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Counting Nonmarket, Ecological Public Goods

The Elements of a Welfare-Significant Ecological Quantity Index

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RESOURCES FOR THE FUTURE

Counting Nonmarket, Ecological Public Goods: The Elements of a Welfare-Significant Ecological Quantity Index

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Abstract

In this paper, I address a difficult, important, and long-standing problem in national income accounting: How to capture the welfare contributions of nonmarket, public environmental goods? The strategy I advocate here is to use principles from economic accounting, welfare economics, and environmental valuation to define the nonmarket units that should be used in a quantity index of ecological goods and services. A goal is to mimic the household-level foundations of conventional national income or product accounts, but extend them to the nonmarket natural economy. I describe the underlying theory and show how it can be used to define a practical, empirical strategy for constructing a welfare-significant ecological quantity index.

Key Words: environmental goods and services, national income and product accounts, NIPAs, public goods.

JEL Classification Numbers: C43, C82, Q2, Q3

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Counting Nonmarket, Ecological Public Goods: The Elements of a Welfare-Significant Ecological Quantity Index

James Boyd*

1. Introduction

This paper addresses a difficult, important, and long-standing problem in national income accounting: How do we capture the welfare contributions of nonmarket, public environmental goods?[1] As I argue here, the key to this endeavor is the construction of a welfare-significant ecological quantity index (WSEQI). Quantity indexes and their price index counterparts are the core of any national income or product account (NIPA).

What quantity units are we to count when markets are not present, meaning that there is no easy way to track or define what is being used, consumed, or enjoyed? Note that market goods usually come in conveniently predefined quantity units—the cars, washing machines, haircuts, and restaurant meals consumers buy every day. In conventional income accounts these goods and services are the building blocks of a quantity index. We can simply ask: How many cars and haircuts were consumed during this period? But for natural capital, its many public, nonmarket goods and services are not defined, provided, and priced by markets.[2] This means, of course, that we lack the market artifacts—units sold, prices paid—so useful to accountants of the market economy.

Not only do we have a missing prices problem—How do we infer value when market prices are absent?—we also have a missing quantities problem. Stated more carefully, we need to replicate the market's ability to define units of consumption, but do so in a nonmarket setting. Accordingly, economists should be involved in defining ecological quantity accounts and work with natural scientists to depict nature in a way useful to utilitarian analysis.[3]

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[1] For histories of the idea and its role in national accounting see Mäler (1991), Nordhaus and Kokkelenberg (1999), and Heal and Kristrom (2005).

[2] Even when nature's goods and services aren't public goods, the private consumption of nature often has ancillary consequences for the scale or quality of public goods. In addition, many natural resource markets for private goods are heavily distorted by inefficient regulatory regimes, rendering the market information that they provide suspect.

[3] Banzhaf and Boyd (2005), Boyd (2006), and Boyd and Banzhaf (2007) develop this theme and analyze concrete ways in which economics and ecology can productively interact.

Here, I advocate using principles from economic accounting, welfare economics, and environmental valuation to define the nonmarket units that should be used in a quantity index of ecological goods and services. My goal is to mimic the household-level foundations of conventional NIPAs, but extend them to the nonmarket natural economy. In this paper, I describe the underlying theory and show how it can be used to define a practical, empirical strategy for constructing a welfare-significant ecological quantity index (WSEQI).[4]

Capturing nature in a comprehensive way is a tall order. Ecological systems are complex, with an uncountable number of components interacting nonlinearly. Is it realistic to think we can capture such a complex system in a practical account? It depends on the goal, of course. If the goal is comprehensive knowledge of nature, that is impossible. But accounting systems serve narrower ends. They provide a rough, but valuable, guide to the more complex systems they describe. The conventional economy is also complex, multidimensional, and nonlinear. We do not look to gross domestic product (GDP) and other NIPAs for the complete truth about our economies. Instead, we look to them as important signals of our welfare. Nature's nonmarket contributions to our well-being deserve a similar set of signals.

1.1 The Goal of the Index

The index described here is intended to create a "welfare-significant" measure of nonmarket ecological consumption. Such an index has several characteristics: First, it is anthropocentric and rooted in utilitarian economics. Second, the index is an account, not an indicator system.[5] Accounting systems rely on "identities" to facilitate and discipline measurement. At the firm level, double-entry bookkeeping is an example. At the national level, so is the definition of GDP.[6] Accounting identities facilitate aggregation and comparison of the components of an index in ways that indicator systems do not. Despite being constructed from myriad components, GDP can be reported as a single value because accounting identities

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[4] Practicality and a sound theoretical base are the prerequisites for a successful accounting system. As Heal and Kristrom note (2005, *1211*), the way forward is "to find an even happier marriage between theorists and empiricists in green accounting."

[5] All accounting systems are indicator systems, but the reverse is not true. The distinction is that accounting systems are constrained by their structure in a way that measurement systems are not. Ecological accounting to date takes the form of indicator systems. For an example, see Binning et al. (2001).

[6] Double-entry bookkeeping means that each transaction results in at least one account being debited and at least one account being credited, with total debits equal to total credits. GDP is defined as the sum of consumption, investment, government purchases, and net exports.

discipline its construction. The political and social influence of NIPAs derives largely from the fact that they are rule-based accounting systems.

What accounting identities are binding in a WSEQI? They are the same as those in a GDP-like NIPA, with one difference. Because the focus is on nonmarket goods and services, “virtual” prices and income are important. Although the measurement of virtual prices and income is not my focus here, the weights eventually attached to the quantities I define in this paper should be the virtual prices that emerge in a general equilibrium constrained by the sum of real and virtual income.[7] An additional set of constraints arises relating to the distinction between intermediate and final goods. I address this in detail in Section 3.

1.2 Relationship to Other Environmental Accounting Approaches

A full review of the many alternative approaches to environmental accounting is beyond the scope of this paper.[8] The ecological quantity index I describe in the sections that follow is related to, but different from, both material accounts and NIPA-like environmental accounting systems, often loosely referred to as “green GDP” or “green national accounts.” As I will argue, a WSEQI comprises physical material measures. A WSEQI, however, is not a “material account” as that term is used in national accounting. I describe the difference between a WSEQI and a material account in detail in Section 3.2.

Most green income accounts start with the presumption central to this paper, that nature’s contributions to welfare should be measured. In practice, however, existing green accounts differ from the WSEQI described here. For very good reasons, existing accounts focus on “near-market” clues to nature’s value.[9] Examples include economic damages arising from air pollution (using health costs), the valuation of timber stocks (using land values) or fisheries (using the value of commercial harvests), and the value of water (for hydropower generation). China’s environmental accounting system, for example, focuses on near-market accounts—such as its accounts of environmental expenditures—along with aggregate assets such as fish populations,

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[7] I should emphasize that GDP-like NIPAs and the accounting system described here are not, and can never be, a measure of welfare itself. Instead, the indicators they produce are best thought of as practical approximations of welfare.

[8] For descriptions of existing environmental accounting initiatives, see Hecht (2000, 2005), Haas et al (2002), Heal and Kristrom (2005), and Anielski (2006).

9 As an input to marketed goods, nature’s value is partially captured by NIPAs, although nature’s specific contribution to the value of the market goods and services is not extractable as an independent set of measures.

forests, water, and minerals (The World Bank 2006). It is natural for accounting systems to focus on near-market assets, goods, and services because the near market is where credible price estimates are most practically derived.

The downside of near-market accounts, of course, is that the scope of these accounting systems is relatively narrow. They ignore the environment's public, nonmarket goods and services, focusing instead on goods and services that can be credibly priced. The WSEQI makes a different trade-off. It seeks comprehensive measurement of public, nonmarket goods and services, but in doing so it moves away from the market and the prospect of easily derived virtual prices. We can see, then, that green national accounts and a WSEQI share the same motivation but are applied to different streams of goods and services. They are complements, not competitors.[10]

Although recognized as important, ecological income accounts are in an early stage of development.[11] No practical example exists.[12] Ecological accounts are beginning to be developed, but these are not income accounts in an economic sense.[13] As a result, for China—or for any other country—the accounts described here are not necessarily the most practical first step in efforts to make NIPAs reflect environmental costs and benefits. But nature's nonmarket contributions to welfare may be at least as large as its near-market contributions (The World Bank 2006). It is important and interesting to understand the sheer magnitude of that virtual natural economy.[14]

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[10] Arguably, neither of these should be called green GDP because that term suggests a comprehensive measure of market- and nonmarket well-being.

[11] According to Hecht (2000, *iii*), existing environmental NIPA efforts "include neither meaningful adjusted macroeconomic indicators nor the value of non-marketed environmental goods and services."

[12] Describing the recent System of Integrated Environment and Economic Accounting (SEEA) Smith (2007, *597*) observes that "ecosystem accounts are in their relative infancy and are presented more by way of suggested avenues for exploration in the handbook than as clearly worked out recommendations."

[13] See Weber (2007) for discussion of current ecological accounting in Europe.

[14] The U.S. National Research Council (Nordhaus and Kokkelenberg 1999, *23*) states the mission thus: "We must not forsake what is relevant and important merely because it presents new problems and difficulties….We must endeavor to find dimly lit information outside our old boundaries of search, particularly when the activities are of great value to the nation."

2. Quantities versus Weights

Economic measurement of nonmarket benefits typically ignores the distinction between quantity q and value p. What matters is the product of the two, $p \cdot q$, the social benefit of an air-quality improvement, for example. Welfare-significant accounting systems require a precise, consistently maintained delineation of the quantity measured and the price or other weight attached to the quantity.

2.1 The Index Number Problem

Accounting measures, by their very nature, distinguish between quantity and price. We can think of economic accounting theory as a search for ways to factor the benefits of production into (1) their two core components, price and quantity, in a way that is (2) logically and economically consistent. This challenge is called the "index number problem."

With quantities and prices clearly differentiated, one of the quantity/price sets can be held constant. Real GDP, for example, is a measure of quantity, in which prices are held constant over time. With prices held constant, movements in the output index meaningfully describe changes in quantity produced and consumed. If prices are not held constant, the interpretation of the index is muddied: Is an increase in the index evidence of changing prices or changing output? Accordingly, economic accounting systems require a clear and consistently maintained distinction between q and p..

It is interesting that the distinction between q and p gets so little attention in environmental economics. Nonmarket goods and services do not come in convenient packages, where q is defined by the market. So how do nonmarket environmental economists think about this? The truth is, they don't, largely because they haven't needed to. Environmental economics is often called on to analyze the following type of issue: What are the benefits of a tighter air quality standard in Los Angeles? To answer this question, all that matters is the comparison between $p \cdot q$ before the policy is implemented and $p \cdot q$ after it is in place. It is unimportant what part of the benefit is considered an improvement in output, versus an increase in the value of the output. For example, is the number of people in Los Angeles, n, considered part of the value of the benefit or part of the quantity? It could be either.[15] And for many questions in environmental economics, it doesn't matter.

But it matters a lot to economic accounting. Because output and price measures are constructed separately, their units must be distinct and consistently applied.

2.2 What Is Quantity and What Is Value?

If q and p are to be distinguished, how should this be accomplished? What principles, if any, should be applied? Because nonmarket ecosystem goods and services do not emerge from factories and are not sold in markets, defining and measuring their "units of account" requires theoretical and empirical innovation. The conceptual distinction between ecosystem services and their value is often surprisingly difficult to make.

Accountants use the term "goods and services" to denote the quantities measured in accounts. This same convention is applied here: Ecosystem goods and services are the quantities to be measured. Prices, virtual and otherwise, are the weights applied to the goods and services. A problem arises, though, in that the term "ecosystem services" has no consistent definition in environmental economics.

Next, I offer a brief mathematical synopsis of Banzhaf and Boyd (2005), using a simple production technology to convey the semantic and practical distinction between q and p. The model features a final good F, and two inputs, capital K and an ecosystem good E. The final good and the inputs have prices P_F, P_K, and P_E, where P_E is a virtual, not observed, price. The production function is some $F = \mathrm{F}(K,E)$.

Two common approaches are taken to the depiction of the ecological input. First, the value of the ecological input can be derived from the value of its productivity with respect to the final good times the price of the final good.

$$P_E = (\partial \mathrm{F}/\partial \mathrm{E})\, P_F. \tag{1}$$

Second, using the production function itself and some rearrangement of terms, the ecological input's value can be expressed via the other input's role in production. Specifically,

[15] If the quantity is defined as a per capita air-quality improvement, the number of people benefiting would increase the weight (p) given to the quantity. If, on the other hand, we defined the quantity as the change in the total amount of human exposure, n would increase the quantity q, not the weight p.

$$P_E = \frac{\partial F/\partial E}{\partial F/\partial K} \cdot P_K, \tag{2}$$

where the ecological input's value is derived from its substitution relationship with the capital input times the price of the capital input.[16]

Now consider a marginal change in the ecological input, ∂E. The total value of that change can be expressed in three different but equivalent ways.

$$P_E \cdot dE = (\partial \mathrm{F}/\partial \mathrm{E}) \cdot P_F \cdot dE = \frac{\partial F/\partial E}{\partial F/\partial K} \cdot P_K \cdot dE. \tag{3}$$

Do these expressions give us a clear guide to the "quantity" (the ecosystem good or service) and the "value" of the good or service p? Both in principle and practice, the answer is no.

For example, individual chapters in a well-known environmental economics text (Kopp and Smith 1993, Chapters 2, 7, and 14) define ecosystem services in three completely different ways. One defines the service as the total value – $q = P_E \cdot E$ in our example. Another refers to the service as the contribution of the environmental input to production of the final good as E changes. Denote this as $q = \Delta \mathrm{F}(K,E)$.[17] Yet another refers to the service as the environmental input itself, $q = E$. In a total benefit framework, each of these definitions is consistent with the identity in equation (3). In other words, none of the definitions is "wrong." From an accounting perspective, though, the lack of clarity and consistency is problematic.

So which definition of q—the ecosystem services to be counted—is preferable? We can immediately rule out the first because it defines q as the product $P_E \cdot E$, instead of something that can be decomposed into distinct quantity and value components. The distinction between $q = \Delta \mathrm{F}(K,E)$ and $q = E$ is more subtle. Both definitions permit multiplication by a price to achieve a total value.[18] In that sense, both work from an accounting perspective. But the latter definition, where the ecological input is the quantity measure ($q = E$), is preferable.

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[16] Algebraically, this is derived from the producer's tangency condition $(\partial \mathrm{A}/\partial E) / (\partial \mathrm{A}/\partial K) = \mathrm{P_B} / \mathrm{P_K}$.

[17] For example, if the ecological input goes from E^1 to E^2, $q = \mathrm{F}(K, \mathrm{E}^2) - \mathrm{F}(K, \mathrm{E}^1)$.

[18] In the former case, the final good's price P_F pertains. In the latter case, we require either knowledge of the virtual price P_E or knowledge of the production function and P_K.

This definition eliminates the need to understand economic production functions for the purposes of developing the quantity index. This means, though, that the economic production functions depicted in equation (3) must be captured on the value side of the accounting system. If clean water is a quantity to be measured in the index, estimation of the value of that water is where substitution relationships and knowledge of the way they translate into final production are captured.[19] Absent direct knowledge of P_E, we cannot avoid the complexities arising from joint ecological and nonecological production. But there are practical reasons to move those complexities to the valuation side of the ledger.

If we use $q = \Delta F(K,E)$, that definition of quantity can obscure, rather than clarify, underlying ecological changes. If all we observe and count is an increase in final production, we will not know whether that increase results from changes in the ecological or the nonecological inputs. In fact, innovation or other changes in production may lead to higher production levels even if ecological inputs are declining in availability or quality. This is an undesirable property for an ecosystem services quantity index. An ecological quantity index should tell us about ecological conditions; it should not require economic interpretation. Consequently, $q = E$ is preferable.

There are other reasons to prefer $q = E$. The measure of value associated with $q = \Delta F(K,E)$ is P_F. If that price is available, we would have a practical reason to prefer its associated quantity measure. But there will be no such price for nonmarket goods and services. Also, ecological measures $q = E$ are concrete and intuitive, they make sense to noneconomists, and they are in the empirical realm of the natural sciences. Economists should have something to say about which elements E are measured. But economists themselves will not do any of that measuring. In addition, ecological measures $q = E$ already have a close analogue in national accounting systems. They resemble the material accounts already observed in many international systems.

In summary, an index composed of concrete, physical, ecological quantities and qualities is the appropriate place to begin a system of ecological public good accounts. Moreover, such an index—because it is “material and physical” instead of “economic”—provides a natural point of

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[19] The production functions described here should be thought of as economic production functions, where ecological inputs are combined with nonecological inputs to produce outputs that are consumed or enjoyed by society. A distinct set of biological, hydrological, and ecological production functions describe the way in which ecological outcomes arise from ecological and social conditions.

collaboration between the natural and social sciences. I develop this point in more detail in Section 4.

Keep in mind that the quantity index advocated here, although material and physical in composition, is not equivalent to material accounts as they are understood by the international accounting profession (Smith 2007). I develop the distinction in more detail in the sections that follow.

3. The Elements of a WSEQI

In this section, I describe physical ecological measures—the quantity index—but they are physical measures consistent with an economic, rather than materials-based, approach to accounting. I use the word "quantity" as shorthand for all of the following: countable biophysical features (e.g., land cover types and species populations); biophysical qualities (e.g., particulate or toxics concentrations); and stochastic depictions of quantities and qualities (e.g., hydrographs).

Previously, I advocated using ecological inputs themselves as the elements to be valued in a WSEQI. But as I pointed out earlier, nature presents us with an uncountable number of such inputs. So, to comprehensively depict its contributions to well-being, must we count all nature's features and qualities? The answer is no. Much as GDP does not count all the units exploited and traded in the market economy, an ecological quantity index need not count all the elements of nature. In both cases, a utilitarian approach to accounting allows us—requires us, actually—to focus on "final" units of consumption. The intermediate inputs to those final units are explicitly excluded from an economic quantity index. If they weren't, the quantity index would double count numerous elements of consumption, which violates the accounting identities so central to an economic index.

What do "final goods" mean in an ecological context? In the absence of markets, is final ecological good a concept that can even be interpreted? That is the main subject of this section, although I also address several other issues, including the relationship of the WSEQI to material and asset accounts.

3.1 Biophysical Final Goods

In Section 2, I argued that the ecological quantities best suited for an economic index are biophysical inputs (E) to economic production. I then introduced the notion that we should count final goods and services. This construction suggests that the things we should count are both inputs and final goods—an apparent contradiction. To clarify, let me restate the role of an ecosystem account in a larger system of economic accounts. The goal of the quantity index described in this paper is to comprehensively describe both market and nonmarket ecological "exports" to the economic system. Semantic confusion can arise because two distinct systems are in play. First is the biophysical system (nature). Second is the economic system that translates biophysical inputs into economic benefits. The terminological difficulty crops up because the ecological quantity index counts the biophysical system's final goods and services. But these final biophysical quantities then appear as inputs to GDP or other economic accounts. The final goods and services described here, then, are final only in a biophysical sense. They need not be final in an economic sense.[20]

To define biophysical final goods, let's start with how these goods are defined in existing economic accounting systems. Two principles help define what it means to be a final good. First is the need to avoid double counting. Second is the importance of consumer choice to valuation.

First consider the issue of double counting in a welfare-significant account. If we count both cars and the steel used to make them and then weight cars and steel by their market prices, we will have double counted the value of the steel because the steel's value in car production is embodied in the value of the car. In calculating GDP, final and intermediate goods are distinguished in the following way. If a good or service's value adds to the value of a good or service subsequently sold in the market, it is an intermediate good. Otherwise it is a final good. Returning to my example, cars are final goods. The labor, leather, steel, and human capital required to make the car are intermediate goods.

The concept of double counting illustrates a fundamental difference between material and economic accounts. Material accounts can resemble input–output models, where the goal is to track the life cycle of physical resources so that resource demand, waste, and externalities can be clearly identified. In general, double counting is not an issue in material accounts because a goal of such accounts is to track the transformation of a resource as it moves through the economic system.[21] For example, in material accounts, wood will appear in many different forms throughout the accounts—perhaps as standing forest, raw timber, pulp, waste, and finished

[20] Some final ecosystem goods are also final economic goods. An endangered species, for example, is a final good in both a biophysical and economic sense because the existence benefit of the species requires no intervening, noneconomic inputs to yield an economic benefit.

[21] "Physical accounts suffer from one major drawback – at least in the eyes of users who view the world through an economic lens: they offer very little chance of aggregation." (Smith 2007, *597*)

lumber. In contrast, where economic accounts are concerned, double counting violates the underlying economic identities that constrain the account.[22]

> *Thus, it deserves emphasis that a WSEQI is material in nature. But material and physical accounts—as commonly understood—are not themselves a welfare-significant quantity index.*

Second, the importance of consumer choice is taken for granted in GDP, but should not be taken for granted in environmental and other nonmarket accounts. When counting market goods, those goods are subject to consumer choice by definition. In fact, the value of final goods is revealed by consumer choices in the market. In a nonmarket context, the point at which consumers make choices can be less clear. GDP tends to count items that are concrete and subject to tangible consumer (market) choices.[23] If we are ever to attach welfare-significant weights to ecological inputs, the quantities we count should have the same properties.

Given that the ultimate aspiration of the index is to weight ecosystem goods and services with their virtual, nonmarket prices, the quantity index needs to be composed of units subject to valuation. The only way to ever estimate these virtual prices is to come as close as possible to the point at which people reveal those virtual prices through choice. This is the rationale for viewing ecological accounting units as the final inputs to "home production." Another way of putting this is

> *The final biophysical units used in an ecosystem quantity index should be the ecological features, quantities, and qualities that are directly combined with other (nonecological) inputs to produce market and nonmarket benefits.*

With units such as these, virtual prices can then—in principle—be derived via analysis of the ecological inputs' contribution to market outputs, as in equation (1), or by knowledge of substitution possibilities, as in equation (2).

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[22] In some cases, material accounts are constrained by different, physical identities (conservation of mass or energy, for example).

[23] This is an oversimplification. The U.S. Bureau of Economic Analysis (U.S. BEA), for example, often relies on proxies for difficult-to-measure service outputs (such as accounting and financial services; see, for example, Griliches 1992).

3.2 Illustrations

In practice, the procedure is to first identify utilitarian benefits that require ecological inputs, then identify the ecological final goods used as inputs to those benefits. Consider the following incomplete list of benefits, associated final ecological inputs, and nonecological substitutes.

Recreational angling. As a recreational experience, angling benefits arise from a combination of ecological final goods such as lakes, streams, riparian land cover, and fish populations present in the water bodies. Benefits also arise from nonecological inputs such as capital goods (rods, lures, boats, and docks) and human capital (expertise).

Note that the "number of fish caught" is not the quantity measure we seek in this index. Why? Because the number of fish caught is a function of ecological and nonecological inputs. The better the equipment and the greater the skill of the angler, the more fish are caught—independent of the state of the underlying ecosystem. This example reflects the principle that the index's quantities are those relevant at the point of possible substitution to nonecological inputs.

Also note that there are multiple ecological inputs to the ecological final goods identified here. Fish populations relevant to angling depend on the populations in those species' food chains, for example. But food chain species should not be counted as final goods in this context (the benefits of recreational angling).[24] Instead, their value is embodied in the bass, trout, salmon, or other population targeted by anglers.

Flood damage mitigation. Reduced frequency and severity of floods is a utilitarian benefit to which ecological inputs can contribute. Wetlands, in particular, absorb and slow flood pulses. To a lesser extent, other natural land cover types do so as well. The quantity of wetlands, then, is a final ecological input to the provision of flood damage mitigation.

The virtual price of wetlands (the value side) could, in principle, be derived either from knowledge of the direct effect of wetlands on property and other damages, or indirectly via the effects of nonecological substitutes such as dikes, dams, or other forms of property protection.

[24] These other species may be relevant quantity measures where other benefits are concerned, such as species existence benefits. Later in the paper, I discuss the benefit-contingent nature of final ecological quantities in more detail.

Pollination of commercial crops. Native species play an important role in pollinating commercial crops and can directly influence crop yields. As a result, the presence and density of native pollinator populations is an important input to commercial agriculture.

Again, commercial harvests are not the appropriate ecological quantity measure because harvests are the product of both ecological and nonecological inputs. The virtual price of pollinator populations can, in principle, be inferred by controlling for the presence of other inputs (and thus learning about the pollination–harvest production function) or from the prices and substitutability of commercial pollination services.

Public health damage mitigation. Air, soil, and water quality are the appropriate quantity measures in this context. Because reductions in acute health events, morbidity, and mortality result from combinations of ecological stressors and nonecological inputs, such reductions are not the proper quantity measure. Substitutes include medical interventions, filtration, and damage avoidance actions.

Aesthetic benefits. Ecological features that directly give rise to aesthetic benefits tend to be related to land cover types. Undeveloped terrain, including open water and mountain areas, are relevant final quantities here. So too are certain types of air and water quality. Clear water and clear air, apart from their other benefits, can also contribute to aesthetic benefits.

There may be no clear substitutes for certain aesthetic features of the natural landscape. Economic production of these benefits, however, often requires complementary investments in time and access. After all, a beautiful view has no aesthetic value if it cannot be seen.

Stewardship benefits. Existence, nonuse, bequest, or stewardship benefits arise from altruistic and ethical motivations. But there are clear quantity measures of these benefits, namely the species, wilderness, and natural features to which we attach existence value. For example, a raw count of viable global species—perhaps weighted by the charisma of individual species—is a quantity measure of species existence benefits.

Uniquely, there are no nonecological substitutes for stewardship benefits. Moreover, no economic production function intervenes between the ecological final goods and the benefits arising from them.

I should emphasize that the examples I give here are not exhaustive of the benefits to which nature contributes.

3.3 Final Goods Are Benefit-Contingent

Although the principles and constraints imposed by accounting identities are central to an economic accounting system's power and validity, they can lead to confusion. A prime example is the way in which final goods are benefit-contingent. This means that a good can be final in the provision of one benefit and not final in the provision of a different benefit. Consequently, many of the final goods identified in my illustrations are final goods only in that particular context. Ecological inputs, then, will switch back and forth between final and intermediate, depending on the benefit being accounted for.

Consider a hillside forest and two different kinds of benefit: aesthetic benefit and public health damage mitigation. Aesthetically, people with visual access to the hillside directly enjoy the forest's physical features, so those features should be counted as a beauty-related final quantity. In terms of public health, forests may sequester pollutants. In this benefit context, however, the forest is an intermediate, not final good. The final, public-health-related good is the air quality itself. The forest has a positive, but intermediate, impact on that final good. Accordingly, from an accounting perspective, the forest is both final and intermediate.

Other examples of this phenomenon abound. Wetlands should be counted as final goods for flood protection but are intermediate goods when they lead to improvements in drinking water quality (in which case the drinking water quality is the final good). In a conventional GDP context, the same thing happens. Tomatoes, onions, lettuce, and ground beef are counted if purchased in a grocery store, but are not counted if sold as a McDonald's hamburger.

3.4 Counting Discrete Ecological Goods and Services, Not Ecological Assets

An ecological index cannot be welfare-significant if it cannot disaggregate ecological inputs along spatial and temporal dimensions. For example, what is the value of U.S. water resources in 2007? This question cannot be meaningfully answered without more detailed knowledge of the location and timing of the waters' availability.

To date, most green accounting systems have adopted a different approach, which we can call an "aggregate" approach to environmental inventories. Mineral and forest resource accounting, for example, often uses national aggregates, such as the total supply of harvestable timber, copper, and water resources.[25] In these applications, an aggregate approach to accounting makes sense. Aggregate measures of these kinds of commodities are entirely appropriate because lumber and copper are fungible (homogeneous, transportable, and storable). Second, it makes sense to make use of aggregate asset prices when they are available, as they are in the case of many commodity-type natural resources. Most existing green accounts exploit the availability of commodity asset prices in just this way, making aggregate asset measures the natural, corresponding quantity measure.

An aggregate approach to ecological nonmarket value, though, is unsatisfactory.[26] Ecological inputs are not fungible in the way that most economic goods and services are. Rivers and forests cannot be shipped across state lines. Similarly, most ecological inputs cannot be accelerated or inventoried across time (note, though, that this is precisely the purpose of reservoir management). If welfare significance is the empirical goal, the quantity units in the index must reflect a fine-grained sense of space and time.[27]

This is particularly true given the ultimate goal of valuation. Like any benefits, environmental benefits are a function of scarcity, substitutes, and complements. Environmental benefits are often not fungible precisely because substitutes and complements in the economic production function are themselves not fungible.[28] If a beautiful vista is to yield social value, people must have access to it. In other words, the vista must be spatially "bundled" with infrastructure—roads, trails, and parks—that are themselves not transportable.

Recreational fishing and kayaking require docks or other forms of access. Substitutes for a given recreational experience depend on a recreator's ability to reach them in a similar amount of time. For this reason, the location of nonfungible substitutes is important. The value of surface water irrigation is a function of the location and timing of alternative subsurface water sources. If wetlands are plentiful in an area, a given wetland may be less valuable as a source of flood pulse

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[25] For examples, see Peskin and Delos Angeles (2001), United Nations et al. (2003), Schoer (2006), and The World Bank (2006).

[26] Practically speaking, there is always a trade-off in accounting between the (costly) desire for specificity and the loss of information that attends "lumpy" undifferentiated quantities.

[27] This bears close resemblance to the Arrow-Debreu perspective on commodity differentiation, where the timing and location of delivered products is used to differentiate them. I thank Heal (2007) for reminding me of this analogy.

[28] This is what has thwarted so-called benefit-transfer studies in environmental economics (*Ecological Economics*, Special Issue 2006).

attenuation than it might be in a region where it is the only such resource. Accordingly, ecological goods are not fungible and neither are the substitutes and complements necessary to their eventual valuation.[29]

Many market goods are bought and sold as assets (e.g., real estate, financial products, and firms), but nonmarket public goods are unlikely to ever be sold this way. Even when they are, the observed prices should be treated with suspicion, given the necessary role of government in assigning quasi-property rights and setting prices.[30] Ecological accounting, then, should not expect aggregate, asset-type market prices to be empirically relevant. Instead, the opposite is true. Public good, nonmarket ecological assets are much more likely to be valued by "building up" the value via valuation of the services flows arising from the asset.[31]

This mind-set is very different from that expressed in the SEEA's (System of Integrated Environment and Economic Accounts) discussion of ecological accounting (although note that the SEEA offers no concrete proposals for the way in which ecological accounting should occur). According to the SEEA, "it is not generally the components of ecosystems that benefit humans, but the systems as a whole."[32] This is both philosophically debatable and practically unhelpful. Society surely benefits from the ecological system, but the same can be said of the market system. Nevertheless, when we account for the market economy, we do not value the system as a whole. Instead, we construct the system's value from its discrete components.

3.5 Ecological Quality

How are goods and services of different quality handled in economic accounting systems? And how should they be handled in an ecosystem index? Clearly, because quality matters to welfare, it should be captured by the accounting system. Interestingly, quality differences can appear on either the quantity side q of the accounts or on the value side p. Which

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[29] The role of service zones in environmental valuation is well appreciated. For example, travel cost models require analysis of recreational substitutes, which is an inherently spatial issue.

[30] In the United States, for example, the price of oil, gas, and mineral leases may not bear a close resemblance to their true social value.

[31] Note that accounts like GDP are not in general composed of assets either, although assets are important to some accounts. GDP is itself built up from economic units—cars, hamburgers, haircuts—valued at the household and firm levels.

[32] This reflects an over-reliance on "asset" rather than "service" in the current thinking embodied in the SEEA 2003. See Section 5, "Implications of SEEA 2003." (United Nations et al. 2003, *257*)

way it is done is a matter of practical choice. The choice is not based on a black-and-white economic principle.[33]

Consider two different kinds of wetlands, one that significantly absorbs flood pulses and one that doesn't.[34] Ideally, we should treat these as distinct goods, account for them separately, and assign them distinct virtual prices. Clearly, though, there are practical limits to the level of disaggregation that can take place in a working set of accounts. The alternative is to count at a higher level of aggregation and have the corresponding virtual price reflect the underlying quality heterogeneity. The existing NIPAs routinely confront this kind of choice.

Imperfect quality differentiation and adjustment is a recognized weakness of existing NIPAs. Consider the way in which U.S. accounts treat changing product qualities over time. GDP counts computers, but because of technological innovation a computer in 1990 is clearly not the same as one in 2005. Unfortunately, adjustment for quality differences resulting from innovation or even certain basic product characteristics (shouldn't Apple computers be a different product category than PCs?) creates measurement difficulties. Currently, the national accounts selectively apply hedonic quality adjustments only in certain product categories.

The practical measurement of ecosystem goods and services will raise similar issues. But an ecological quantity index—like an economic quantity index—should differentiate goods and services by their quality to the greatest extent practicable.

4. Ecological Prediction, Sustainability, and Depletion Adjustments

It is possible—and many fear—that our current human footprint is robbing our children of future well-being. The fear is expressed economically as a concern that we are overconsuming, eating into our natural capital's principal, and consuming natural resources faster than they can reproduce or regenerate. A central tenet of welfare-significant economic accounting is that unsustainable consumption should create a debit in the current account. A depletion-adjusted account is a fact-based, rigorous way to measure sustainability or its lack. An

[33] Again, this issue is mirrored in the national accounts. We count tires sold, rather than the vehicle miles over which the tires last. Prices at the time of purchase reflect consumers' understanding of the quality difference, but ideal output measures would not aggregate products of different quality.

[34] Some wetland classification systems differentiate wetlands in just this way.

ecological index that does not grapple with depletion will be unsatisfying to environmentalists, ecologists, and economists alike.

The problem, of course, is that depletion analysis is difficult, since it requires us to know the complex, underlying causes of depletion (El Sarafy 1989). Even in the case of subsoil assets (e.g., coal, natural gas, and copper), the depletion relationships used in accounts are relatively crude and subject to ongoing debate. Ecological depletion will be an even taller order in this respect. How do air emissions from coal-powered plants affect water quality throughout the airshed? How does a residential subdivision affect species populations in surrounding counties? Today, we know that these questions are important, but we are far from the empirical consensus needed to make depletion adjustments in practice.[35]

A richer understanding of ecological causality is necessary if we are to create economic accounts that capture depletion phenomena. Causality will empower prediction, and prediction will empower the incorporation of depletion costs into current economic accounts. Then, the practical question becomes: How can we promote a richer understanding of ecological causality? One answer is the constructions of an ecological quantity index such as the one I describe in this paper.

A quantity index is a snapshot of consumption. In the GDP context, the quantity index counts the level of goods and services consumed in a given period. Similarly, an ecological quantity index would count natural features and qualities occurring in a given period. Directly, this doesn't tell us anything about the direction or rate of change of those features and qualities. Enough snapshots over enough time, though, create a multilayered, national-scale, biophysical, time-series database, which would be a huge boon to the biophysical sciences. It would allow us to analyze ecological causality at the landscape level in a way that is currently impossible.[36] Depletion adjustments to a current account can occur only if there is an empirically defensible record of ecological causality to justify them. The early years of data collection won't tell us

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[35] Several NIPAs and green accounts incorporate some form of depletion analysis. Primarily, though, these efforts demonstrate the empirical difficulties of doing so. See Weber (2007) for an accounting-based view of ecological depletion.

[36] Many ecologists, geographers, planners, and conservationists already think in these terms. But a consistent data network, one that helps unite disparate location-based analyses, is unavailable to these practitioners. Although the U.S. government sporadically attempts sustained monitoring at the national level, no one agency has been given such a mandate.

much about the future. But with each passing year prediction will improve, as will our ability to adjust the accounts intertemporally.

5. The Political Economy of Environmental Information

If voters in coming elections are asked, “Are you better off environmentally today than you were four years ago?” their answers will be anecdotal and impressionistic, not based on a comprehensive set of hard facts. This is true in part because no set of national statistics summarizes our environmental well-being. When the market economy suffers from inflation, unemployment, or negative growth, our society can largely agree on these facts because they are a culturally, governmentally, and scientifically sanctioned set of measures: the NIPAs. How do we make available to voters a similarly credible set of statistics that reveal the state of our environmental well-being?

This paper makes a small contribution to the theory and practice of environmental accounting by focusing on one of its most difficult challenges: the measurement of ecological, nonmarket public goods in a way consistent with economic accounting principles. Here, using ideas from both environmental valuation and national income accounting, I advocate constructing a WSEQI. I also identify a set of practical principles to guide the identification of quantity units suitable for such an index.

Eventually, such an index will need its corresponding value index (the virtual prices used to weight quantities). But as I show in this paper, focusing on the valuation side of the ecological index problem puts the cart before the horse. We can value only what we can consistently count. Those quantity units should be constructed so that they are amenable to valuation. For this reason, I stress issues like temporal and locational specificity, avoidance of double counting, and quality adjustments. But until we debate and develop “a theory of quantities,” and marry the theory to concrete methods of measurement, the valuation problem will remain academic, not practical.

Economists have naturally focused on the valuation side because that’s where their skills lie. But economic principles are also important to the quantification side. More economic thinking should be devoted to the material and physical accounts economists normally ignore. Why? Because physical accounts are a precondition of welfare-significant ecological accounting.

To conclude, it is worth reflecting on the practical, institutional issues raised by the need for environmental information. What are the prospects for an “environmental information movement” that could advance the practice of ecological accounting? National accounts take decades to develop, even when created in response to an institutional mandate, and they require financial and political support. The methodologies of existing accounts, such as U.S. GDP, are still actively debated and corrected even 75 years after they were first constructed (Carson 1975). But even so, environmental accounts have been slow to develop, although they have been advocated for decades (see, for example, Ayres and Kneese 1969; U.S. BEA 1982; United Nations 1984; El-Sarafy 1989; Peskin (1989); and Repetto et al. 1989).

The current lack of comprehensive environmental accounts can be explained, of course, by country-specific factors. But several generic barriers are worth noting—all of which can be overcome in the years ahead. The first barrier is the need for coordination between the natural and social sciences. Conventional NIPAs do not rely on the natural sciences to any great degree. Environmental accounts demand biophysical analysis and measurement. Alone, ecologists can study and report on the characteristics of nature. Alone, economists can opine on the economic value of nature to households and the market economy. But national environmental accounting requires complementary, coordinated activity from the two realms. The accounting approach I describe in this paper aspires to precisely this kind of integration.

Fortunately, the two disciplines are now working more closely than ever before. Ecologists increasingly see nature's broad contributions to economic well-being as a subject for ecological study (Daily 1997; Kremen 2005; Millennium Ecosystem Assessment 2005). Conservationists and environmental trustees also increasingly view economic arguments as useful to their mission. Likewise, economists have become much more sensitive to and skilled at analyzing nature's goods and services, including those that resist traditional economic analysis (Heal 2000).

The second barrier is the cacophony that results from an overabundance of unrelated environmental indicators, performance measures, and statistics. It is hard to argue against any particular effort, but as a whole these competing measures undermine the power of all. Imagine what would happen if we had several competing sets of economic statistics. None would be trusted and all would be used opportunistically to serve the political ends they support.

Clearly, numbers that appear to be provided by biased sources lose their political and economic power.[37] The global experience with NIPAs clearly demonstrates that credible statistics require a combination of institutional independence and accountability. Independence is achieved by housing the effort in politically and bureaucratically insulated institutions. As a corollary, environmental accounting should probably not be housed in an environmental agency. An agency responsible for environmental management should not also be the keeper of the books. Accountability is achieved via centralization, which makes information providers more accountable to the political process, not less.[38] Moreover, national-scale data collection is expensive and likely to have scale economies. This is another virtue of centralization.

A third barrier to national environmental statistics is the government institutions charged with protecting and managing our environment. Although they create a lot of information, U.S. agencies such as the U.S. Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers, and the Department of Interior have not to date been sources of consistent, comparable, and national statistics. This is largely because the agencies serve distinct and limited missions and mandates, and each collects information related to its narrow sphere of authority. There is no bureaucratic incentive to harmonize statistics because no agency has the authority or budget to comprehensively track environmental outcomes. Federal environmental agencies may actually oppose the centralization and independence of environmental statistics. Finally, government environmental agencies are accustomed to a culture of political consensus, and rightly so. But NIPAs require more than political consensus. They also necessitate scientific consensus based on vigorous intellectual debate that is insulated from bureaucratic politics.

A final barrier to be confronted is the fact that environmental statistics benefit no one in particular, but everyone in general. In other words, environmental statistics are themselves a public good. As Olson (1965) noted 40 years ago, the public goods least likely to be provided are

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[37] This is more than a theoretical concern. Witness, for example, recent events in Argentina. In January 2007 Argentina's government intervened in the calculation of inflation statistics by removing the official in charge and publishing inflation estimates viewed by economists as politically rather than economically derived. Naturally, this has called the credibility of Argentina's statistical reporting into question.

[38] Note, however, the ability of online communities to both provide public information goods and police their quality. Are online information communities like Wikipedia capable of producing and policing the kind of data I advocate here? It is certainly an exciting and hopeful possibility.

those where the costs are concentrated and the benefits are widely shared. The benefits of environmental statistics are certainly diffuse, not concentrated.

The science of ecological measurement is advancing rapidly. So too is the idea of concretely measuring nature's contributions to our well-being. A political mandate for comprehensive national environmental accounting, though, is lagging. When that mandate arrives, a WSEQI will hopefully be pursued alongside other accounting tools. If, as many believe, nature is so central to our well-being, we need better information on the state of our natural wealth. A WSEQI is one important way obtain this information.

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