing changes in soil quality: (1) through the use of computer models to determine how changes in the MDS impact the important functions of soil, such as productivity; and (2) using statistical quality control procedures, through which a MDS is repeatedly measured over time and the temporal pattern of variation of a MDS parameter or PTF is evaluated (Pierce and Larson, 1993).

TABLE 8-1 Soil Attributes and standard methodologies for their measurement to be included as part of a minimum data set (MDS) for monitoring soil quality (adapted from Larson and Pierce, 1991).

Soil Attribute	Methodology
Nutrient availability for region	Analytical soil test
Total organic carbon (OC-T)	Dry or wet combustion
Labile organic carbon (OC-L)	Digestion with KCl
Texture	Pipette or hydrometer method
Plant-available water capacity (PAWC)	Best determined in field or from water desorption curve
Structure	Bulk density from intact soil cores field measure permeability or Ksat
Strength	Bulk density or penetration resistance
Maximum rooting depth	Crop specific—depth of common roots or standard
pH	Glass electrode-calomel electrode pH meter
Electrical conductivity	Conductivity meter

The use of models for dynamically assessing soil quality is illustrated by the use of productivity indices by Pierce et al. (1983) to quantify soil productivity and the loss in productivity with accelerated soil erosion (Pierce and Larson, 1992). Using a modification of a productivity model developed by Kiniry et al. (1983), Pierce et al. (1983) used the PTFs to calculate a normalized sufficiency of soil pH, bulk density and available water capacity (AWC) for root

TABLE 8-2 A Limited Listing of Proposed Pedotransfer Functions (adapted from Larson and Pierce, 1991).

PTF No.	Estimate	Relationship
		Chemical
1	Phosphate-sorption capacity	PSC + 0.4 ($Al_{ox + F}$Eox)
2	Cation-exchange capacity	CEC = A OC + b C
3	Change in organic matter	C = + b OR
		Physical
4	Bulk density	$D_b = b_0 + b_1$ OC + b_2 Si + b_3 M
5	Bulk density	Random packing model using particle size distribution
6	Bulk density	$D_b = f$(OC, clay)
7	Water retention	$q_{10 =}$ b0 + b1 C + b2 Sy
8	Water retention	q = $b_{1\ (\%}$Sa) + b2 (%Si) + b3 (%Cl) + b4 (%OC)
9	Random roughness from moldboard plowing	RR = *f* (soil morphology)
10	Porosity increase	P = *f* (MR, IP, clay, Si, OC)
		Hydraulic
11	Hydraulic conductivity	$K^s = f$ (texture)
12	Seal conductivity	SC = *f* (texture)
13	Saturated hydraulic conductivity	$D_s = f$ (soil morphology)
		Productivity
14	Soil productivity	PI = *f* ($D_{b,\ A}$WHC, pH, Ec, ARE)
15	Rooting depth	RD = *f* (D_b, WHC, pH)

growth. Once determined, the product of the sufficiencies was weighted by a normalized rooting function to calculate a productivity index, PI as:

$$PI = \sum_{i=1}^{r} (A_i \times C_i \times D_i \times WF) \qquad (3)$$

where A_i is sufficiency of AWC, C_i is the sufficiency of bulk density, D_i is the sufficiency of pH, WF is a weighting factor, and r is the number of soil horizons in the depth of rooting. Using soil survey data contained in the SOILS-5 database and land use and erosion data from the National Resources Inventory, the effect of erosion on soil productivity was estimated for the Corn Belt Region of the United States (Pierce et al., 1984). Both the quality (PI) and the change in quality (PI) were estimated using the concepts given in Equations (1) and (2).

A second approach to assess the dynamics of soil quality from the MDS is the use of statistical quality control. Statistical tools appropriate for assessing changes in soil quality may be found in the use of "control charts." Control charts are a standard device used in statistical quality control in the manufactured goods and services industry. The statistical basis for their use is well established and the types and uses of control charts are very diverse (Gilliland, 1990; Montgomery, 1985; Ryan, 1989). Control charts can be thought of as indicators of changing soil quality.

The basic use of control charts is illustrated in Figure 8-4. Under this procedure, soils would be sampled over time for soil attributes (MDS) representing *quality parameters* or transformed using PTFs to other *quality parameters*. The upper control limit (UCL) and lower control limit (LCL) are set based on known or desired tolerances, or based on the mean variance obtained from past performance or known through some other means. It may be desirable to design the control limits to represent minimum levels for sustainability, beyond which management cannot be sustained, such as minimum soil organic matter content. In the simplest case, as long as the sample mean plots within the control limits, the process or system is considered in-control. When a sample mean plots outside the control limits, the process or system is considered out-of-control, i.e., soil quality is changing. Additionally, trends may occur within the control chart and statistical quality control procedures are. available to analyze these trends. Trends may be indicative of instability in the management system or merely characteristic of the process. For example, the data in Figure 8-5 would be indicative of a system with cyclic variation that operates within the control region (Pierce and Larson, 1993). It is worth noting here that the variance should be charted as well as the mean since changes in variance can be indicative of a system out of control.

The concept of using control charts for each MDS and PTF parameter is useful in quantifying the dynamics of soil quality. It is likely that for a given management system some q_i's may be stable, others *out-of-control*, and others showing trends. A sustainable management system will be characterized by q_i's which are stable over time and if trends occur in the control charts, they are indicative of an aggrading soil quality, not degrading.

An important aspect of process control is that it be in the hands of those managing the process. The manager should be able to interpret the control charts and take appropriate action to adjust the process and bring it back into control. Informing the manager that the *outcome* of

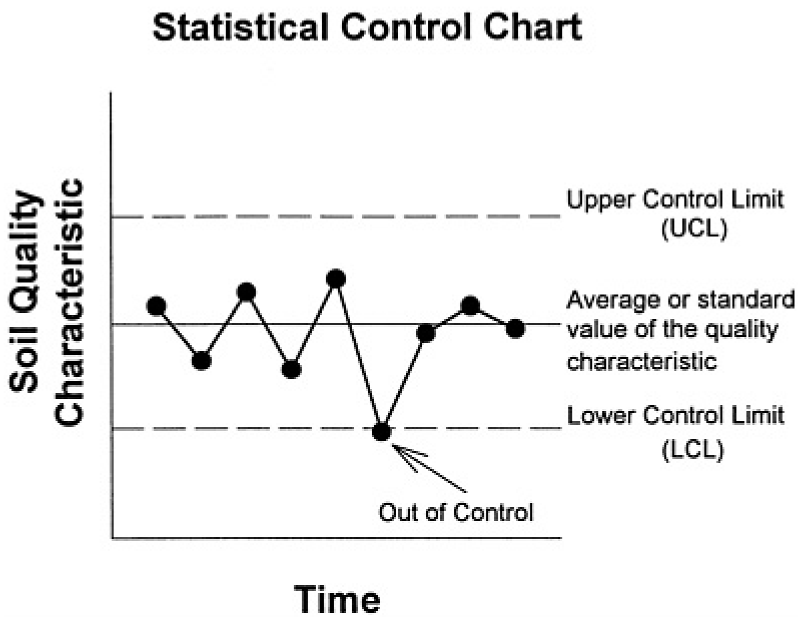

FIGURE 8-4 The basic concept of a Shewhart control chart used for soil quality monitoring. SOURCE: From Pierce and Larson, 1993. After Montgomery, 1985, and Ryan, 1989.

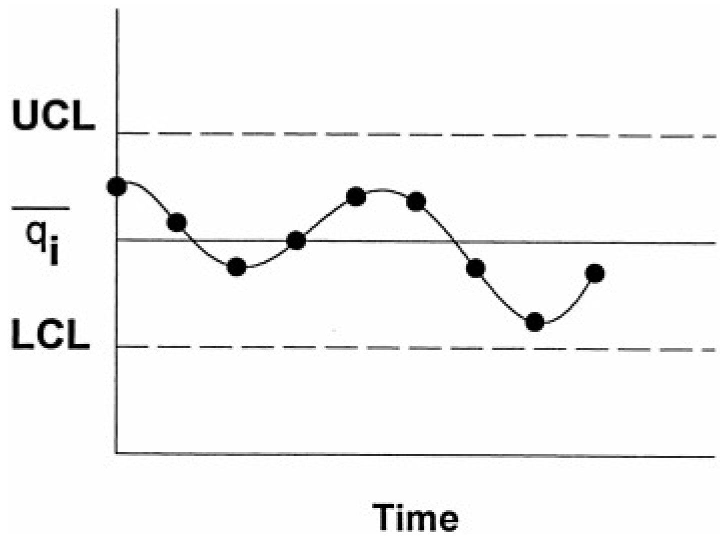

FIGURE 8-5 An example of a control chart with variation within the control limits but exhibiting a pattern in the variation of a soil quality parameter. Source: From Pierce and Larson, 1993.

the process is unacceptable is useless in helping the manager achieve the desired quality of the output. Consider the management of crop residues for erosion control as an example of a management practice that relies on monitoring with little regard for the notion of design and process control (Pierce and Larson, 1993). Residue cover is a key factor influencing erosion control. Until recently, interest focused specifically on the amount of residue cover after planting and it was not uncommon that conservation tillage systems failed to meet the target residue coverage amount of 30 percent on the erosive landscape positions. The problem is that the standard measure of residue cover occurs after most of the management practices that affect residue cover are completed. At this time, it is not possible for the farm manager to alter those practices to ensure the proper residue cover. How would process control measures impact residue cover, if it can be assumed that the design of the system is correct? Since the harvest, tillage, and planting operations impact residue distribution, statistical process controls could be implemented to monitor machinery performance relative to residue management to detect when machinery adjustments are required to achieve desired residue coverage. This level of management is nearly achievable with the site-specific crop management technology currently available (Robert et al., 1993). Thus, if the system is designed to meet the intended output, then through process control the output can be reasonably assured.

Consider the management system design procedure illustrated in Figure 8-3. In this system, soil survey data, MDSs, and PTFs provide input to simulation models to design sustainable management systems and establish standards for soil quality. Control charts of various q_i's are monitored with time and used alone, or in combination with models, to detect *quality control* problems and identify improvement opportunities in the system. Control charts can also be used in combination with MDSs and PTFs to monitor soil quality and serve as thresholds and criteria for *quality standards*.

A design criteria for an MEY system would certainly include the impact on undesirable system outputs to the environment. Figure 8-6 gives a hypothetical plot of profit versus an environmental output from soil such as nitrate-N. The MEY will allow for environmental outputs of nitrate-N that is greater than what might be considered sustainable loss. The MSY must be designed so that it does not exceed the sustainable loss value. As illustrated, MSY would be less profitable. The difference in profit between MEY and MSY would have to be born by the farmer or society.

The following steps are important in the design and evaluation of sustainable management systems that fit the MSY concept (Pierce and Larson, 1993).

- Explicit identification of the desired outputs of a management system.
- Assessment of the design of the system to determine if it will produce the desired output.
- Identification of the soil quality parameters of importance and establishment of *quality standards*.
- Establishment of the starting point for evaluation of a management system. Knowledge of the condition of the soil at the initiation of the management change is required unless the historical record of the site is good.
- Assessment of the system output to determine if it results from the system design, the system process performance, or both.

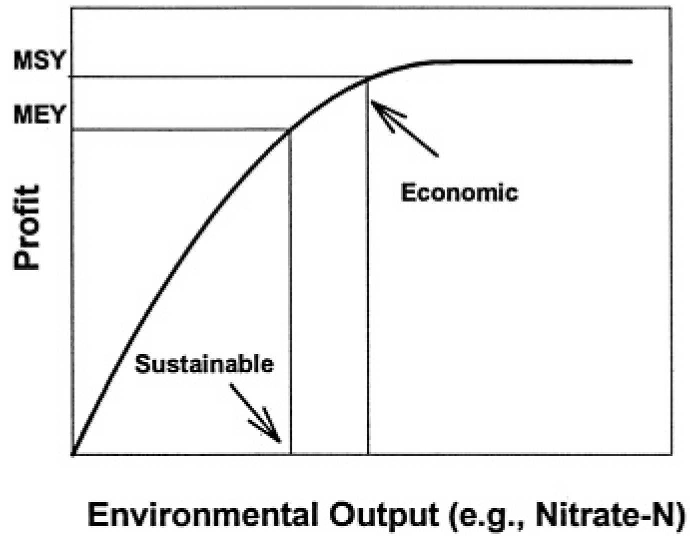

FIGURE 8-6 Illustration of a design criteria for sustainable management systems comparing the profitability of MSY management systems to MEY systems.

- Stabilization of a system process that is *out-of-control*. A stable system of variation is one in which the variation is solely a result of the system in place; there are no special causes of variation (Gilliland, 1990).
- Improvement of the sustainability of a *stable* management system by adjusting it with proper experimental design techniques (note: tampering with a stable system will make the system less stable) (Montgomery, 1985).

SUMMARY AND CONCLUSIONS

I have addressed weaknesses in conventional measures of crop yields from a soil science perspective. I have attempted to show that crop yields are important but alone are not sufficient as a measure of soil productivity or soil value. Crop yields by soil type are difficult to obtain and yields alone do not account for the cost of production. Farmers must operate on economic, and not biological yields, and have realized this for 'some time. It would appear that economic yields may not be the correct measure either as other costs of production (environmental, erosion loss, social, etc.) are realized. A shift to sustainable yields may be forthcoming. However, sustainable management systems must be designed and quality standards set for their proper evaluation. An approach to achieving sustainable management is presented that has utility in accounting for soil degradation and environmental damage from agricultural systems. This requires a shift in the agricultural paradigm from a short-term to a long-term view.

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9

Valuing Biodiversity: An Application of "Green Accounting"

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As concern for environmental degradation grows there has been a corresponding growth in interest in "green accounting": constructing measures of economic activity that accurately reflect the costs of environmental degradation. The effects of such degradation are not immediately apparent. Rapid extraction of petroleum reserves, overfishing, or excessive logging, to give three examples, may result in high short-term values of earnings. Excessive demands on other types of resources may also generate short-term surges in earnings. Production of goods and services may be more plentiful in the short term if the processes of production are allowed to foul air and water, or diminish biological diversity. When viewed over the long run, however, each of these phenomena may result in a decline in future well-being. Accounting measures that do not incorporate such considerations can, then, yield very misleading results.

The realization that short-term flows do not necessarily measure long-term well-being is reflected in the principles of personal, business, and—perhaps to a lesser extent—national accounting. Accounting measures of "income" include corrections for changes in capital stocks. Rather than purporting to measure year-to-year flows of gross production or consumption, they reflect attempts to capture changes in long-term profitability, production potential, or well-being. These long-term changes are induced by changes in the ability to produce goods and services. The stock of capital (in combination with other factors of production) determines this ability to produce.

The measurement of capital can be a difficult problem. Capital is something that is used to transform one (or more) good into another (or others) without itself being transformed. This definition is, of course, too simple. If it were literally true that capital is not transformed with use (or if it did not deteriorate with age), one of the more difficult accounting questions would be side-stepped: we would not need to be concerned with the measurement of depreciation. The essence of the measurement problem, however, is that capital is not itself consumed or transformed. Since it is the services of capital, as opposed to capital itself, that is being consumed in production, we must measure the value of capital in terms of its ability to provide a stream of services, and measure the depreciation of capital as a deterioration in that ability to provide services.[1]

Measurement of the value of capital and the losses arising from its depreciation could, in general, be rather difficult exercises. The value of a capital asset is the expected net present discounted value of the stream of services that it will provide over its useful life, plus whatever salvage value it might have at the end of that period. It is important to realize that this value is computed "at the margin." That is, when we are talking about valuing capital, we consider the net present discounted value of the stream of services provided by one incremental unit of capital. A common error is to confuse the average value—total value divided by total capital stock—with the value of an incremental unit. Doing so can give rise to what are sometimes referred to as diamonds-and-water paradoxes: how can it be that something that is so useful and essential (water for example) is so much cheaper than something that is of such limited practical importance (diamonds)? The answer is that the former is very common and the latter very scarce. We will suggest that many natural assets are like water in their abundance, their total value, and their low value at the margin.

Performing the calculations necessary to value an incremental unit of capital could be a daunting exercise. The value of the stream of services is a derived quantity. In order to compute it, one would have to know both the values to be assigned to the outputs that are produced with the use of capital and other factors and what the contribution of an additional unit of capital is to the production of the outputs. What might one expect the value of the stream of future services to be? What assumptions on future earnings are built into such an estimate? How do we factor in uncertainties about future market conditions and the life of the asset? What is the appropriate interest rate by which to discount future returns?

There is, however, a powerful tool to assist us in valuing many capital assets. If one is willing to assume the existence of more-or-less competitive markets for capital assets, he can use the information provided by these markets in assigning the assets value and in inferring the rates at which value is lost through depreciation. An accountant might avoid painstaking reviews of the many factors that determine the expected net present discounted value of capital assets if she is willing to assume that someone (or many someones) has performed such calculations, and they are reflected in the market prices of capital assets. The accountant can then assume that the value of a new capital asset is what it costs to purchase it, while the rate of depreciation is revealed by the difference between the prices of new and used assets.

This discussion of the measurement of capital and the use of market information to aid in doing so has been something of a digression. The issue at hand concerns the measurement of natural capital. Great difficulties arise in assigning values to natural capital precisely because the markets in which it is traded are limited. The point we want to make is not so much that it would be a good thing if there were more and better markets for trading in natural capital

[1] An analogy may be useful here. Capital is like labor in some ways. One cannot (in the current state of civilization, at least) "buy" a laborer; the services of labor can, however, be purchased, and the payment made for them is the wage. Capital may be both purchased and rented.

(although it most certainly would be a good thing if there were), but rather, that unless or until there are such markets, "green accounting" exercises must remain extremely speculative.

This conclusion begs the question of the purposes for which environmentally accurate national accounting is to be used. It is true that properly constructed national accounts give a snapshot view of national income, although there might still be substantial disagreement as to whether or not what is being measured is in fact the—or even an—appropriate measure of national well-being. It is not clear that changes in national accounting practices will necessarily lead to improvements in economic performance, however. One might think of some cases in which more accurate accounting would feed back to better performance; overseeing the management of public lands, or monitoring the performance of international lending programs are examples that come to mind. In general, however, economic performance will be enhanced by getting incentives right. The national income accounts are a report card from which we can infer performance after the fact, but to modify behavior we must intervene at a much earlier stage. Nor does it seem likely that we can mollify proponents of growth at the expense of environmental amenities by cooking the books. It is unlikely that an increase in measured net national product would spur elation if the trend it plotted were contradicted by other aggregate (e.g., unemployment, wages) and individual (my job, my salary) indicia.

Having said this, there is, of course, no reason not to get the national accounts right, at least if doing so can be accomplished at a socially acceptable cost. We are only advising caution in the expectation of benefits to be achieved by doing so. An environmentally correct system of national accounts would, at best, indicate only the success or failure of efforts to allocated natural resources appropriately; other than serving as a warning that this is not being done, more accurate accounting cannot be expected to induce change in and of itself.

In the following section we very quickly review some principles of national income accounting and .discuss some of its controversial aspects. After that we discuss some of the special issues likely to arise in the depletion of natural assets, and, particularly, of what are called non-rival goods. We discuss a particular example in which national income accounting might be extended to biodiversity in the third section following. A final section concludes.

NATIONAL ACCOUNTING: A VERY BRIEF OVERVIEW

This paper will be largely devoted to the discussion of an example of the possibilities and potential difficulties of including a particular type of natural capital—genetic diversity—in national income accounts. For a discussion of the fine points of the conceptual rationale and practical details of constructing environmentally accurate national income accounts, the reader is referred to the excellent summaries prepared by other authors (see, e. g., Solow, 1992; Dasgupta and Maler, 1991; Ahmad, E1 Serafy, and Lutz, 1989; the papers collected by Costanza, 1991; and Krautkraemer, Pezzey, and Toman, 1993). We will, however, attempt self-containment by alluding to some basic principles of national product accounting.

A good starting point is with what it is that national accounting purports to measure. Regrettably, a narrow definition of even such a basic point as this is unlikely to be agreed upon by everyone. We will beg the reader to bear with us as we call this goal "long-run consumption possibilities."[2] Now "long-run consumption possibilities" may differ from "current consumption" as the latter may not recognize the depletion of resources necessary to maintain future consumption.

We will gloss over a great many important considerations by merely citing in a schematic form a result due to Weitzman (1976): national product, if properly measured, indicates the "stationary equivalent of future consumption" (Weitzman, 1976, p. 160). In other words, if Y* is this year's national product, the total net present discounted value of all future consumption would be the same as that arising from consuming Y* every year. Excessive consumption in the present—using up resources in consumption, or consuming more rather than replacing depreciated assets—results in a decline in the level of consumption we could enjoy in all future periods.

Another important concept is due to Hartwick (1977, 1978; see also Solow, 1986): constant consumption levels may be maintained even if some resources are exhausted if the value of the exhaustible resources consumed is offset by new investments in capital. Thus we have "Hartwick's Rule": intergenerational equity[3] can be achieved by investing the scarcity rents arising from the depletion of natural resources in the acquisition of man-made capital assets.[4] Hartwick's rule is only meaningful in circumstances in which man-made capital can be substituted for natural assets, however. This may well be the case for fossil fuels and minerals; Daly (1991; see also Daly and Cobb, 1989) and others have argued eloquently that it is not the case for biological assets and ecosystems.

[2] We do not ask that the reader necessarily agree with the utilitarian foundations we are sketching, only that he acknowledge that if one takes a utilitarian approach, something like national income is likely to be of importance. Having agreed to look at the problem from a utilitarian perspective, the next question is how we are to define "consumption." We will be deliberately vague on this point, stating only that consumption in this broad sense is a function of the goods and services available in the economy.

[3] We use this term advisedly; equity is, of course, very difficult to define. It seems reasonable to suppose that the sense of equal consumption across generations is appropriate, however.

[4] This sentence may require some additional explanation. Natural assets whose stock can be reduced by human activity command "scarcity rents." Consider an oil well. The owner has a choice between taking an additional barrel out of the ground now or leaving it in and waiting until next year to take it out. This being the case, if the owner is not to remove the entire deposit, she must be indifferent between the earnings she will receive on that barrel of oil next year and the earnings she will receive now. Since she could take that barrel of oil out now, take the profits, and put them in the bank, the profits on the incremental barrel of oil must grow at the same rate if it is left in the ground as it would if they were put in the bank. It is these incremental profits that are considered rents. A similar rule governs reproducible assets: the expected profit from cutting a tree must also grow at the rate of interest if the owner of a forest is to be indifferent between cutting it down or letting it stand. In this case, of course, the size of the resource base is growing also.

We should expect, however, that if man-made capital is not substitutable for natural capital, and the latter is of vital importance in the production of the goods and services on which we rely for our continued well-being, then the value of an incremental unit of natural capital would increase as its scarcity increases. The problem is again that we do not have much information on which to infer such values. To make these inferences, we would have to have either markets in which natural capital is traded, or be able to infer the value of natural capital inputs in the production of other goods.

The question, then, is how one might go about measuring the value of, or the decline in, natural capital, and incorporate such results in the types of analyses suggested by Weitzman, Hartwick, and others. It is this issue that we will address in the remainder of the paper. In doing so, we put aside more complex—and possibly metaphysical—matters, such as whether or not the objectives implicit in these authors' analyses are in fact appropriate.[5] While one might address the matters in either order, suggestions for the measurement and interpretation of national accounts must be both conceptually valid and practically feasible if they are to be of value.

GREEN ACCOUNTING AND ECOLOGICAL ECONOMICS

Most accounting exercises may be fairly mechanical. One observes the values of things that are bought or sold, adds up these values, and records the result. Some careful distinctions may need to be made in determining which items belong on which side of ledger lines, but the basic notion is one of recording rather than imputing. As we have said above, even more difficult calculations involving capital depreciation may be facilitated by reference to market transactions.

It is precisely in calculating the figures of greatest interest that we lose the guide of market experience, however. While there might be some argument that the way in which existing markets allocate most goods is fair, equitable, or even efficient, the motivation for "green accounting" largely concerns the treatment of resources that are not traded in existing markets. Even the exceptions prove the rule: measured harvest rates are deemed excessive either because those performing the harvest do not consider the damage they cause to other resources, or because property rights to the resources harvested are not well defined and a "tragedy of the commons" ensues.[6] The former phenomenon describes the collateral damage

[5] We should also note that the notions of "optimal" investment inherent in Weitzman's formulation and that of "sustainable" depletion of resources are not necessarily synonymous; see, for example, Krautkraemer, Pezzey, and Toman (1993).

[6] This phrase is due to Hardin (1966). It describes a situation in which everyone has access to a resource to which no one can claim ownership. This being the case, overharvesting occurs: everyone can argue that "if I don't take some now, someone else will," and this is indeed the case.

to watersheds and fisheries when logging occurs. The latter might describe the state of both fisheries and forests in many nations.[7]

Resources not traded in markets give rise to externalities: benefits or costs not reflected in the prices at which they are available to or from those receiving the benefits or incurring the costs. Present effects of environmental externalities will be reflected in current consumption and production. If, for example, pollution has degraded a fishery or acid rain is killing a forest, harvests from both resources will be diminished. In order to infer the loss of value of the capital asset, that is the fishery or the forest, however, one must know what are the effects of the externalities on the ongoing ability of the resource to produce valuable commodities.

If one can observe consequent declines in, for example, timber leases or other assets used in fishing, she might be able to infer the induced loss of value in the underlying asset. Again, however, it is often impossible to impute the value of environmental assets from observable indices. This is particularly true when we regard ecosystems as assets.

The value of a capital asset is determined by its contribution to the production of value in the form of other goods. Gross payments for the use of a capital asset will be determined by the incremental contribution of that asset in the production of other goods or services; the rental charged for the use of a shoe machine should be equal to the value of the additional shoes produced as a result of renting the machine. Net payments consist of gross payments less depreciation (or plus appreciation) in value. The purchase price of such a machine should be equal to the discounted present value of the incremental stream of payments that would be forthcoming from its use.

Shoe machines and natural assets are different types of "machines," however. Consider attempting to quantify the value of a rainforest and the loss in value as a result of deforestation. Recall that we need to compute the losses in future ability to produce other items as a result of deforestation. 'There are, of course, a myriad of "products" of a rainforest. One might be timber. To the extent that the values created by the forest in this context are reflected in marketed products and, moreover, that these values can be captured by the owners of the forest, we might hope that computation of the contribution of these elements to the national accounts would be little more than a report of efficient resource use.[8] This would be unlikely to be the case with other rainforest "products." Carbon sequestration, watershed protection, and preservation of biodiversity are all aspects of rainforest performance that are not only not directly compensated, but involved in so complex an array of other production processes as to make the separation of its contribution virtually impossible.

Absent the development of markets in these areas—a deus ex machina for which we might earnestly hope, but for which realistic prospects are virtually nil—the best we might

[7] We have found in other work that half of all tropical leases are abrogated within three years of a change of regime in tropical countries (Sedjo, 1991). Given the frequency of regime changes, sustainable forestry is unlikely to be in a lease-holder's interests.

[8] That this would be the case is, of course, extremely doubtful. Insecurity of tenure may lead titular or de facto owners to harvest their forests at excessive rates. Still more difficult problems may affect other aspects of valuation, however.

expect are meaningful contributions in what is becoming known as the discipline of ecological economics. The study of economics has always lay at the intersection of the psychology of wants and the mechanics of production possibilities. From an economist's perspective, the most pressing need in order to do meaningful green accounting is for more concise statements from the natural sciences—and especially from ecologists—as to how ecological degradation diminishes production possibilities.

This is admittedly a very tall order. Inasmuch as the essence of the problem is its pervasiveness—the impacts of global warming and diminished biodiversity might be felt in all sectors of the economy—attempts to incorporate these factors in meaningful national accounts might prove quixotic. We cannot even say if it would be wise to make such attempts. If it is one's goal to complete national accounting in this way, however, it is important to recognize the enormity of the task.

VALUING RESERVES OF BIODIVERSITY

We are going to step back from the broad view to consider a much narrower issue. We have argued that accurate accounting is made much more difficult in the absence of functioning markets, and, by implication, market prices, for natural assets. This is clearly a long way off for many assets. It may be instructive to take a look at one area in which markets are coming into existence, however. This is, on one hand, an encouraging phenomenon: the establishment of property rights and the realization of economic value leads to incentives to protect natural assets rather than allowing them to be squandered. To the extent that protection is in fact taking place, we should suppose that little deterioration of natural capital would be reflected in national accounts. If, on the other hand, substantial deterioration were recorded, it would point to a need to husband the assets more carefully.

We will see in this example, however, that the fact that transactions are beginning to be observed is no guarantee that values will be identified and reported immediately and unambiguously. The appearance of property rights and sales, at least in their incipiency, does not assure that meaningful statistics will be forthcoming. The example we present is also interesting in that it demonstrates some of the areas in which economists—and national income accountants—might gain from greater instruction from ecologists.

The example we will use is that of indigenous genetic resources.[9] Plants and animals produce a myriad of chemicals to enhance reproductive success, resist infection, overcome prey, and thwart predators. These chemicals can be of potentially enormous value in agricultural, industrial, and, particularly, pharmaceutical applications.

We refer to these naturally produced chemical compounds as genetic resources, as the recipe for their creation is encoded in an organism's genetic instructions. Useful compounds can either be extracted and employed in their naturally occurring forms, or can serve as "blueprints" for synthetic molecules. In either case, the natural molecules are important inputs in the

[9] Those interested in acquiring more detail on these matters are referred to Sedjo (1992), Simpson and Sedjo (1993), and Reid (1993).

research and development process. Millions of generations of evolution by trial and error may result in combinations more ingenious than the designs of synthetic chemists. Random screening of natural compounds occasionally yields extremely valuable leads.[10]

In order to earn a return for the preservation and provision of naturally occurring molecules, countries in which they are found must enforce property rights in them. Just as intellectual property (patents, copyrights, and trademarks, for example) exclude non-payers from the use of inventions or innovations, a number or recent national statutes and international agreements are coming to establish the rights of states. to their genetic resources and the requirement of their prior informed consent before genetic resources are appropriated.[11]

Commercially useful compounds are most likely to be found in the areas in which biological diversity is greatest. It has been estimated that half of the world's extent species are to be found on only six percent of its land area: that covered by the tropical rainforests (Wilson, 1988). To the extent that destruction of rainforest habitat results in the extinction of unique genetic resources, then, the felling of these forests represents an irreversible loss of natural assets.[12]

As we have noted, however, these resources are coming to be assigned values, and it is to be hoped that this realization of values will motivate greater conservation. To say that the value of genetic resources is coming to be appreciated is not to say that there is an emerging consensus on the amount, or even the order of magnitude of these values, however. While several agreements for the sale of rights to access of genetic resources have been finalized in recent years, it is difficult to infer from these arrangements the monetary value of the resource being exchanged in the particular transaction, let alone the value of other undiscovered resources in situ.

A number of factors prevent the observation of the value of resources being exchanged in particular transactions. First, particular details are not divulged in public documents. Merck and Company, for example, has made public the fact that it has made an up-front payment of $1 million to Costa Rica's Insituto Nacional de Biodiversidad (INBio) for access to samples provided by INBio. Neither Merck nor INBio has revealed the number of samples or the rate at which royalties are to be paid in the event that a commercially valuable product is developed, however. Published sources have varied by an order to magnitude in their estimates of both

[10] In one sense or another, most drugs were developed by random screening or chance observation—compounds used in traditional medicine were first discovered by happy accident. In modern times drugs have been developed from microorganisms discovered in the soil of a Japanese golf course and airborne spores that happened to float through an open laboratory window and contaminate another experiment, to give two examples.

[11] The most noted example is the Biodiversity Convention offered for signature at the 1992 UNCED meetings in Rio de Janeiro, but a number of tropical countries have also introduced national statutes outlawing the uncompensated appropriation of genetic resources.

[12] Other areas of the earth also harbor great diversity of life—and may be similarly imperiled. These include coral reefs and isolated areas in which the profusion of species may not be as great but those that do occur are unique.

quantities. Similar uncertainties surround the values being exchanged in other, less celebrated, arrangements. Even if royalty rates were known, of course, one would have to know the probability distribution of expected values in order to infer the value of the resource in situ.

The second source of uncertainty in ascertaining the value of genetic resources in situ arises from the combination of inputs represented in a typical transaction for sample materials. Rarely does a pharmaceutical, agricultural, or industrial laboratory purchase the rights to access to a certain collection of samples only. More commonly, the good purchased is a group of samples that has been collected, classified, dried, ground, and/or extracted by the seller. The compensation offered for the material reflects not only the value of the resource in situ, but also payments for the labor, materials, and machinery involved in the other operations.

For these reasons, it is extremely difficult to infer the value of genetic resources from what is observed concerning existing transactions. In fact, existing efforts to impute such values have not concentrated on transactions, but rather on attempts to infer values from the profitability of successful products and the probability of finding a product that proves to be successful (Pearce and Puroshothaman, 1992; Principe, 1989).

We might attempt such a valuation exercise as follows. We will think of prospecting for genetic resources as a process of trying to find a "cure" for a certain condition. The "cure" might be analogous to the search for a particular industrial product or an agricultural strain. Inasmuch as we should be concerned with the preservation of unknown genetic combinations—uncatalogued species—it may be reasonable to assign to each the same independent unconditional probability of containing the cure. Then if we believe there to be n unknown species that might be tested to find the cure, the probability that at least one of them does contain the secret is equal to one minus the probability that none of them do: $1 - (1 - p)^n$.

What is the value of preserving one additional species as a possible source of genetic resources? Differentiating the probability of finding at least one cure with respect to n yields $-1n(1 - p)(1 - p)^n$. Since p is likely to be a very small number, we can use the approximation $S_i = n\beta A_i^{\alpha}$, to say that the contribution to success of the "marginal" species is approximately $p(1 - p)n$.

We do not want to take this example too far, but, for the sake of illustration, phytochemicals—chemicals produced by plants—are thought by many to be unique in chemical structure and for this reason particularly worthy of preservation. There are about 270,000 species of higher plants (Wilson, 1992). Taking the often-cited figure of one in 10,000 (see, e. g., Roberts, 1992) as the probability of success, the incremental contribution of the "marginal" species of flowering plant would be on the order of 10^{16}. This figure must be multiplied by the value of such a discovery (net of research and development costs), and we should also allow for the possibility that the same organism will be tested at regular intervals for further applications. Nonetheless, even if we assign a fairly large number to the value in perpetuity of having extent genetic resources to be explored, the resulting figure for the value of a marginal species is unlikely to be large.

We have been discussing the value of a "marginal species," but conservation of unexplored species must generally take the form of habitat preservation. We might then ask how much of this form of natural capital we would lose by clearing a square kilometer of natural habitat. For help here we might appeal to the theory of island biogeography (MacArthur and

Wilson, 1967; Wilson, 1992). It predicts that the species diversity of a region varies as approximately the fourth root of its area. Let us suppose that this relationship is true and that the proportion of endemic species in an area is *n*. Then the endemic-species-to-area relationship might be expressed as

$$S_i = n\beta_i A_i^{\alpha},$$

where S_i is the number of endemic species, A_i the area, β_i is a constant giving the region's capacity to support species, and a constant on the order of one-quarter. Differentiating with respect to area, we find that

$$\frac{\partial S_i}{\partial A_i} = \alpha n_i \beta_i A_i^{(\alpha-1)} = \alpha \frac{S_i}{A_i}$$

(i. e., endemic species loss is proportional to initial density).

To get some idea of the relative magnitudes involved, we might consider the species densities in areas defined by Myers (1988, 1990) as biodiversity "hot spots." In only two of these (Western Ecuador and Southwestern Sri Lanka) does the density of endemic higher plants exceed one per square kilometer of primary forest preserved. Continuing in the same vein of heroic assumptions, then, even if we are talking about the preservation of a species of higher plant for which tens of billions of dollars in earnings might be anticipated, the expected value lost by losing a square kilometer of habitat for the purpose of preserving higher plants for pharmaceutical research might be negligible.

The point of this exercise has not been to argue that the value of natural capital involved in genetic resources is high or low. While our own guess is that it is relatively low at the margin, the real issue is the compounding of imprecision inherent in any attempt to measure these values. We could very well generate estimates of the value of the "marginal" square kilometer of plant habitat for use in pharmaceutical research that would differ by several orders of magnitude, by changing the underlying assumptions in not implausible ways.

These estimates are at best a small part of the picture, however. In our example we have considered only higher plants. Inasmuch as there are on the order of one hundred species of other organism per higher plant species, estimates of value would be rendered still less precise by considering their contribution. We also have not considered the relationship between numbers of species and genetic diversity. While economists have done some preliminary work in an attempt to elucidate these relationships (see, e. g., Polasky and Solow 1993), this is another area in which we need guidance from natural scientists.

Moreover, we have confined out attention very narrowly to values in pharmaceutical and other research applications only. It is not unreasonable to suppose that this is just the tip of the iceberg. Perhaps the greatest contribution of biological diversity lies in its ability to maintain itself. Some evidence suggests that diversity breeds diversity: complex webs of obligate relationships between species evolve, and the demise of one species may doom many. This raises the spectre of "ecosystem collapse." The curious layperson may be justified in wondering whether such a "collapse" is a profound tragedy or merely an occurrence that, while regrettable, is of no great lasting consequence. More to the point, the layperson may wonder if she should cast her own lot with those who take the former view or those who take the latter. In short, economists attempting a valuation of biodiversity have been given very little guidance from ecologists as to the magnitude of the losses, or even the risks, involved.

CONCLUSIONS

To recap, national product accounts should reflect both current production (or consumption) and changes in capital stock that reflect changes in our ability to produce and consume in the future. The valuation of capital stocks is often a difficult exercise. It may be made considerably easier if the accountant can impute values from observed market transactions. In the absence of direct market prices, the accountant may be forced to attempt an indirect imputation of values from estimates of the product of an incremental unit of capital. This exercise may become practically impossible if we are dealing with assets such as climate, ozone protection, and biological diversity, whose contributions are important in virtually all production processes and are, at present, unpriced in most. The accountant's task is rendered still more difficult by the unpredictability of the effects of global externalities. When even the probability distribution of outcomes is unknown, and most likely unknowable, we have to wonder if any prescriptions for valuation will be of any practical use.

We have presented as examples some of our own findings concerning the commercialization of genetic resources and the valuation of those assets. It might be suggested that developments in this field represent an encouraging trend which, furthermore, might demonstrate the practical irrelevance of green accounting. An argument to this effect might go as follows. Genetic resources are so plentiful as to have been, for most of history, of negligible value at the margin. As they are becoming more scarce and our technology for exploiting them is becoming more sophisticated, they are being protected by both national laws and international agreements, and their value is coming to be incorporated in market prices. As this process continues, transactions in these resources will come increasingly to be drawn into the national accounts.

As the values of other, still less conventional, natural assets come to be realized, markets for their allocation and preservation will also come into existence. This will happen at the points at which the establishment of property rights is efficient. Thus, again, we may expect efficient outcomes, and correct national product accounting would record economic activity accurately, but would be of little help in suggesting reallocations of resources.

This view is certainly a Panglossian caricature. Given the imprecision with which markets are now valuing such relatively concrete goods as genetic resources, it seems very unlikely that markets will soon be effective in valuing global environmental externalities. While institutions and instruments for allocating and conserving environmental and ecological assets should certainly be encouraged, it is vanishingly unlikely that we will see an allocation of such assets that can be defended as "optimal" in any meaningfully concise way. We are a long way, then, from being able confidently to construct indices of economic well-being by simply recording transactions.

The best policy might combine a faith in the ability of markets to do many things right, a great deal of caution in dealing with resources that are not, and perhaps cannot soon be, traded in markets, and healthy skepticism concerning the reliability of the entire national accounting apparatus. Accounts might reasonably be expanded to include losses in natural capital in those instances in which values are recorded or might reasonably be backed out from observed statistics for closely related assets. In other, more speculative areas, we might maintain the hypothesis that these assets are not recorded in the accounts because they have yet to realize sufficiently high values on the margin to warrant the establishment of markets. At the same time, however, it would be prudent to recognize that national product estimates should be taken with several grains of salt. Further deterioration of natural assets should be allowed only to the extent that relatively large tangible gains are very likely.[13]

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[13] A useful analogy to note here may be with the literature on irreversible investment. Investment (or disinvestment) should only be undertaken when the expected gains strictly exceed the opportunity cost, and the threshhold becomes higher the greater the uncertainty in the gains (for an introduction to these models, see, for example, Pindyck 1991).

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Appendix

Workshop Planners and Participants

WORKSHOP ON "VALUING NATURAL CAPITAL FOR SUSTAINABLE DEVELOPMENT" HELD IN WOODS HOLE, MASSACHUSETTS, JULY 1-3, 1993

Co-sponsored by the Commission on Geosciences, Environment, and Resources (CGER) and the Commission on Behavioral and Social Sciences and Education (CBASSE)

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The following materials were distributed in advance to participants in the workshop on "Valuing Natural Capital in Planning for Sustainable Development." Items marked with an asterisk are included in this volume.

1. A System of Integrated Environmental and Economic Accounts (SEEA)

Peter Bartelmus

2. Accounting for Sustainable Growth and Development

Peter Bartelmus

3. Integrated Environmental and Economic Accounting—A Case Study for Papua New Guinea

Peter Bartelmus, Ernst Lutz, and Stefan Schweinfest

*4. Valuing the Environment: Methodological Issues of Intergenerational "Green Accounting"

Paul P. Craig and Harold Glasser

*5. Natural Resource and Environmental Accounting in U.S. Agriculture

Pierre Crosson

6. What Use is Biological Diversity?

Eric A. Fischer

7. Conceptual Framework for Regulatory Benefits Assessment

Baruch Fischhoff and Louis Anthony Cox, Jr.

8. Blueprint for a Green Economy

David Pearce, Anil Markandya, and Edward B. Barbier

9. Economic Valuation and the Natural World

David Pearce

10. Alternative Environmental and Resource Accounting Approaches

Henry M. Peskin

*11. Sustainable Resource Accounting

Henry M. Peskin

*12. Soil Quality in Relation to Value and Sustainable Management

Francis J. Pierce

*13. The Feasibility of Incorporating Environmental and Natural Resource Availability Into the National Accounts

Raymond Prince

*14. What Can Policymakers Learn From Natural Resource Accounting?

Robert Repetto

*15. Natural Resource Accounting for the Forestry Sector: Valuation Techniques and Policy Implications in Thailand

Claudia W. Sadoff

*16. Valuing Biodiversity: An Application of "Green Accounting"

R. David Simpson and Roger A. Sedjo

*17. An Almost Practical Step Toward Sustainability

Robert Solow

18. Integrated Environmental and Economic Accounting—A Case Study for Mexico