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Accounting for the Environment in Agriculture

James Hrubovcak
Michael LeBlanc
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Accounting for the Environment in Agriculture. By James Hrubovcak, Michael LeBlanc, and B. Kelly Eakin. Natural Resources and Environment Division, Economic Research Service, U.S. Department of Agriculture. Technical Bulletin Number 1847.

Abstract

Detailed information derived from the national income and product accounts provides the basis for economic interpretations of changes in the Nation's income and wealth. This paper attempts to more accurately measure agriculture's contribution to national income. Specifically, the effects of soil erosion on agricultural productivity and income, the economic effects of decreased water quality, and the depletion of water stocks are presented as examples of the potential scope of accounting adjustments needed in the agricultural sector. Estimated adjustments to net agricultural income are in the range of $4 billion and have declined as a percentage of net farm income since 1982. Our estimates suggest that agriculture's contribution to social welfare far exceeds the environmental damages and deterioration of the stock of natural capital resulting from the production of food.

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Introduction

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

Early criticism of the NIPA centered around the treatment of capital, leisure, and government expenditures. Recent critiques, with historical roots in the early 1970's, question the use of estimates of NNP as a measure of social welfare because it does not account for the value of changes in the stock of natural resources nor does it include the value of environmental goods and services. Critics question the credibility of the accounts because natural and reproducible capital are treated asymmetrically and the value of nonmarketed environmental goods and services is not captured (Prince and Gordon, 1994).[1,2] NNP, it is argued, is not a useful measure of long-term sustainable growth partly because natural resource depletion and environmental goods are not considered. The failure to explicitly consider the environment in the accounts misrepresents the current estimate of well-being, distorts the representation of the economy's production and substitution possibilities, and fails to inform policymakers on important issues related to economic growth and the environment.

Several attempts to adjust income measures to account for the environment exist (Repetto, 1992a and 1992b; Smith, 1992; Nestor and Pasurka, 1994; U.S. Department of Commerce, 1994).[3] It is most common for these studies to focus on accounting for natural resource depletion. Theoretical and empirical problems persist, however, particularly when the level of environmental services and damages is estimated. For example, no consistent approach for the treatment of "defensive expenditures" in response to or in anticipation of environmental injury has emerged from the literature (Ahmad, El Serafy, and Lutz, 1989).

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

[1] Our definition of nonmarketed goods includes environmental amenities and disamenities.

[2] Names in parenthesis refer to sources listed in the references at the end of this report.

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

The theoretical framework developed for this study is grounded on the work of Arrow and Kurz (1970), Weitzman (1976), Solow (1986), Hartwick (1990), and Mäler (1991). Weitzman has shown the current value Hamiltonian in a neoclassical growth model of the aggregate economy can be interpreted as NNP.[4] Solow incorporated exhaustible resources as distinct capital assets into Weitzman's treatment of NNP. Hartwick and Mäler extended Solow's approach to capture renewable resources and environmental capital (pollution abatement).

In our analysis, the Hartwick-Solow-Weitzman framework is extended to include three production sectors (agriculture, nonagriculture, and household production). This extension allows us to adjust both agricultural and national income. Rather than viewing nonmarket environmental goods as externalities, we follow the prescription of Solow (1992) and cast the environment as a set of natural capital assets providing flows of goods and services to the economy. Economic use of natural capital results in feedback effects: depletion of stock of natural capital reduces future flows of goods and services from the environment and degradation due to the disposal of residuals results in costs imposed on third parties. In addition, firms and households are allowed to make expenditures for pollution abatement and control.

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

Theoretical results from our model mirror Hartwick's results. That is, GDP includes priced resource input flows and these flows from capital stocks should be off-set by deductions from GDP to incorporate the value of changes in natural resource capital stocks to arrive at NNP.[5] Our empirical application suggests only minor changes are necessary when agricultural natural resource effects are incorporated into the national income accounts. Adjustments to the national accounts are minor because agricultural production is a small component of GDP (less than 2 percent) and most extra-agricultural effects are currently captured in GDP. Larger changes are warranted, however, in the adjustment of net agricultural income. Most effects represent income transfers between agriculture and other sectors.

Agricultural income is adjusted to reflect the value of changes in the stocks of "effective" farmland, water quality, and the stock of ground water. These natural capital stocks may change due to damages associated with agricultural production. Specifically, the effects of soil erosion on agricultural productivity and income, the economic effects of decreased surface-water quality, and the depletion of ground-water stocks are presented as examples of the potential scope of accounting adjustments needed in the agricultural sector. We adjust income for changes in the stock of ground water because there has been a sustained withdrawal of ground-water stocks in some regions of the United States. Our estimated adjustments would require net agricultural income to be revised downward by $4 billion (6 percent). These estimates of adjustments to net farm income are consistent with a view of U.S. agriculture where environmental problems exist and the resource base is depreciating, but also suggest that agriculture's contribution to social welfare far exceeds the environmental damages and deterioration of the stock of natural capital resulting from the production of food.

National Income Accounting

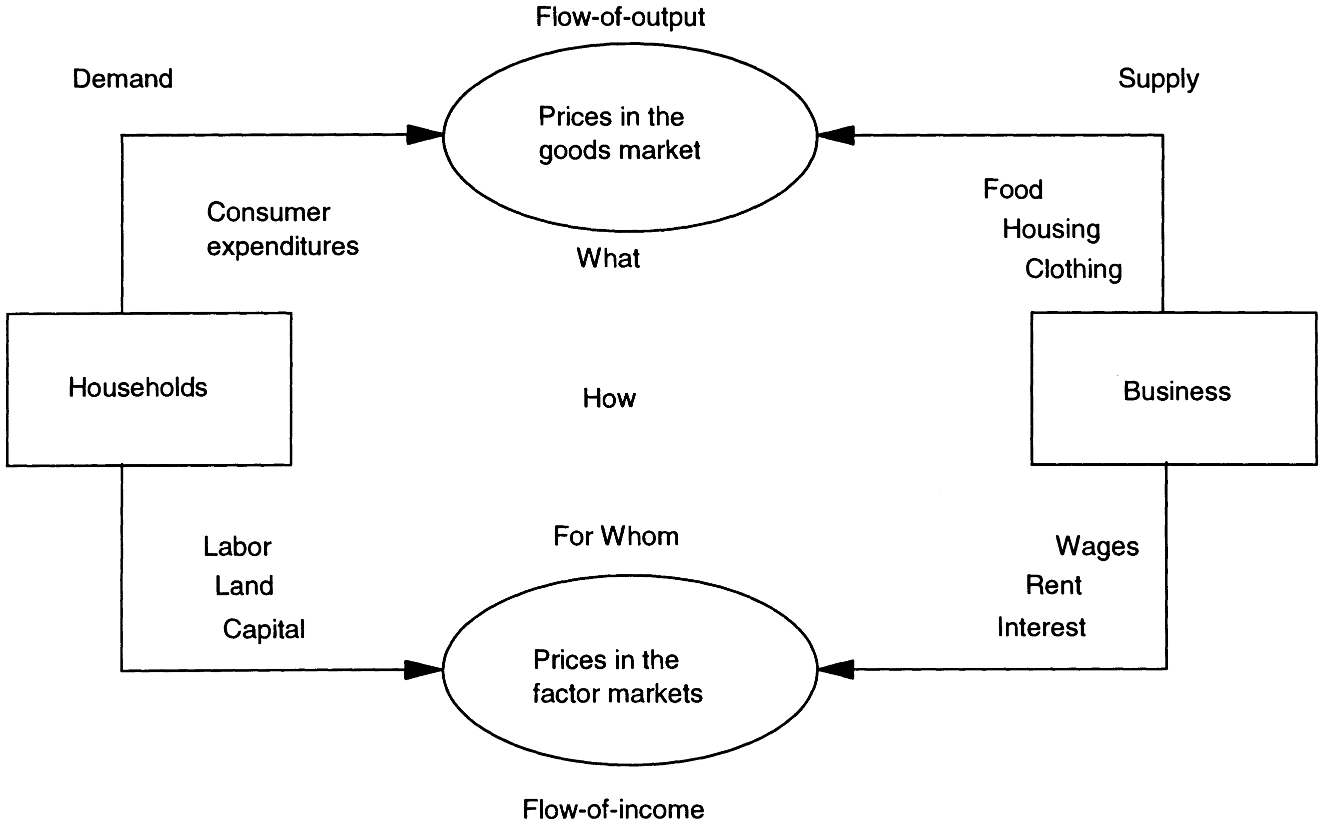
The national income and product accounts (NIPA) were developed primarily to monitor the macroeconomic performance of the economy. The most widely used measure or statistic of economic activity is gross domestic product (GDP). GDP is highly correlated with employment and capacity utilization and therefore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

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

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

[5]Possible increases in the stock of natural or environmental capital are not excluded.

Figure 1
Circular flow model



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

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

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

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

Table 1--Overview of the existing NIPA accounts, 1992

Flow-of-income		Flow-of-output	
	Billion dollars		*Billion dollars*
Compensation of employees	3,582.0	Personal consumption expenditures	4,139.9
Proprietors' income	414.3	Gross domestic investment	796.5
Corporate profits	407.2	Government purchases	1,131.8
Net interest	442.0	Net exports	-29.6
Rental income	-8.9		
National income	**4,836.6**	**Gross domestic product**	**6,038.6**
		Consumption of fixed capital	-657.9
Business transfer payments	27.6	Rest of world net factor income	7.3
Individual tax and nontax liability	502.8	Statistical discrepancy	-23.6
Subsidies less government surplus	-2.7	Business transfer payments	-27.6
Consumption of fixed capital	657.9	Individual tax and nontax liability	-502.8
Gross national income	6,022.2	Subsidies less government surplus	2.7
Statistical discrepancy	23.6		
Gross national income	6,045.8		
Rest of world net factor income	-7.3		
Gross domestic product	**6,038.5**	**National income**	**4,836.7**

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of Current Business, 1993.

Table 2 summarizes the calculation of farm income for 1992 using a flow-of-income approach. Gross farm product in 1992 was $84.4 billion or about 1.4 percent of U.S. GDP. While wage income (compensation to employees) is by far the largest income category at the national level (74 percent of U.S. national income), proprietors' income (65 percent) and net interest (15 percent) are the largest components of net farm income. Consumption of fixed capital in agriculture is 26 percent of gross farm product, over twice as large as the aggregate national rate.

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

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

Table 2--Summary of farm income, 1982, 1987, 1992

Flow-of-income components	1982	1987	1992
		Billion dollars	
Compensation of employees	10.2	9.4	11.9
Proprietors' income	24.6	31.3	43.7
Corporate profits	1.1	1.1	1.0
Net interest income	18.1	12.5	10.2
Net farm income	54.0	54.3	66.8
Indirect tax and nontax liability	3.3	3.6	4.4
Subsidies less current government surplus	-2.4	-13.9	-8.4
Consumption of fixed capital	22.0	22.0	21.6
Gross farm product	76.9	66.0	84.4

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of Current Business, various years.

income accounts adjusted accordingly. The value of housing services received from owner-occupied houses is the best example.

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

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

Environmental Accounting

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

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

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

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

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

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

The United Nations System for Integrated Environmental and Economic Accounting (SEEA) is a set of satellite environmental accounts supplementing the current System of National Accounts (SNA).[7] The intent is to develop an environmental accounting framework consistent with the concepts and principles underlying conventional income. Harrison (1989) presents criteria for guaranteeing the satellite accounts are complementary to rather than a substitute for the current accounts. A primary requirement is the parallel treatment of "natural capital" (natural resources) and physical capital in the national accounts.

Although there have been other attempts to capture environmental effects in national accounts (Nordhaus and Tobin, 1972), Nestor and Pasurka (1994) is the most ambitious. Nestor and Pasurka disaggregate the U.S. input-output tables into environmental and nonenvironmental components. Adopting the framework of Schafer and Stahmer (1989), Nestor and Pasurka divide the environmental account into three categories. The "internal environmental protection sector" captures intermediate goods and services produced and used within the environmental protection industry. The "external environmental protection sector" captures the purchase of intermediate inputs from outside the sector. Examples include waste disposal, sewage treatment, and environmental construction activities. The "final demand sector" for environmental protection includes fixed capital formation for environmental protection, direct pollution abatement activities by governments and households, and net exports of environmental protection goods.

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

[7]See United Nations (1993) and Bartelmus, Stahmer, and Van Tongeren (1991).

NNP and Welfare

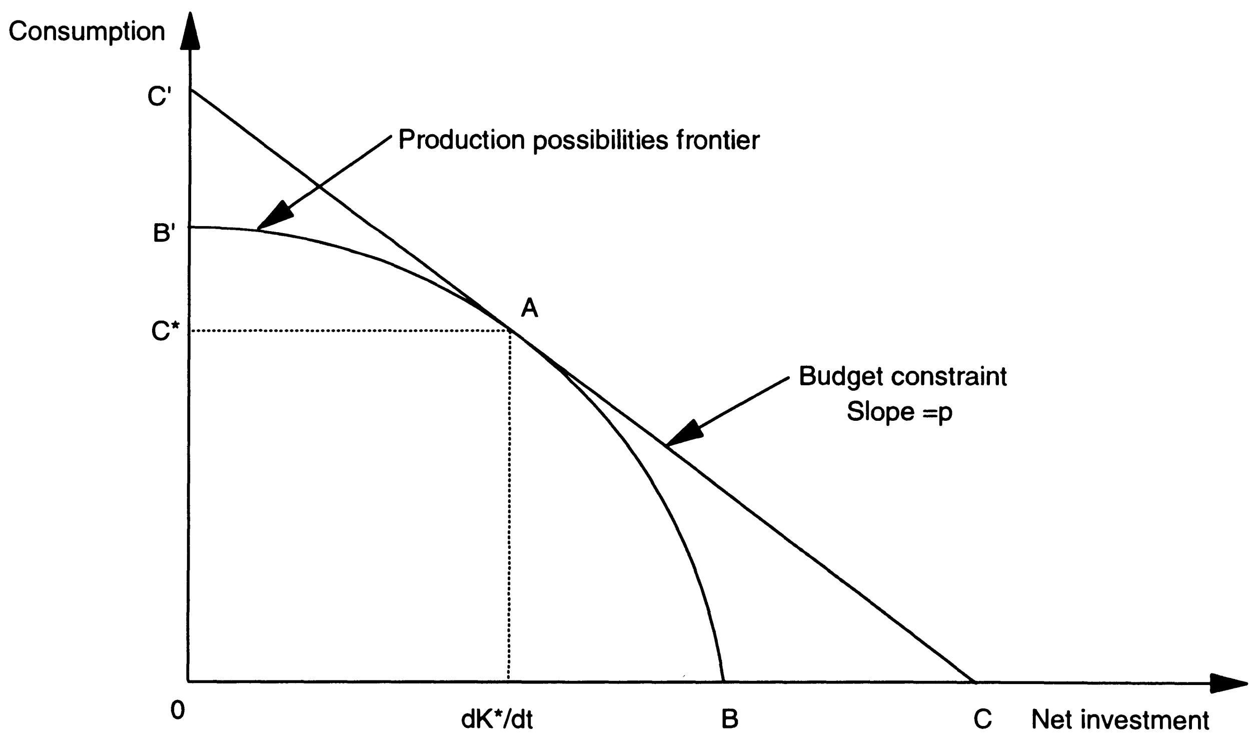
NNP is the premier indicator of current market-based economic activity. NNP has also been promoted and, more importantly, intèrpreted as an indicator of social welfare. Samuelson (1961) rejected all current income concepts as meaningful welfare measures and argued instead for a "wealth-like magnitude"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

In figure 2, the production possibilities frontier B'B represents the economy's technical ability to transform investment goods into consumption goods. The budget constraint C'C represents society's willingness to trade-off future consumption for current consumption, which depends on the rate at which society discounts future consumption. The economy is located at point A on the production possibilities frontier B'B.

Optimal consumption and net investment are given by C* and dk*/dt. Real NNP, is geometrically represented as OC'. The only point where measured income is supported by production is at A. OC' is a strictly hypothetical consumption level at the present time, because the largest permanent consumption level obtainable is OB'. Production and income are equivalent only at A unless the transformation of investment goods into consumption goods does not exhibit diminishing marginal returns. That is, if the production possibilities frontier is linear, OB' is income, where income is interpreted as the maximum consumption possible. The correct measure of "income" or NNP at the dynamic optimum is indicated by A. The level of constant consumption OC' gives the same present value of welfare as the discounted maximum welfare received along the optimal consumption path. Thus, Weitzman calls OC' the stationary equivalent of future consumption.

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

Figure 2
National income



the degradation or depletion of nonrenewable resources.

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

Application Framework

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

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

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

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

Each of our natural capital assets are regenerative or renewable but may be exhausted from over-use if the rate of use exceeds the natural and managed regenerative rate of the asset. The net rate of regeneration is the rate at which the stock of the asset changes over time.[8] For land, surface-water quality, and the stock of ground water, the net rate of regeneration depends on the intensity of use, the natural rate of regeneration, and the effectiveness of management to offset the intensity of use of the asset. Land, for example, is usable until the productivity of soil for producing agricultural goods approaches zero. The loss in soil productivity is offset by the soil's natural capability to regenerate itself. The productivity of soil to produce agricultural goods is also enhanced (managed) by applying labor, intermediate inputs (fertilizer), and capital to improve soil quality.

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

While agriculture's share of NNP includes a deduction for the consumption of physical capital, a similar deduction is not made for other types of capital, including farmland or natural resource

[8]The net rate of regeneration defines the equation of motion for each asset (see Appendix A).

stocks such as water quality or water quantity. In addition, NNP is not adjusted for externalities associated with agricultural production. For example, agriculture's contribution to NNP is not reduced by offsite damages to water quality associated with soil erosion.

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

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

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

$$
\begin{aligned}
NWM = {} & \frac{\partial U}{\partial q}\left[\frac{\partial q}{\partial n_1}n_1 + \frac{\partial q}{\partial k_1}k_1 + \frac{\partial q}{\partial Z_1}Z_1 + \frac{\partial q}{\partial T_1}T_1 + \frac{\partial q}{\partial W_1}W_1\right] \\
& + \frac{\partial U}{\partial x_2}\left[\frac{\partial x}{\partial n_2}n_2 + \frac{\partial x}{\partial k_2}k_2 + \frac{\partial x}{\partial Y}Y + \frac{\partial x}{\partial L_2}L_2\right] \\
& - \frac{\partial U}{\partial x_2}\left[x_3 + x_4 + x_5 + x_6 + l_1 + l_2 + l_3 + l_4 + l_5 + l_6\right] \\
& + \frac{\partial U}{\partial Y}Y \\
& + \sum_{i=1}^{6}\mu_i \dot{k}_i + \rho_3 \dot{T}_1 + \rho_4 \dot{Y} + \rho_6 \dot{W}_1 \, . \qquad (1)
\end{aligned}
$$

The first line of equation (1) represents expenditures on final goods and services produced by the agricultural sector as the sum of the value of the marginal contributions of each input used in producing the agricultural good. That is, the expenditures on final agricultural goods are the sum of the value of labor (n_1), capital (k_1), an environmental input (Z_1), effective farmland (T_1), and the stock of ground water (W_1) that is used to produce the agricultural good. The inputs used to produce the agricultural good are valued in terms of the marginal contribution of the agricultural good to the utility of society ($\partial U/\partial q$).

The second line in equation (1) represents expenditures on total goods and services produced in the nonagricultural sector. Expenditure on these goods is a function of the value of labor (n_2), capital (k_2) water quality (Y), and land (L_2) used to produce nonagricultural goods, valued in terms of the marginal contribution of these goods to the utility of society ($\partial U/\partial x_2$). The third line in equation (1) represents expenditures on intermediate inputs used to produce the agricultural and nonagricultural goods and services. Intermediate expenditures are excluded from NNP to avoid double counting.

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

The fourth line in equation (1) represents the value ($\partial U/\partial Y$) of the stock of clean water (Y) to consumers. This value is also not captured in conventionally measured NNP. The final line in equation (1) reflects the addition of the value of net investment in both reproducible capital ($\dot{k}_i$) and natural capital: effective farmland ($\dot{T}$), water quality ($\dot{Y}$), and ground-water quantity ($\dot{W}$).

Current period production is valued in terms of its marginal contribution to the utility of society today. Net investments in both reproducible and natural capital are valued by their marginal contributions to the utility of society today and their marginal contribution to the utility of society in the future.[9]

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

Effective Farmland/Soil Productivity

The link between agricultural production practices, erosion, and farmland's ability to produce output has been studied extensively (Crosson, 1986). In 1989, as part of the Second Resources Conservation Act (RCA) Appraisal, the U.S. Department of Agriculture (USDA) estimated a 3-percent loss in productivity over the next 100 years if farming/management practices remained as they were in 1982 (table 3). Similarly, Alt, Osborn, and Colacicco (1989) found that the net present value of both the crop yield losses and the additional fertilizer and lime expenses associated with agricultural production totaled $28 billion. Both studies employ a crop production model, Erosion Productivity Impact Calculator (EPIC), which links production practices, erosion rates, and productivity, to provide estimates for physical depreciation rates of land.[10] Linking physical depreciation rates with crop prices can provide an estimate of economic losses attributable to soil erosion over time. However, a productivity loss of 3 percent over 100 years will not change NNP significantly.

Table 3--Productivity impacts on cropland associated with soil erosion, 1982

Region	Sheet and rill	Wind
	Percent	
Northeast	7.1	*
Appalachia	4.7	*
Southeast	1.3	*
Lake States	0.9	0.7
Corn Belt	3.5	*
Delta	1.6	*
Northern Plains	0.6	0.3
Southern Plains	0.2	2.1
Mountain	0.4	1.4
Pacific	2.3	0.2
Total	1.8	0.5

* = less than 0.01 percent.
Source: U.S. Department of Agriculture (1989).

While our theoretical model for adjusting NNP for the impact of erosion on loss of soil productivity is straightforward, it is more difficult to assess a more comprehensive view of land quality over time (National Academy of Sciences, 1993). For example, the RCA report also concluded that less than 50 percent of all agricultural land was "adequately" protected. Adequately protected soil was defined as soil within acceptable limits with respect to soil erosion and other factors limiting sustained use. Soil scientists have developed "soil loss tolerance" or "T-values" which vary by type of soil. A general rule of thumb is that erosion rates less than 5 tons per acre per year (T) do not result in damage to crop yields. Although results from the RCA seem to indicate soil erosion's effect on productivity is economically unimportant, the report also indicates about 40 percent of cropland was eroding at rates greater than T.

Water Quality

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

Because data on wind erosion are limited, our estimates focus on the offsite effects associated with sheet and rill erosion. We link sheet and rill erosion and the adsorption of nutrients to soil particles to estimate the effects of agricultural production on siltation, stream sedimentation, and water pollution. Table 4 presents estimates of sheet and rill erosion for cropland and pastureland for 1982, 1987, and 1992 from the National Resources Inventory (USDA, 1994).

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

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

Table 4--Gross annual sheet and rill erosion (cropland and pasture/range), 1982, 1987, 1992

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

Source: U.S. Department of Agriculture, Natural Resource Conservation Service (formerly known as the Soil Conservation Service).

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

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

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

We do not measure the stock of water quality (Y) or the marginal utility of water quality ($\partial U/\partial Y$). Because no comprehensive measure exists, we use Ribaudo's (1989) estimate of the off-site damages to water quality from soil erosion. The off-site damages in dollars per ton of soil erosion (converted to $1982) are listed in table 5. The estimates reflect the off-site effects of soil erosion on freshwater and marine recreation, water storage, navigation, flooding, roadside ditches, irrigation ditches, freshwater and marine commercial fishing, municipal water treatment, municipal and industrial uses, and steam power cooling. We reorganize the damages into those affecting industry (water storage, navigation, flooding, roadside ditches, irrigation ditches, freshwater and marine commercial fishing, municipal water treatment, municipal and industrial uses, and steam power cooling) and those directly affecting consumers (freshwater and marine recreation). The industry and consumer damages per ton of soil erosion are highest in the Northeast.

Table 5--Off-site damages associated with soil erosion, 1982

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

Source: Ribaudo, 1989.

The value of total damages presented in tables 6 and 7 is calculated by applying Ribaudo's per ton estimates to the total level of sheet and rill erosion for cropland and pasture by region.[11] Total damages are $4.4 billion 1992, with $2.7 billion associated with industry effects. Interestingly, while the dollar per ton effects are highest in the Northeast, the total industrial damages are greatest in the Southern Plains ($406 million).

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

Ground-water Quantity

Our final adjustment to the national and agricultural sector accounts is an adjustment for the value of the change in the stock of ground water over time. In the long run, an equilibrium is generally reached in terms of recharges (precipitation, imports from other regions) and discharges (natural evapotranspiration, exports to other regions, consumptive use, and natural outflow) from any ground-water system. However, in five water resource regions, the rate of discharge has consistently been greater than the rate of recharge and has led to a continued decline in the stock of ground water (U.S. Department of the Interior, 1984). Those five regions are: the Missouri Basin (Montana, Wyoming, North Dakota, South Dakota, Nebraska, and parts of Colorado and Kansas), the Arkansas-White-Red (southern Kansas, Oklahoma, north Texas, and western Arkansas), the Texas-Gulf (most of Texas), the Lower Colorado (Arizona), and California. While it is difficult to assess agriculture's contribution to the overall change in the stock of ground water in those regions, the sector accounted for 79 percent to 88 percent of total ground-water withdrawals in the United States (table 8).

Because the most recent estimate of the change in the stock of ground water for the United States is for 1980 (U.S. Department of the Interior) and because the data are not specified by sector of use, we adopt the following four step procedure. First, we employ the 1980 water resource budgets and use agriculture's share of total ground-water withdrawals (Solley and others, 1983) to allocate the change in the stock of ground water for each of the five water resource regions exhibiting declines in the stock of ground water in 1980. For example, in 1980, agriculture accounted for about 86 percent of ground-water withdrawals in the California water resource region. Therefore, we assume that agriculture accounted for 86 percent (1.2 billion gallons per day (BGD)) of the total decline in the stock of ground water in the California water resource region (1.4 BGD) for 1980.

Second, because water use data are collected every 5 years, we use the change in total ground-water withdrawals to update the total change in the stock of ground water for each of the water resource regions. For example, from 1980 to 1985, the total (both agricultural and nonagricultural) withdrawals of ground water for the California region fell by about 30 percent from 21.0 to 14.8 BGD. Therefore, we assume that the rate of ground-water depletion in the region fell by about 30 percent from 1.4 BGD to 1.0 BGD.

Third, we again use agriculture's share of total ground-water withdrawals to allocate the change in the stock of ground water. Continuing with our California example, in addition to the decline in

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

Table 6--Estimated inter-industry annual soil erosion damages, 1982, 1987, 1992

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

Table 7--Estimated annual consumer soil erosion damages, 1982, 1987, 1992

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

Table 8--Ground-water withdrawals by water resource region, 1980, 1985, 1990

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

Source: Solley and others (1983 and 1993).

Table 9--The effects of agricultural production on ground-water storage, 1982, 1987, 1992

Region	1982		1987		1992	
	BGD[1]	*Million dollars*[2]	*BGD*[1]	*Million dollars*[2]	*BGD*[1]	*Million dollars*[2]
Missouri Basin	2.1	46	1.5	36	1.4	43
Arkansas-Red-White	3.2	60	2.7	53	2.6	68
Texas-Gulf	2.4	66	2.2	84	2.4	108
Lower Colorado	1.8	46	1.2	24	1.1	46
California	1.2	32	0.7	15	0.7	26
Total	10.8	249	8.3	212	8.2	291

[1]BGD = billion gallons per day.
[2]1980, 1985, and 1990 ground-water withdrawals are utilized to reflect 1982, 1987, and 1992 rates of ground-water depletion.
Source: 1980 data from U.S. Department of the Interior, U.S. Geological Survey.

overall ground-water withdrawals, the share of withdrawals attributed to agriculture fell from 86 percent to about 70 percent. Therefore, the rate at which agriculture contributed to the decline in the overall stock of ground water in the California water resource region fell from 1.2 BGD in 1980 to 0.7 BGD in 1985 (table 9).

This process leads to some interesting comparisons over time. The change in overall ground-water withdrawals coupled with changes in agricultural uses indicates that by 1990, agriculture's contribution to overall decline in the stock of ground water declined since 1980 and remained stable since 1985. Regionally, however, there are some differences. For the Lower Colorado and California water resource regions, both total ground-water withdrawals and the share of ground-water withdrawals attributed to agriculture have fallen significantly. In both regions, the share of ground-water withdrawals attributed to agriculture has fallen from close to 90 percent in 1980 to about 75 percent by 1990. Much of this decline in ground-water withdrawals can be attributed to the decline in irrigated acres in the Pacific coast over that period.[12] However, for the Missouri Basin, Arkansas-Red-White, and Texas-Gulf, agriculture's share of total withdrawals of ground water has remained fairly constant since 1980.

And fourth, we need to associate values with the estimated changes in the rate of ground-water depletion. We estimate the value of ground water based on the ratio of energy expenses for on-farm pumping of irrigation water to the estimated amount of water applied to farms from wells. The data on energy expenses and water application are from Farm and Ranch Irrigation Surveys (U.S. Department of Commerce, Census of Agriculture, 1982, 1986, and 1990).[13] The values range by water resource region and for 1992 range from $0.10 to $0.12 per 1,000 gallons in California, the Lower Colorado, and the Texas Gulf to $0.07 to $0.09 in the Missouri Basin and the Arkansas-Red-White regions. While there is considerable uncertainty regarding the appropriate value of water, the estimates used in this analysis are similar to those used by Grambsch and Michaels (1994). Grambsch and Michaels estimate, based on water price data for the 120 largest metropolitan areas and government capital and operating expenses, was $0.09 per 1,000 gallons. The adjustment to farm income presented in table 9 combines the value of ground water with the rate of ground-water depletion associated with agriculture. Total damages range from $212 million in 1987 to $291 million in 1992.

Impacts on Income

Agriculture affects both production in other sectors of the economy and consumer utility through its use of environmental and natural resource assets. Production in other sectors of the economy is affected because changes in environmental assets affect the productivity of other inputs and therefore the cost of producing nonagricultural goods and services. Consumer utility is affected directly through changes in consumption and indirectly through changes in option or existence value.

[12]Irrigated acres in the Pacific coast fell from 12 million to 10.5 million from 1978 to 1992 (USDA, ERS).
[13]The data in the Census of Agriculture are for 1979, 1984, and 1988. The GDP implicit price deflator is used to match census years with the dates used in this analysis.

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

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

The relative effects on net farm product are significantly greater. Adjustments to net farm product range from 6 to 8 percent. The relative share of environmental adjustments to conventional net farm product, however, decreased from 1987 to 1992. Measured agricultural environmental costs per dollar of farm income are declining. This suggests estimated environmental costs flowing from

Table 10--Summary of adjusted national income and product accounts, 1982, 1987, and 1992

Income components	1982	1987	1992
		Billion dollars	
Traditional farm income	54.0	54.3	66.8
Water quality:			
Industry transfer	-2.4	-2.7	-2.7
Consumer effects	-1.1	-1.2	-1.3
Water quantity	-0.2	-0.2	-0.3
Green farm income	50.2	50.2	62.5
Traditional nonfarm income	2,468.5	3,638.0	4,769.8
Water quality:			
Industry transfer	+2.4	+2.7	+2.7
Consumer effects			
Water quantity			
Green nonfarm income	2,470.9	3,640.7	4,772.5
Traditional national income	2,522.5	3,692.3	4,836.6
Water quality:			
Industry transfer	0.0	0.0	0.0
Consumer effects	-1.1	-1.2	-1.3
Water quantity	-0.2	-0.2	-0.3
Green national income	2,521.1	3,690.9	4,835.0

agriculture are not growing as fast as farm income. One possible explanation is policies and programs for controlling soil erosion were effective during this period. In particular, highly erodible acreage enrolled in the Conservation Reserve Program increased from 13.7 to 35.4 million acres from 1987 to 1992. Removing nearly 22 million acres of highly erodible land from production contributed to a nearly 21-percent decrease in estimated soil erosion on cropland during this period even though planted acreage for grains increased by 6 percent. Conservation compliance requirements promulgated under the 1985 farm legislation have provided additional incentives for reducing erosion.

The estimates are consistent with Smith's (1992) work on environmental costing. Smith aggregates the effects of off-site soil erosion, wetland conversion, and ground-water contamination and estimates environmental costs relative to the value of crops produced in 1984. His estimates range from 0.08 to 7.5 percent in the Mountain region to 3.5 to 40 percent in the Northeast. Corn Belt estimates range from 6 to 7 percent.[14]

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

Conclusions

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

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

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

Estimates of adjusted or "green" income presented here are incomplete. Because the objective of our analysis is to illustrate some of the adjustments necessary to improve NNP and NFP as measures of

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

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

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Appendix A: Theoretical Model

Definitions

Output of the agricultural sector (q) is given by the production function:

$$q = q(n_1, k_1, Z_1, T_1, eW_1) \quad \text{(A.1)}$$

where:

- n_1: agricultural labor,
- k_1: agricultural capital,
- Z_1: environmental input,
- T_1: "effective" stock of land used in agricultural production,
- e: ground-water extraction rate, and
- W_1: stock of ground water.

Output of the nonagricultural sector (**x**) is given by the production function:

$$x = x(n_2, k_2, Y, L_2) \quad \text{(A.2)}$$

where:

- **x**: nonagricultural good,
- n_2: nonagricultural labor,
- k_2: nonagricultural capital,
- Y: water quality effect on nonagricultural production ($\partial x/\partial Y > 0$), and
- L_2: land used in nonagricultural production.

Household or nonmarket production (h) is given by:

$$h = h(n_6, x_6, k_6) \quad \text{(A.3)}$$

where:

- n_6: household labor,
- x_6: intermediate inputs used in household production, and
- k_6: household capital.

The household production function includes nonmarketed activities beyond those related to the environment.

The equation of motion for the effective productivity of farmland is

$$\dot{T}_1 = \gamma\left(\frac{n_3}{L_1}, \frac{x_3}{L_1}, \frac{k_3}{L_1}\right)L_1 - dL_1 \quad \text{(A.4)}$$

where land can be managed (improved) by adding labor, intermediate inputs (fertilizer), and capital according to a management function

$$\gamma = \gamma\left(\frac{n_3}{L_1}, \frac{x_3}{L_1}, \frac{k_3}{L_1}\right) \quad \text{(A.5)}$$

where:

- γ: is a rate of land appreciation,
- n_3: labor used in managing land,
- x_3: intermediate inputs used in managing land,
- k_3: capital used in managing land, and
- d: soil erosion rate.

The management function $\gamma(\cdot)$ is assumed linearly homogeneous in its arguments (n_3/L_1, x_3/L_1, k_3/L_1) and in n_3, x_3, and k_3.

The equation of motion for water quality is

$$\dot{Y} = [a - D(Z_1) + \eta(n_4, x_4, k_4)]Y \tag{A.6}$$

where the impact of agricultural production on water quality is represented by:

$$D = D(Z_1) \ . \tag{A.7}$$

Water quality can be managed (improved) by adding labor, intermediate inputs, and capital:

$$\eta = \eta(n_4, x_4, k_4) \tag{A.8}$$

where:

- n_4: labor used in managing water quality,
- x_4: intermediate inputs used in water quality,
- k_4: capital used in managing water quality, and
- a: natural repair of water quality.

The damage function $D(Z_1)$ and the repair function $\eta(\cdot)$ are also assumed linearly homogeneous in their respective arguments.

Our equation of motion for the stock of ground water is

$$\dot{W}_1 = [\psi - e(n_5, x_5, k_5)]W_1 \tag{A.9}$$

where the extraction of ground water for use in agriculture is represented by:

$$e = e(n_5, x_5, k_5) \tag{A.10}$$

where:

- n_5: labor used in extracting ground water,
- x_5: intermediate inputs used in extracting ground water,
- k_5: capital used in extracting ground water, and
- ψ: the rate ground water is replenished.[15]

As discussed in the text, each natural capital asset is regenerative or renewable but could be exhausted from over-use. The net rate of regeneration, as captured by the equations of motion is a function of the intensity of use, the effectiveness of management to offset the intensity of use of an asset, the level of the stock of the resource itself, and the natural rate of regeneration.

[15]This is a simplified representation. The ground-water replenishment rate ψ is a function of precipitation, inflows and outflows, and the return flow of water extracted for agricultural uses.

The Model

Social welfare (U) is defined as a function of final goods and services (q, x_2), household production (h), an index of water quality (Y), land in its natural state (L_0), land used in agriculture (L_1), and leisure (n_7). The social planner's goal is to maximize:

$$Max\int_0^\infty e^{-rt}\ U(q, x_2, h, Y, L_0, L_1, n_7)\ dt \qquad \textbf{(A.11)}$$

where:

- q : agricultural output (final good),
- x_2: nonagricultural (final) goods and services,
- h : household production,
- Y : index of water quality, ($\partial U/\partial Y > 0$)[16]
- L_0: unused land (natural state),
- L_1: land used in agriculture,
- n_7: leisure, and
- r: social discount rate

subject to the equations of motion for the stock of effective land, surface-water quality, and the stock of ground water:

$$\dot{T}_1 = \gamma(\frac{n_3}{L_1}, \frac{x_3}{L_1}, \frac{k_3}{L_1})L_1 - dL_1 \qquad \textbf{(A.12)}$$

$$\dot{Y} = [a - D(Z_1) + \eta(n_4, x_4, k_4)]Y \qquad \textbf{(A.13)}$$

$$\dot{W}_1 = [\psi - \theta(n_5, x_5, k_5)]W_1\ . \qquad \textbf{(A.14)}$$

In addition to natural capital, there are equations of motion for each of our six types of reproducible capital:

$$\dot{k}_i = I_i - \delta_i k_i \qquad for\ i = 1, \ldots, 6 \qquad \textbf{(A.15)}$$

where: I_i represents gross investment in the ith type of reproducible capital and δ_i represents the depreciation rate for each type of reproducible capital.

A materials balance equation and constraints for labor and land complete the model:

$$x(n_2, k_2, Y, L_2) = x_2 + x_3 + x_4 + x_5 + x_6 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 \qquad \textbf{(A.16)}$$

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[16]Corner solutions are problematic. For perfect water quality, human efforts at improvement have no impact. With no water quality, agriculture creates no added damages. We assume these situations are unique so that our results are not affected.

$$N = \sum_{i=1}^{7} n_i \tag{A.17}$$

$$L = \sum_{i=0}^{2} L_i \, . \tag{A.18}$$

The materials balance equation accounts for the output of the nonagricultural sector, **x,** in the economy. For example, some nonagricultural output goes to final nonagricultural consumption goods and services x_2. Nonagricultural output is also used as investment goods I_i; inputs that go into managing the stock of effective farmland x_3, water quality x_4, and the stock of ground water x_5; and as inputs in the household production function x_6.

The current value Hamiltonian in flow of output terms is:

$$\begin{aligned}
H \equiv\; & U\,[q(n_1,\, k_1,\, Z_1,\, T_1,\, eW_1), \\
& x(n_2,\, k_2,\, Y,\, L_2) - x_3 - x_4 - x_5 - x_6 - I_1 - I_2 - I_3 - I_4 - I_5 - I_6, \\
& h(n_6,\, x_6,\, k_6),\, Y,\, L_0,\, L_1,\, n_7] \\
& + \rho_3[\gamma(\frac{n_3}{L_1}, \frac{x_3}{L_1}, \frac{k_3}{L_1})L_1 - dL_1] \\
& + \rho_4[a - D(Z_1) + \eta(n_4,\, x_4,\, k_4)]Y \\
& + \rho_5[\psi - e(n_5,\, x_5,\, k_5)]W_1 \\
& + \sum_{i=1}^{6} \mu_i[I_i - \delta_i k_i] \\
& - \omega[\sum_{i=1}^{7} n_i - N] \\
& - \Omega[\sum_{i=0}^{2} L_i - L]
\end{aligned} \tag{A.19}$$

where ρ_i, μ_i, ω, and Ω are co-state variables.

The Measurement of Net Welfare

The Hamiltonian along the optimal trajectory is the national welfare measure in utility terms (Mäler, 1991). The linear approximation of the Hamiltonian along the optimal path is the exact correspondence to the net national welfare measure. It measures the current utility of consumption (of goods and services and environmental services) and the present value of the future utility stream from current stock changes. This follows because stock prices measure the present value of the future contribution to welfare from a marginal increase in the stocks.

Net welfare is measured as

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

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

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

$$+ \frac{\partial U}{\partial h}[\frac{\partial h}{\partial n_6}n_6 + \frac{\partial h}{\partial x_6}x_6 + \frac{\partial h}{\partial k_6}k_6] + \frac{\partial U}{\partial L_0}L_0 + \frac{\partial U}{\partial L_1}L_1 + \frac{\partial U}{\partial Y}Y + \frac{\partial U}{\partial n_7}n_7$$

$$+ \sum_{i=1}^{6} \mu_i[I_i - \delta_i k_i]$$

$$+ \rho_3[\gamma(\frac{n_3}{L_1}, \frac{x_3}{L_1}, \frac{k_3}{L_1})L_1 - dL_1]$$

$$+ \rho_4[a - D(Z_1) + \eta(n_4, x_4, k_4)]Y$$

$$+ \rho_5[\psi - \theta(n_5, x_5, k_5)]W_1 \ . \qquad \text{(A.20)}$$

Recognizing the relationship between net welfare and net product, equation (A.20) can be viewed as the flow-of-output or expenditure approach to income accounting. That is, GDP = consumption + gross investment and NNP = GDP - capital depreciation = consumption + net investment. The first line in equation (A.20) represents final expenditures on the agricultural good. We assume all output of the agricultural sector (food) is a final consumption good, thus abstracting from the food processing sector. The second line captures total expenditures on the nonagricultural good **x**. Some **x** is, however, used as intermediate goods or inputs into the production of other goods. The expenditures on **x** that do not represent final consumption are subtracted in the third line of equation (A.20). The second and third lines, therefore, capture expenditures on the final consumption of the nonagricultural good.

The fourth line of equation (A.20) captures implied expenditures on the household product, natural-state land, aesthetic farm landscape, water quality, and leisure. The fourth line contains most of the extensions to the traditional GDP accounts. However, some of these expenditures may already be included in the GDP accounts. For example, government expenditures to improve water quality and explicit expenditures by environmental groups to save natural-state land such as old growth forests already show up in the accounts. The fifth line of equation (A.20) captures net investment in each of the six types of physical capital, while the last three lines report net investment in the three types of natural capital. The gross investment components of these last three lines are also extensions of the GDP accounts.

The first three lines of equation (A.20) and the gross investment components of line 5 sum to the traditional measure of GDP. Adding line 4 and the gross investment components of lines 6, 7, and 8 gives the extended GDP measure. Lines 1, 2, 3, and 5 sum to the traditional NNP measure. The entire expression given by equation (A.20) represents the extended NNP measure.

Two final observations stemming from equation (A.20) are worth noting. First, concern for sustainability and properly valuing natural resource depletion leads to extending the accounts by including lines 6, 7, and 8 of equation (A.20). Second, concern with including "nonmarket" goods (for example, housework, land in its natural state, rural landscape, water quality, and leisure) in the accounts leads to expanding the accounts by including line 4.

Appendix B: The Optimality Conditions

The optimality conditions are obtained by partially differentiating the Hamiltonian (equation A.19) with respect to the control and state variables. The control variables are the seven uses of labor, the uses of the manufactured output **x**, gross investment in the six types of reproducible capital, the three uses of land, and the level of water pollution, Z_1. For labor, the optimality conditions are:

$$\frac{\partial H}{\partial n_1} = \frac{\partial U}{\partial q}\frac{\partial q}{\partial n_1} - \omega = 0 \tag{B.1}$$

$$\frac{\partial H}{\partial n_2} = \frac{\partial U}{\partial x_2}\frac{\partial x}{\partial n_2} - \omega = 0 \tag{B.2}$$

$$\frac{\partial H}{\partial n_3} = \rho_3\frac{\partial \gamma}{\partial n_3} - \omega = 0 \tag{B.3}$$

$$\frac{\partial H}{\partial n_4} = \rho_4\frac{\partial \eta}{\partial n_4}Y - \omega = 0 \tag{B.4}$$

$$\frac{\partial H}{\partial n_5} = \frac{\partial U}{\partial q}\frac{\partial q}{\partial e}\frac{\partial e}{\partial n_5}W_1 - \rho_5\frac{\partial e}{\partial n_5}W_1 - \omega = 0 \tag{B.5}$$

$$\frac{\partial H}{\partial n_6} = \frac{\partial U}{\partial h}\frac{\partial h}{\partial n_6} - \omega = 0 \tag{B.6}$$

$$\frac{\partial H}{\partial n_7} = \frac{\partial U}{\partial n_7} - \omega = 0\ . \tag{B.7}$$

Equations (B.1), (B.2), and (B.6) indicate the value of the marginal product of labor is equalized across the three production sectors. This value ω, the shadow wage rate, is also the marginal value of leisure, equation (B.7), and the marginal value of labor in enhancing land, equation (B.3), repairing water quality, equation (B.4), and depleting ground-water stocks, equation (B.5).

The manufactured good **x** can be directly consumed (x_2), used as intermediate input, or used for investment. The optimality conditions for **x** as an intermediate input for improving land, water quality, and depleting ground-water stocks are:

$$\frac{\partial H}{\partial x_3} = -\frac{\partial U}{\partial x_2} + \rho_3 \frac{\partial \gamma}{\partial x_3} = 0 \tag{B.8}$$

$$\frac{\partial H}{\partial x_4} = -\frac{\partial U}{\partial x_2} + \rho_4 \frac{\partial \eta}{\partial x_4} Y = 0 \tag{B.9}$$

$$\frac{\partial H}{\partial x_5} = \frac{\partial U}{\partial q}\frac{\partial q}{\partial e}\frac{\partial e}{\partial x_5} W_1 - \frac{\partial U}{\partial x_2} - \rho_5 \frac{\partial e}{\partial x_5} W_1 = 0 \; . \tag{B.10}$$

These conditions show that the value of the marginal product of the manufactured good in each of its intermediate uses must equal $\partial U/\partial x_2$, the opportunity cost of direct consumption.

The optimality conditions for **x** as investment in reproducible capital are:

$$\frac{\partial H}{\partial I_l} = -\frac{\partial U}{\partial x_2} + \mu_l = 0 \qquad (l = 1,...,6). \tag{B.11}$$

As with intermediate goods, the marginal value of investment in each type of capital (μ_i) must equal the marginal value of the consumption good x_2 ($\partial U/\partial x_2$).

Partially differentiating with respect to each land type determines the distribution of land across sectors:

$$\frac{\partial H}{\partial L_0} = \frac{\partial U}{\partial L_0} - \Omega = 0 \tag{B.12}$$

$$\frac{\partial H}{\partial L_1} = \frac{\partial U}{\partial L_1} + \rho_3[\gamma(\cdot) - \frac{\partial \gamma}{\partial A}\frac{n_3}{L_1} - \frac{\partial \gamma}{\partial B}\frac{x_3}{L_1} - \frac{\partial \gamma}{\partial C}\frac{k_3}{L_1}] - \rho_3 d - \Omega = 0 \tag{B.13}$$

where $A = n_3/L_1$, $B = x_3/L_1$, and $C = k_3/L_1$. Because γ is assumed homogeneous of degree 1 in A, B, and C, equation (B.13) reduces to:

$$\frac{\partial H}{\partial L_1} = \frac{\partial U}{\partial L_1} - \rho_3 d - \Omega = 0 \; . \tag{B.14}$$

The remaining use of land, L_2, is chosen so that

$$\frac{\partial H}{\partial L_2} = \frac{\partial U}{\partial x_2}\frac{\partial x}{\partial L_2} - \Omega = 0 \; . \tag{B.15}$$

Recall the unique character of each type of land. Land in its natural state, L_0, has only a direct welfare effect and no productivity effect. Land used in nonagricultural production, L_2, affects welfare indirectly as an input in production. Farmland, L_1, however, has both a productivity effect in agriculture and a direct welfare effect in utility in terms of providing rural landscape. The shadow value Ω gives the price of land in its natural state. This price exceeds the direct marginal contribution of farmland to welfare because some farmland erodes, while pristine land and nonagricultural land are assumed not to erode. This price Ω also equals the value of the marginal product of land in the nonagricultural sector.

An additional control variable to consider is Z_1, the environmental input to agricultural production. The optimality condition for this variable is:

$$\frac{\partial H}{\partial Z_1} = \frac{\partial U}{\partial q}\frac{\partial q}{\partial Z_1} - \rho_4 \frac{\partial D}{\partial Z_1} Y = 0 . \quad \text{(B.16)}$$

Here the choice of Z_1 can be interpreted as the optimal use of an environmental input, water quality. Equation (B.16) indicates that the value of the marginal product of water pollution in agricultural production is equal to the marginal change in welfare from increasing water quality. The optimality conditions associated with the state variables describe the choice of stock levels for the six types of physical capital and the three types of natural capital. For the physical capital variables, the optimality conditions are:

$$\frac{\partial U}{\partial q}\frac{\partial q}{\partial k_1} = (r + \delta_1)\mu_1 - \dot{\mu}_1 \quad \text{(B.17)}$$

$$\frac{\partial U}{\partial x_2}\frac{\partial x}{\partial k_2} = (r + \delta_2)\mu_2 - \dot{\mu}_2 \quad \text{(B.18)}$$

$$\rho_3 \frac{\partial \gamma}{\partial k_3} = (r + \delta_3)\mu_3 - \dot{\mu}_3 \quad \text{(B.19)}$$

$$\rho_4 \frac{\partial \eta}{\partial k_4} Y = (r + \delta_4)\mu_4 - \dot{\mu}_4 \quad \text{(B.20)}$$

$$\frac{\partial U}{\partial q}\frac{\partial q}{\partial e}\frac{\partial e}{\partial k_5} W_1 - \rho_5 \frac{\partial e}{\partial k_5} W_1 = (r + \delta_5)\mu_5 - \dot{\mu}_5 \quad \text{(B.21)}$$

$$\frac{\partial U}{\partial h}\frac{\partial h}{\partial k_6} = (r + \delta_6)\mu_6 - \dot{\mu}_6 . \quad \text{(B.22)}$$

These conditions demonstrate that the value of the marginal product of reproducible capital in each activity (including land enhancement, water quality repair, and diminishing ground-water stocks) is equal to a rental price of capital. Because the investment good is treated as the undifferentiated intermediate good, $\mu_1=\mu_2=\mu_3=\mu_4=\mu_5=\mu_6$. However, the rental prices may differ because of different economic depreciation rates.

The final optimality conditions involve our natural capital stocks: effective farmland, water quality, and ground-water stocks. These conditions are:

$$\frac{\partial U}{\partial q}\frac{\partial q}{\partial T_1} = r\rho_3 - \dot{\rho}_3 \quad \text{(B.23)}$$

$$\frac{\partial U}{\partial Y} + \frac{\partial U}{\partial x_2}\frac{\partial x}{\partial Y} = (r\rho_4 - \dot{\rho}_4) - \rho_4[a - D(Z_1) + \eta(n_4, k_4, x_4)] \quad \text{(B.24)}$$

$$\frac{\partial U}{\partial q}\frac{\partial q}{\partial W_1} e = (r\rho_5 - \dot{\rho}_5) - \rho_5[\psi - e(n_5, k_5, x_5)] . \quad \text{(B.25)}$$

Equation (B.23) has a straightforward interpretation as rental price of effective farmland. Unlike the conditions for physical capital stocks, equation (B.23) does not have a depreciation rate. Soil erosion, which is similar to a *physical depreciation* rate, is already captured in equation (B.23). The optimality condition for the stock of water quality is also a rental rate similar to those for physical capital. However, given the form of equation (B.24), this rental rate is adjusted for water quality *appreciation* rather than depreciation.

Finally, it is interesting to compare the shadow values for reproducible capital with natural capital. For example, a unit of reproducible capital that is used in the agricultural sector has a value:

$$\mu_1 = \frac{\frac{\partial U}{\partial q}\frac{\partial q}{\partial k_1}}{(r + \delta_1)} + \frac{\dot{\mu}_1}{(r + \delta_1)} \tag{B.26}$$

or

$$\mu_1(t) = \int_t^{\infty} e^{-(r + \delta_1)(s - t)} \frac{\partial U}{\partial q}\frac{\partial q}{\partial k_1}(s)\, ds . \tag{B.27}$$

In other words, the value of a unit of reproducible capital in time t is equal to the discounted value of the future services it will provide in terms of agricultural output. An increase in the discount rate (r) or the rate of depreciation (δ_1) will reduce the value of capital.

Our shadow value of natural capital has similar characteristics. For example, a unit of water quality has a shadow value:

$$\rho_4 = \frac{\frac{\partial U}{\partial Y} + \frac{\partial U}{\partial x_2}\frac{\partial x}{\partial Y}}{[a - D(Z_1) + \eta(n_4, k_4, x_4)]} + \frac{\dot{\rho}_4}{[a - D(Z_1) + \eta(n_4, k_4, x_4)]} \tag{B.28}$$

or

$$\rho_4(t) = \int_t^{\infty} e^{-[r - a + D(Z_1) - \eta(n_4, k_4, x_4)](s - t)} \frac{\partial U}{\partial Y} + \frac{\partial U}{\partial x_2}\frac{\partial x}{\partial Y}(s)\, ds . \tag{B.29}$$

For natural capital, an increase in the natural rate of regeneration or an increase in human attempt to improve the quality of water reduces the discount rate and increases the shadow value associated with water quality. In addition, unlike reproducible capital, the shadow value captures the discounted value of water quality to both consumers ($\partial U/\partial Y$) and producers of the manufactured good [$(\partial U/\partial x_2)(\partial x/\partial Y)$].