Draft: January 27, 2011

BIODIVERSITY, ECOSYSTEM SERVICES AND WEALTH ACCOUNTING

Charles Perrings

ecoSERVICES Group, Arizona State University, Tempe. AZ 85287

Abstract

The appropriate measure on which to compare the economic performance of different countries at a point in time, or the performance of a particular country over time, is per capita wealth. This is the only measure that tests whether the wellbeing generated by a flow of services is expected to be sustainable (non-declining over time), and so the only measure that allows sustainability comparisons between countries. This paper considers the implications of (a) changes in our understanding of ecosystem services, and (b) the welfare theoretic basis for wealth accounting, for the generation of comprehensive asset accounts. It argues that the set of accounts used to measure the growth, equity and sustainability of resource use should cover all surficial assets on which human wellbeing depends, and that estimates of the value of surficial assets should include off-site ecosystem service flows.

1. Posing the problem

There is accumulating evidence that human 'management' of the biosphere is having a major effect on the abundance and diversity of other species, on ecological functioning, and on ecosystem processes. The most heralded impact of the conversion of land to human use is the extinction of other species, but anthropogenic environmental change has many other dimensions. Emissions to air, soil and water are affecting ecosystem processes at many different scales, extending from the global effect of greenhouse gas emissions on climate to the local effects of nitrate emissions on groundwater. Two global assessments have documented the effect of people's use of terrestrial and marine resources on biodiversity change, and have offered some evidence for why it matters. The problem remains, however, that there are few reliable indicators of the importance of biosphere change for human wellbeing.

The Millennium Ecosystem Assessment (MA) attempted to relate changes in biodiversity to human wellbeing through the identification of a set of 'ecosystem services', defined as ‘the benefits that people get from ecosystems’. These comprised provisioning services (production of foods, fuels, fibers, water, genetic resources), cultural services (recreation, spiritual and aesthetic satisfaction, scientific information), regulating services (controlling variability in production, pests and pathogens, environmental hazards, and many key environmental processes) and supporting services (the main ecosystem processes). The MA was not, however, able to do more than say whether the physical flows of these services had been enhanced or degraded in the previous half century. It was unable to assign a value to the loss of, for example, cultural or regulating services relative to provisioning services. It was not, therefore, able to say whether the trade-offs being made between ecosystems services were warranted in terms of either their efficiency or fairness. Nor was it able to say whether the investments people had made in the conversion ecosystems for the production of valued goods and services left society collectively richer or poorer—whether those investments were sustainable.

What the MA and many other studies have been able to show is that without information on the value of the ecosystem services forgone through land-use change, landholders do not take that value into account in their own decisions. In other words, the same thing that makes it difficult for us to know whether land-use change is socially efficient, equitable, or sustainable, also discourages landholders from taking the wider consequences of their decisions into account. Without information on the value of biosphere change, society is unable either to judge its effects or to provide individual resource users with incentives to take those effects into account.

We are here concerned with the first of these two problems—developing metrics of the social importance of biosphere change. Whether society is concerned with inter-country comparisons, with tracking its own performance over time, or with understanding the distributional effects of biosphere change, the informational requirements are the same. What is needed is a measure of the impact of biosphere change on wealth and wealth distribution. The paper discusses the implications of this requirement, first in terms of the welfare-theoretic foundations of wealth accounting, and then in terms of the steps required to evolve wealth accounts from the current system of national accounts.

2. The welfare-theoretic foundations of wealth accounting

Fifty years ago, Samuelson suggested that the appropriate measure for making intergeneration well-being comparisons is wealth (Samuelson, 1961), as distinct from the income measures commonly reported in the system of national income accounts. It was not until the 1990s, however, that progress was made in formalizing the notion in ways that made it possible to begin constructing wealth accounts and to adjust the system of national accounts to take account of the depreciation of environmental assets (Hamilton & Clemens, 1999; Hamilton, 1994; Pearce *et al.*, 1996; Pearce & Atkinson, 1993; Hartwick, 2000; Hartwick, 1994; Hartwick, 1990). Much of this work was stimulated by the Brundtland Report, published in 1987, which defined sustainable development in terms of intergenerational changes in wealth: ‘Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (World Commission on Environment and Development, 1987).

From a welfare-theoretic standpoint, the central requirement of a sustainable consumption program for the current generation is that it should not reduce the consumption possibilities available to future generations. This idea was first introduced by Lindahl in the 1930s (Lindahl, 1933) who defined 'income' to be the maximum amount that could be consumed without reducing the value of the capital stocks available to future generations. Income in the Lindahl sense is equivalent to the SNA concepts of net national product or net national income.

To see what it contains, and how it relates to changes in the value of capital stocks, consider the simplest representation of the economy. In this we adapt an argument from Dasgupta (Dasgupta, 2009) that builds on (Arrow *et al.*, 2003; Dasgupta & Maler, 2000). Define $Y(t)$, or Gross National Product at time t, to be a measure of the output achievable given the produced capital stock, $K(t)$, the human capital stock, $L(t)$, and a stock 'natural resources' which may be thought about as an area of land or sea, along with the biotic and abiotic elements that area contains, $N(t)$, together with the technology, institutions and environmental conditions that collectively determine total factor productivity, $A(t)$. Total factor productivity measures the proportion of output not explained by the amount of inputs used in production, and captures the effect of technical progress, the efficiency with which inputs are used, institutional conditions and the impact of environmental factors such as climate. If we ignore the sensitivity of total factor productivity to investment in produced and human capital, and to the rate at which natural resources are extracted, GNP can be described by the function:

$$Y(t) = A(t) f\big(K(t) L(t) N(t)\big) \tag{1}$$

Suppose that the depreciation rate corresponding each type of capital stock is δ_K, δ_L and δ_N respectively, and that investment in each type of capital is I_K, I_L and I_N. In addition to the effects of investment, natural resources may be expected to regenerate through some set of biogeochemical process according to the function $g\big(N(t), I_N(t)\big)$.

The growth rate for each of the capital stocks may be written as

$$\frac{dK}{dt} = A(t) f\big(K(t) L(t) R(t)\big) - C(t) - I_L(t) - I_N(t) - \delta_K K(t) \tag{2}$$

$$\frac{dL}{dt} = I_L(t) - \delta_L L(t) \tag{3}$$

$$\frac{dN}{dt} = g\big(N(t)\big) - \delta_N N(t) \tag{4}$$

That is, net investment in produced capital is just the difference between gross national product and the sum of consumption, investment in human and natural capital and the depreciation of produced capital. Net investment in human and natural capital is measured by the difference between additions and subtractions—where additions include investment and/or natural regeneration in the case of natural capital.

Aggregate consumption at time t is denoted $C(t)$. It is assumed that intergenerational wellbeing, $V(t)$ depends on aggregate consumption via the relation:

$$V(t)=\int_t^{\infty}U\big(C(t)\big)e^{-r(t-\tau)}d\tau \tag{5}$$

in which $U\big(C(t)\big)$ is instantaneous wellbeing measured at time t, and is assumed to be a concave function—to have positive first and negative second derivatives.

The feature of Dasgupta's approach that makes it particular helpful to the implementation of wealth accounting is that no assumption is made about the optimality of $V(t)$, $C(t)$, or the time paths of the various capital stocks. Denote the state of the system at time t by:

$$S(t)=\big(K(t),L(t),N(t)\big) \tag{6}$$

An economic program is then a consumption and investment path from t onwards, $\{E(\tau)\}_t^{\infty}=\{C(\tau),K(\tau),L(\tau),N(\tau),I_L(\tau),R(\tau)\}_t^{\infty}$, that satisfies the equations of motion of the capital stocks, (2)-(4). Dasgupta (2009) defines a resource allocation mechanism to be a mapping from the state of the system to an economic program: $\alpha:\{S(t),t\}\to\{E(\tau)\}_t^{\infty}$, making the point that there is no requirement that the program be efficient. This is particularly relevant if some of the services associated with the capital stocks are public goods, having benefits or costs beyond the jurisdiction of the country concerned. Institutions having responsibility for the domestic allocation of international environmental public goods have little incentive to satisfy the Samuelson condition for the efficient allocation of public goods.

The intergenerational measure of wellbeing corresponding to a particular economic program is thus:

$$V\big(S(t),t\big)=\int_t^{\infty}U\big(C(t)\big)e^{-r(t-\tau)}d\tau \tag{7}$$

and the shadow or accounting prices of the capital stocks are simply the partial derivatives of this function with respect to those stocks. For assets for which there are well-functioning markets and few externalities, shadow prices and market prices should be reasonably closely aligned. For assets for which there are no markets, or for which there are significant externalities, shadow prices would be expected to deviate substantially from market prices. Dasgupta (2009) offers a number of propositions that follow from such a formulation of the problem.

1. In the special case where total factor productivity is constant, the time derivative of $V\left(S\left(t\right)\right)$ is simply the sum of the change in each of the capital stocks evaluated at the shadow price of those stocks. That is,

$$\frac{dV\left(S\left(t\right)\right)}{dt}=\frac{\partial V\left(S\left(t\right)\right)}{\partial K\left(t\right)}\frac{dK\left(t\right)}{dt}+\frac{\partial V\left(S\left(t\right)\right)}{\partial L\left(t\right)}\frac{dL\left(t\right)}{dt}+\frac{\partial V\left(S\left(t\right)\right)}{\partial N\left(t\right)}\frac{dN\left(t\right)}{dt}$$

Since the equations of motion for each of the capital stocks record the net effect of investment and depreciation, together with the regeneration of natural capital stocks, this is a measure of aggregate net investment—what Dasgupta refers to as comprehensive investment. Aggregate net investment, evaluated at the shadow or accounting prices of assets, is a measure of the rate at which marginal intergenerational wellbeing changes over time.

2. Aggregate net investment is also a measure of the discounted stream of consumption that it induces.

3. An economic program is sustainable if and only if aggregate net investment is positive.

4. Aggregate wealth is the shadow value of the stocks of all assets available to the economy.

5. An economic program at time *t* is sustainable if and only if, holding shadow prices constant, aggregate wealth is non-declining at *t*.

6. $\frac{dV\left(S\left(t\right)\right)}{dt}>0$ if and only if $U'\left(C\left(t\right)\right)\frac{dC\left(t\right)}{dt}<$ net national product . That is, Lindahl's condition on 'income' holds. Intergenerational wellbeing is growing if and only if consumption is less than net national product.

7. Intergenerational wellbeing in a country is higher/lower than in another country if its wealth, evaluated in terms of its shadow prices, is greater/less.

Note that these propositions hold whether or not the allocation mechanism is efficient. They imply that if we wish to understand changes in intergenerational wellbeing, we need to understand changes in wealth, and to do this we need to track changes in aggregate net investment.

Now consider the more general case where total factor productivity is not constant. In a closed economy, if all factors of production were fully accounted for, and if all effects of new technical knowledge, institutions and so on were captured in investment in those factors of production, then the residual would be equal to zero: i.e. $\frac{dA(t)}{dt}\frac{1}{A(t)} = 0$. In practice, not all factors of production are fully accounted for. In particular, many natural resources lie outside the market and are not taken into account in production decisions. The effects of changes in technical knowledge—especially technical knowledge due to publicly funded R&D—are not captured in factor prices. Nor are changes in the efficiency of the allocation mechanism, or environmental conditions. So even in a closed economy, the residual will not be zero. In an open economy there are, in addition, the effects of international technology transfers and the effects of transboundary environmental externalities. All of these have the capacity to change total factor productivity.

Suppose, for example, that total factor productivity depends on a global public good, *G*, which is influenced by the natural resource use decisions of all countries. To fix ideas, it might be thought of as a public good characterized by an additive supply technology, such as climate change mitigation through carbon sequestration. So the size of the public good at time *t* would be $G(t) = \sum_{i=1}^{n} G(t)_i$, i.e. the sum of the contributions of all *n* countries. If total factor productivity in country *i* is $A_i(t) = A_i(G(t),t)$, $i = 1,\dots,n$, and if $\frac{dV_i(S(t))}{dG_i(t)} = \frac{\partial V_i(S_i(t))}{\partial A_i(t)}\frac{dA_i(t)}{dG_i(t)}$, the i^{th} county is able to affect its GDP through its own carbon sequestration efforts, $G_i(t)$, it will internalize that impact. However, it will ignore any effects it has on total factor productivity in other countries. Intergenerational wellbeing in country *i* is now a function of the allocation mechanism in that country, the state of its capital assets, and the global public good:

$$V_i(t) = V_i(\alpha_i, S_i(t), G(t), t) \tag{8}$$

and the rate at which it changes is given by:

$$\frac{dV_i(\alpha_i, S_i(t), G(t))}{dt} = \frac{\partial V_i(t)}{dt} + I_i(t) + \frac{\partial V_i(S_i(t))}{\partial G(t)}\left(\frac{dG_i(t)}{dt} + \sum_{j\neq i}\frac{dG_j(t)}{dt}\right) \tag{10}$$

where

$$I(t) = \frac{\partial V_i(S_i(t))}{\partial K_i(t)}\frac{dK_i(t)}{dt} + \frac{\partial V_i(S_i(t))}{\partial L_i(t)}\frac{dL_i(t)}{dt} + \frac{\partial V_i(S_i(t))}{\partial N_i(t)}\frac{dN_i(t)}{dt}$$

Only the quantity $\frac{\partial V_i\left(S_i\left(t\right)\right)}{\partial G\left(t\right)}\left(\frac{dG_i\left(t\right)}{dt}+\sum_{j\neq i}\frac{dG_j\left(t\right)}{dt}\right)$ is part of the i^{th} country's decision. The contribution of all other countries to the wellbeing of country *i*, given by $\frac{\partial V_i\left(S_i\left(t\right)\right)}{\partial G\left(t\right)}\sum_{j\neq i}\frac{dG_j\left(t\right)}{dt}$ is taken as given, and the contribution of country *i* to all other countries, $\sum_{j\neq i,j=1}^{n}\frac{\partial V_j\left(S_j\left(t\right)\right)}{\partial G\left(t\right)}\frac{\partial G\left(t\right)}{\partial G_i\left(t\right)}\frac{dG_i\left(t\right)}{dt}$, is ignored. But these impacts have a potentially important effect on the performance of other countries (positive or negative) and should be accounted for.

3. Preliminary estimates of the effect of environmental change on asset growth

The weaknesses of GDP or GNI as a measure of wellbeing have been often rehearsed and are well understood. Adjusting for transboundary flows and for the depreciation of assets to yield NNP or NNI addresses two of the main reasons why the measure is flawed. However, there still remain a number of fundamental problems including the exclusion of most non-marketed production and consumption, externalities, environmental deterioration and public lands and the inclusion of defensive or remedial expenditures (repairing depreciation). Most importantly, NNP or NNI remains a measure of a current flow of production or income. It is not a measure of the sustainability of that income. In other words, it does not test whether NNP is greater than, less than or equal to income in the sense of Lindahl or Hicks (Lindahl, 1933; Hicks, 1939), and hence whether it increases, decreases or has no effect on wealth. While a large number of alternative indices have been proposed in the literature[1] (Goossens *et al.*, 2007), we consider only those that address these specific weaknesses of NNP or NNI.

The Millennium Ecosystem Assessment (MA) (Millennium Ecosystem Assessment, 2005) classified the benefits obtained from ecosystems as belonging to one of four types: provisioning, cultural, regulating and supporting.

- Provisioning services covered the products of renewable resources including foods, fibers, fuels, water, biochemicals, medicines, pharmaceuticals and genetic material.
- Cultural services comprised a range of largely non-consumptive uses of the environment. In the MA they were defined to include the spiritual, religious, aesthetic and inspirational wellbeing that people derive from the 'natural' world,

[1] These include Nordhaus and Tobin's Measure of Economic Welfare (MEW), the Index of Sustainable Economic Welfare (ISEW), the Genuine Progress Indicator (GPI), the UNDP's Human development Index (HDI), the Gender-related Development Index, the Ecological Footprint (EF), the Happy Planet Index (HPI), the Environmental Sustainability Index (ESI), and the Environmental Performance Index (EPI) Goossens, Y., Mäkipää, A., Schepelmann, P., Van De Sand, I., Kuhndtand, M. & Herrndorf, M. (2007) Alternative progress indicators to Gross Domestic Product (GDP) as a means towards sustainable development. European Parliament: Policy Department, Economic and Scientific Policy, Brussels.

the value to science of the opportunity to study and learn from that world, and the market benefits of recreation and tourism.

- The regulating services included the moderation of air quality, climate, water flows, soil erosion, pests and diseases and natural hazards. More generally, they comprise the benefits of biodiversity in regulating the effects of environmental variation on the production of the provisioning and cultural services, or the healthiness of the environment—i.e. benefits that people care about directly. They limit the effect of stresses and shocks to the system.
- Supporting services comprised the main ecosystem processes that underpin all other services such as soil formation, photosynthesis, primary production, nutrient, and water cycling.

Of these, many provisioning services and some cultural services are supplied through well-functioning markets, and enter the national accounts through the product accounts for agriculture, industry and services (SNA, 2009). The prices of many may be distorted through the effects of government policy such as agricultural subsidies, but they are at least directly registered in the national income accounts.

The problem lies with services that are not supplied through the market, and that are therefore unpriced and not currently captured in the national income accounts. Note that this does not include all ecosystem services for which there are no functioning markets. Why? Consider a tract of land in private property that comprises a particular water sub-catchment, and that is used for the production of food crops. The production of food is one of the main MA provisioning services, but it depends on several other MA ecosystem services including the regulation of soil and water flows, pest and disease regulation, pollination, nutrient cycling and so on. These services, and the biotic and abiotic conditions that support them, are what determine the productivity of the land. They are therefore also what determine its price—along with the land's location relative to transport networks, markets, the characteristics that make it suitable as a place to live and so on.

To the extent that the regulating and supporting ecosystem services needed for agricultural production are reflected in the price of the land, they will be appropriately measured in the system of national accounts. Indeed, if all services are contained within the catchment, they will be fully accounted for. It is only the offsite benefits or costs of land management within the sub-catchment that are missing. Off-site flows of nutrients, pests and pesticides, siltation of rivers and the like are externalities of land management that should be valued and accounted for wherever they have significant effects on wellbeing.

The task is not therefore to account for all ecosystem services. It is to account for ecosystem services that are not already explicitly or implicitly priced (and so reflected in the national income accounts), and that have a significant impact on wellbeing. The existence of externalities may be due to a number of things, including ignorance about the mechanisms involved, a lack of well-defined property rights, institutions that 'authorize' implicit rights to impose harm on others, and the public nature of effects (the fact that they are neither rival nor excludable). Of these, the last is frequently the most important. In many cases, the impact is felt via the effect of offsite externalities on the productivity of investment elsewhere—via an impact on total factor productivity. At the national level, for example, $\sum_{j \neq i, j=1}^{n} \frac{\partial V_j\left(S_j\left(t\right)\right)}{\partial G\left(t\right)} \frac{\partial G\left(t\right)}{\partial G_i\left(t\right)} \frac{dG_i\left(t\right)}{dt}$ is a measure of the impact of off-site effects of local decisions on the allocation of $G(t)$. These effects will typically show up in changes in total factor productivity growth in other countries, and should properly be recorded in measures of net national product or income.

3.1 Environmental assets and total factor productivity growth

Vounaki and Xepapadeas have recently explored this effect (Vouvaki & Xepapadeas, 2009) (Table 1). They argue that unaccounted contributions of the environment may be an important driver of estimates of total factor productivity growth, and that explicitly accounting for environmental contributions can reduce it by a significant margin—potentially driving it into the negative range. In particular, they consider energy as an environmental factor of production in the aggregate production function that is priced, but that also generates an unpriced or uninternalized externality in the form of greenhouse gas emissions.

Table 1: Traditional and externality-adjusted TFP

Countries	Traditional TFPG	Externality-adjusted TFPG
CANADA	0.670	-1.979
U.S.A.	0.275	-2.206
AUSTRIA	0.635	-0.779
BELGIUM	1.079	-1.039
DENMARK	0.321	-1.289
FINLAND	1.144	-1.107
FRANCE	0.705	-0.778
GREECE	0.831	-0.479
ITALY	1.537	0.387
LUXEMBOURG	1.699	-2.580
PORTUGAL	1.690	0.649
SPAIN	0.415	-0.695
SWEDEN	-0.040	-2.028
SWITZERLAND	-0.059	-1.122
U.K	0.859	-0.896
JAPAN	1.646	0.235
ICELAND	0.473	-2.533
IRELAND	1.638	-0.172
NETHERLANDS	0.489	-1.414
NORWAY	1.564	-0.247
AUSTRALIA	0.567	-1.226
MEXICO	0.330	-0.814
TURKEY	1.420	0.214
Average	0.865	-0.952

Source: (Vouvaki & Xepapadeas, 2009)

They ask how significant the effect of this has been on total factor productivity in a group of OECD countries, and what options exist to internalize their cost and thus to use them efficiently. The correction involves adjusting traditional total factor productivity growth measures by estimating an aggregate production function for a panel 23 OECD countries, and subtracting the contribution of the unpriced or uninternalized part of energy costs, the CO2 emissions, from output growth.

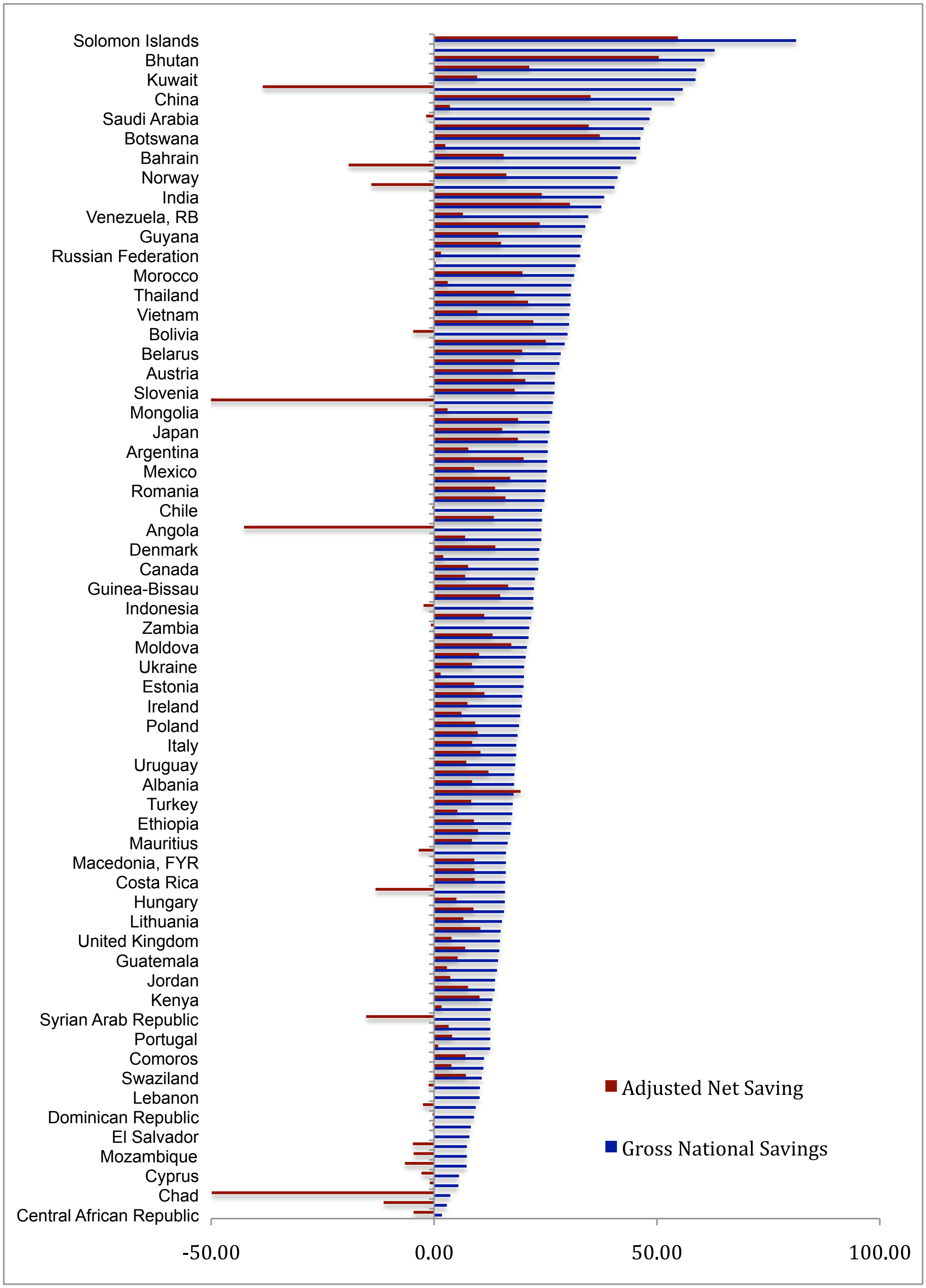
What is striking about their results is the number of cases in which total factor productivity growth has been driven into the negative range. The reason that this may happen is that if ecosystem services are an unpriced factor of production, their use may not be subject to the same discipline as priced factors, and so they may be used inefficiently. Negative total factor productivity growth would then be a measure of this inefficiency, its causes potentially lying in institutional conditions that 'authorize' the externality in the first place (Baier et al., 2006). The net effect is that the potential growth in national wealth is compromised.

3.2 Adjusted Net Savings

Adjusted net savings, as a measure of change in wealth, grew out the work of Pearce, Hamilton and Atkinson in the 1990s (Pearce & Atkinson, 1993; Pearce *et al.*, 1996; Ferreira *et al.*, 2008; Hamilton & Clemens, 1999). It is a direct attempt to measure net change in the value of a country's capital stocks, where that includes produced, human and at least some stocks of natural capital (Hamilton and Clemens, 1999). If wealth is the value of the stock of all assets plus net investment, then the propositions in section 2 imply that a necessary and sufficient condition for wealth to be increasing over time is that net investment be positive. That is, $\frac{dV(S(t))}{dt} > 0$. This in turn requires that $U'(C(t))\frac{dC(t)}{dt}$ < net national product. Adjusted net savings is intended to be a measure of $\frac{dV(S(t))}{dt}$.

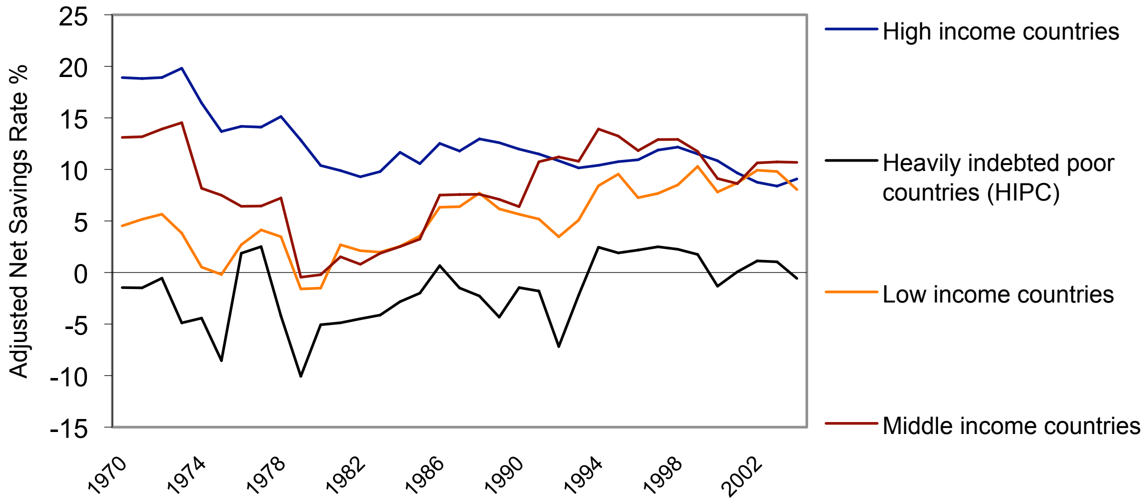
In practice, Adjusted Net Savings estimates are based on a partial correction of the figures in the SNA. The adjustments to gross savings reported in the national income accounts involve: (a) subtraction of the depreciation of produced capital, (b) addition of expenditure on education as a proxy for investment in human capital, (c) subtraction of the rents on depleted resource stocks, and (d) subtraction of specific pollution damages. The resource stocks currently included comprise energy (oil, gas and coal), minerals (non-renewable mineral resources) and forest (rent being calculated on timber extraction

Figure 1: Gross National Saving and Adjusted Net Savings rates, 2008.



Source: Data from World Bank Adjusted Net Savings. http://search.worldbank.org/data

Figure 2: Adjusted Net Savings Rates: high-, middle- and low-income countries plus heavily indebted poor countries, 1970-2005



Source: Data from World Bank Adjusted Net Savings. http://search.worldbank.org/data

in excess of the 'natural' increment in wood volume). Pollution damages currently recorded include carbon dioxide and PM10 damages.

Even though the correction is partial—including only some exploited natural resources, and a limited set of off-site external environmental effects—the impact on wealth assessments is substantial. Figure 1 shows the World Bank's estimates of gross national saving (GNS) and adjusted net saving (ANS) rates, using this method. In almost every case, GNS > ANS, and in many cases strongly positive GNS are associated with strongly negative ANS rates. Taking account of the depletion of valuable non-renewable assets and the environmental cost of industrial production in these cases implies that the value of aggregate capital stocks is declining, not increasing.

While negative ANS in any one year provides a test of the sustainability of investment/consumption decisions in that year, to see whether a development program is sustainable requires evaluation over a longer period of time. Figure 2 reports Adjusted Net Savings rates for four groups of countries over the period 1970-2005. The groups of countries are high-, middle- and low-income countries, together the subset of low-income countries in the International Monetary Fund's Heavily Indebted Poor Country (HIPC) Program. Within that period all except the high-income countries had periods during which their adjusted net savings were negative—they were depleting aggregate capital stocks. However, for the most part the adjusted net savings of most countries were positive. The exception is the HIPC countries, largely in Sub-Saharan Africa.
The group of countries in the HIPC program had negative adjusted net savings rates for most of this period. Since these countries are also characterized by high rates of population growth, the implication is that per capita wealth declined at an even faster rate.

4. Steps on the road to comprehensive wealth accounting

The World Bank's report on global wealth and its distribution between countries in the year 2000, *Where is the Wealth of Nations*, was the first attempt to understand the implications of such savings patterns for wealth and wealth creation (World Bank, 2006). As such, it was a critical first step on the road to global wealth accounting. While it yielded a number of important and powerful insights, however, it also raised more questions than it answered. These relate to four of the issues raised in the literature on the welfare theoretic foundations of wealth accounting:

- What is the role of environmental assets in the Solow residual and how does it affect changes in wealth?
- How should the off-site external environmental effects of resource use be reflected in asset values?
- What is the appropriate treatment of environmental assets that are public goods?
- What is the connection between environmental wealth and poverty both within and across generations?

In what follows we first consider the findings reported in *Where is the Wealth of Nations* reported, and then what they indicate for the incorporation of ecosystem services in national wealth accounts.

4.1 Where is the Wealth of Nations made the assumption that it is helpful to aggregate stocks of assets into three main categories corresponding loosely to the classical factors of production: capital, labor and land. All assets were accordingly assigned to one of the following: produced capital, natural capital or a residual category termed intangible capital. These can be thought of as equivalent to K, N and L in equation 1.

Produced capital was defined as the sum of machinery, equipment, built structures and built infrastructure together with the land on which such structures appears. The decision as to whether land was sufficiently modified to be classified as produced capital was based on existing land-use classifications. For example, urban land was considered sufficiently modified as not to be a 'natural resource', and so was combined with produced capital in the wealth estimates. It was valued using the perpetual inventory method—i.e. by the aggregate value of gross investment less depreciation.

Natural capital was defined as the sum of nonrenewable resources occurring within the jurisdiction of a country such as oil, natural gas, coal, and minerals, together with arable lands, grazing lands, forested areas and protected areas. It was valued by calculating the present value of resource rents over an arbitrary 'lifetime' of 25 years at a discount rate of 4%.

Intangible capital was determined as a residual: the difference between total wealth and the sum of produced and natural capital. This included human capital (the knowledge, technical skills, cognitive capacities, physical attributes etc of the human population), the institutions of a country sometimes referred to as social capital, any produced and natural capital not explicitly accounted for in the produced and natural capital accounts (such as groundwater, diamonds and fisheries), together with net foreign financial assets. Since it is a residual it was not valued. In terms of the

The broad conclusions of the study are summarized in the following tables. Table 2 reports estimates of the value of each of the three types of capital stock for high-, middle- and low-income countries. Table 3 reports the constituents of natural capital.

Table 2 World Wealth in 2000 ($ per capita, %age share)

Income group	Natural capital	Produced capital	Intangible capital	Total wealth	Natural capital share	Produced capital share	Intangible capital share
Low-income countries	1,925	1,174	4,434	7,532	26%	16%	59%
Middle- income countries	3,496	5,347	18,773	27,616	13%	19%	68%
High-income OECD countries	9,531	76,193	353,339	439,063	2%	17%	80%
World	4,011	16,850	74,998	95,860	4%	18%	78%

Source: (World Bank, 2006)

Table 3 Natural capital ($ per capita)

Income group	Subsoil assets	Timber resources	NTFR	Protected Areas	Cropland	Pasture land	Total natural capital
Low-income countries	325	109	48	111	1,143	189	1,925
Middle-income countries	1,089	169	120	129	1,583	407	3,496
High-income countries (OECD)	3,825	747	183	1,215	2,008	1,552	9,531
World	1,302	252	104	322	1,496	536	4,011

Source: (World Bank, 2006)

The main conclusion was that the residual, intangible capital, is increasingly significant as incomes rise, accounting for 80% of aggregate capital in high-income countries, 68% in middle-income countries, and 59% in low-income countries. This reflects the greater importance of the service sector in high-income countries, and is partly accounted for by the fact that many more services fall within the market economy in high-income countries than in low-income countries, and partly by the concentration of skill-intensive services in high-income countries. To understand the relative importance of different factors in intangible capital, the World Bank (2006) modeled the residual in low and middle-income countries as a function of domestic human capital (measured by per capita years of schooling of the working population); human capital abroad (measured by remittances from other countries); and governance/social capital (measured by the rule of law index). It found that most variation was explained by the rule of law, but that years of schooling were also important. While both are highly correlated with other things, it is a reasonable inference that human capital and social capital are both important components of intangible capital, and that these increase with per capita income.

Since intangible capital also includes environmental assets not recorded under natural capital, man-made assets not recorded under produced capital, and since it reflects factor prices that ignore external effects, this should be taken as a very rough guide only. While human capital and social capital are both important, is not possible to say much more. It is certainly not possible to draw conclusions about environmental assets beyond the traditional stocks recorded under natural capital.

A secondary conclusion was that while the share of natural capital in aggregate per capita wealth declines as incomes rise, the absolute level of natural per capita wealth per rises with income. For example, per capita sub-soil assets were found to be an order of magnitude greater in high-income than in low-income countries. Since this does not correlate with the physical size of proven mineral reserves, the implication is that such resources are used more productively in high-income countries. Productivity differences are certainly part of the explanation for the systematic variation in per capita natural capital across income groups. But what does this tell us about the relation between natural capital and poverty? The fact that natural capital accounts for a greater share of total per capita wealth in low-income countries than in high-income countries is taken to mean that the poor are generally more dependent on environmental assets than the rich, and that they are consequently more affected by environmental degradation.

The linkages between poverty and environmental change have been widely studied. The Brundtland Report (World Commission on Environment and Development, 1987) argued for a causal connection between environmental change and poverty both within and between generations, and a large literature has subsequently examined the empirical relation between per capita GNP and environmental change—reviewed in (Stern, 2004). An inverted 'U' shaped curve was found for the relation between per capita income and various atmospheric pollutants using both cross-sectional and panel data, although the relation is by no means consistent. While some have chosen to interpret this relation, the Environmental Kuznets Curve, as evidence that economic growth will be associated with environmental improvement, the consensus view is that there are no general rules to be drawn (Markandya, 2000). The relation between changes in income and changes in the environment are complex, involving feedback effects in both directions.

Markandya's (2001) review of the literature on the relation between poverty, environmental change and sustainable development suggested that to the question, 'does poverty damage the environment?' the answer was broadly 'no'. To the question 'does environmental degradation hurt the poor?' the answer was broadly 'yes'. Hence he concluded while poverty alleviation would not necessarily enhance environmental quality, and may in fact increase stress on the environment, environmental protection would generally benefit the poor (Markandya, 2001). This reflects the fact that a greater proportion of the labor force is employed in the resource sectors, and that agriculture, forestry and fisheries account for a greater share of GNP in low-income countries than in high-income countries. But it also reflects the fact that property rights are frequently less well defined in low-income countries, and that many natural assets are exploited under either open access regimes or as weakly regulated common pool resources. *Where is the wealth of nations* flagged the fact that the specific assets recorded as natural capital accounted for a higher proportion of per capita wealth in low-income countries than in middle-income or high-income countries, but it left open the question of how environmental assets generally relate to poverty—particularly assets in the public domain.

The key issues still to be resolved in developing a full set of wealth accounts include the problem of correctly identifying net changes in physical stocks, the problem of accounting for ecosystem service flows that are external to the markets, and the problem of accounting for the environmental drivers of total factor productivity growth. Identification of net investment in Dasgupta's comprehensive capital, $dV_i\left(\alpha_i, K_i\left(t\right), L_i\left(t\right), N_i\left(t\right), G\left(t\right)\right)/dt$, requires specification of net changes in both physical stocks $\left\{K_i\left(t\right), L_i\left(t\right), N_i\left(t\right), G\left(t\right)\right\}$, $\partial K_i/\partial t, \partial L_i/\partial t, \partial N_i/\partial t, \partial G_i/\partial t$, and their shadow values, $\partial V_i/\partial K_i\left(t\right), \partial V_i/\partial L_i\left(t\right), \partial V_i/\partial N_i\left(t\right), \partial V_i/\partial G\left(t\right)$.

4.2 Subtractions from and additions to natural resources. The first problem requires correct identification of physical stocks, along with additions to and subtractions from those stocks. A significant part of the problem with existing accounts is that the boundary between produced and natural assets is both ill defined and shifting. A number of assets that deliver significant benefits are excluded. The only assets included in the accounts are those that are subject to well-defined property rights and an associated set of claims. This excludes human capital, social capital and many natural resources.[2] Natural resources need both to be owned and capable of generating economic benefits for their owners, under "available technology, scientific knowledge, economic infrastructure, available resources and set of relative prices prevailing on the dates to which the balance sheet relates or expected to do so in the near future" (SNA, 2009). The SNA approach allows for forms of property other than strictly private property, i.e. natural resources may be owned by groups of people, but it excludes resources that are not the property of either individuals or groups. Examples of excluded assets are the atmosphere, the open oceans and uncultivated forests.

Whether investment in natural resources generates produced or natural capital in the SNA depends on the degree to which the resources are modified in the process. Natural resources are land, water, uncultivated forests and mineral deposits. Their modification generally creates a produced asset, and is not regarded as affecting the value of the pre-existing natural resource (SNA, 2009). The problem with this approach is that the social value of the pre-existing assets rests in the discounted flow of the set of ecosystem services they deliver. In practice, what this means is that increasing land modification is assumed to build produced capital without impacting the flow of ecosystem services. Indeed, the value of changes in pre-existing ecosystem services is generally neglected. In *Where is the Wealth of Nations*, for example, urban land is regarded as defined as produced capital—and valued as a proportion of the value of machinery and buildings.

[2] The SNA 2008 puts it as follows: "The coverage of assets is limited to those assets used in economic activity and that are subject to ownership rights; thus for example, consumer durables and human capital, as well as natural resources that are not owned, are excluded" (SNA, 2009).

Natural resources are defined in the SNA to be:

Table 4: SNA Environmental Assets

AN.1 Produced assets
- AN.11 Fixed assets
  - AN.111 Tangible fixed assets
    - AN.1114 Cultivated assets
    - AN.11141 Livestock for breeding, dairy, draught, etc.
    - AN.11142 Vineyards, orchards and other plantations
  - AN.112 Intangible fixed assets
    - *AN.1121 Mineral exploration*
- AN.12 Inventories
  - AN.122 Work in progress
    - AN.1221 Work in progress on cultivated assets

AN.2 Non-produced assets
- AN.21 Tangible non-produced assets
  - AN.211 Land
    - AN.2111 Land underlying buildings and structures
    - AN.2112 Land under cultivation
    - AN.2113 Recreational land and associated surface water
    - AN.2119 Other land and associated surface water
  - AN.212 Subsoil assets
    - AN.2121 Coal, oil and natural gas reserves
    - AN.2122 Metallic mineral reserves
    - AN.2123 Non-metallic mineral reserves
  - AN.213 Non-cultivated biological resources
  - AN.214 Water resources
- AN.22 Intangible non-produced assets
  - *AN.222 Leases and other transferable contracts*

Source: SEEA (2003)

This complicates the treatment of losses (depreciation) and gains (discoveries of non-renewable natural resources, regeneration of renewable natural resources) in natural resource stocks. The major innovation of the World Bank's adjusted net savings estimate was the inclusion of the depletion of particular natural resources. It was limited to mineral deposits, forests and water resources, and so did not capture changes in many other ecosystem services. Nor did it treat gains symmetrically. Nevertheless, it was a significant step in the development of wealth accounts.

At present the SNA 2008 treats all gains and losses to natural resources as 'other changes in the volume of assets account'. These fall into a number of categories: changes in mineral stocks, the natural regeneration of biological resources, the effects of externalities and disasters, the assignment of property rights, monuments and valuables. In principle, natural regeneration is taken to be gross regeneration, but in practice it is recorded net. Depletion of forests, for example, was taken in World Bank (2006) to be depletion in excess of regeneration rates. In general, the SNA takes biological regeneration to be 'produced' or 'non-produced' depending on the degree of control exercised by the resource manager. Cultivation typically implies control, so the value of land in the SNA is exclusive of "any buildings or other structures situated on it or running through it; cultivated crops, trees and animals; mineral and energy resources; non-cultivated biological resources and water resources below the ground. The associated surface water includes any inland waters (reservoirs, lakes, rivers, etc.) over which ownership rights can be exercised and that can, therefore, be the subject of transactions between institutional units" (SNA, 2009). By contrast, in non-cultivated systems, any increment in biomass is recorded as an 'economic appearance' in 'other changes in the volume of assets'.

It follows that ecosystems, as entities that span distinct parcels of land, groundwater bodies and the like, are not assets. Nor can they be recorded as assets in the accounts. The natural productivity and hence the value of a particular parcel of land in some economic use may reflect its place within an ecosystem. If a change in the ecosystem changes the productivity of the land, it will (in principle) appear in 'other changes in the volume of assets'. However, if the interactions between the biotic and abiotic elements of an ecosystem involve flows across property boundaries, and if these are external to the market, they will not be recorded.

4.3 Externalities. Calculation of the shadow value of the different capital stocks effectively demands that the rents on assets be calculated net of externalities. These are not currently accounted for in the SNA, although they may in principle be recorded in 'other changes in the volume of assets'. A discussion of the options for including externalities in the accounts by Nordhaus (Nordhaus, 2006) identifies two major issues: one being the adjustments to the accounts necessary to accommodate non-market activities, the other being the boundary of non-market accounts.

For non-market activities, the real problem concerns activities that generate public externalities. If non-market activities do not generate public externalities, they can be treated in a parallel fashion to private market activities. If there is, for example, a parallel market activity producing the same or a similar product, the 'pricing' of the non-market activity by the market good through the 'third party rule' is adequate. If, however, production of some market good involves co-production of non-market effects, and there is no market analogue to the non-market effect, 'pricing' that effect is more problematic.

Nordhaus considers two cases. One is where externalities are already reflected in the accounts: where, for example, pollution damage inflicted by one activity on another increases the costs faced by the second activity. The advantage of measuring and accounting for such externalities lies in the efficiency gains that would occur if the costs incurred by the first activity fully reflected the damage inflicted on the second. The second case is where externalities cross the boundary between market and non-market activity. In this case they are not already reflected in the accounts, and estimating them would change value added in both the market and non-market accounts. He argues that it is more important to correct for the second case than the first.

The off-site externalities of many land uses may be characterized as ecosystem services/disservices. While most land uses are undertaken to provide benefits from the production of marketed goods and services—foods, fuels, fibers, recreation etc—they typically generate other benefits or costs. It is worth repeating that the ecosystem services we need to measure and account for are these same off-site effects. In the absence of off-site costs or benefits, the rents to some land use should capture the net effect of the full set of ecosystem services generated by that use. If there are off-site costs or benefits it will not.

As a general observation, it will seldom make sense to try to estimate the value of every off-site effect of some land use. It will only make sense to address effects that are sufficiently large that they lead to significant inefficiencies if neglected. For example, the importance of water regulation in the Catskills—a poster child for ecosystem services—lies in the fact that the catchment serves a city of 17 million people. Off-site hydrological effects in many other catchments might not warrant the same effort. What is needed is a system of triage to identify which ecosystem service flows would warrant attention and where.

4.4 Productivity growth. The third major problem still to be addressed in the development of wealth accounts concerns the Solow residual. Total factor productivity growth has a number of drivers, few of which are explicitly accounted for in the national income accounts. Amongst these are public sector research and development and the efficiency of resource allocation. The efficiency of resource allocation in turn depends on the effectiveness of markets and regulatory institutions, the rule of law and the trust that people have in the rule of law—or social capital. Knowing what drives total factor productivity growth in an economy is extremely important for the management of economic growth. The World Bank's wealth estimates found that a residual comprising both human capital and many of the drivers of total factor productivity growth was the primary correlate of income (World Bank, 2006). Currently, the SNA recognizes the need to include research and development as capital formation, and acknowledges that it should be valued at expected future benefits (SNA, 2009). However, most of the drivers of total factor productivity growth are not directly measured in the accounts.

The reason to focus on this problem here is that it is likely that environmental factors are an important element of total factor productivity growth. While this is intuitive in the case of renewable resource-based sectors such as agriculture, forestry, fisheries, conservation, ecotourism, water supply and so on, it also applies to sectors in which productivity may be related to health conditions. For renewable resource-based sectors improvements in ambient animal and plant health, water quality, soil loss and the like would be expected to lead to productivity growth. But it is also the case that improvements in ambient human health are likely to have positive effects on productivity growth in many other sectors. Moreover, there are likely to be interactions between the drivers of total factor productivity growth.

The very high rates of productivity growth achieved in agriculture, for example, are generally assigned to research and development, the rate of return on agricultural R&D investment being estimated to lie between 45% and 55% (Alston *et al.*, 2009; Alston *et al.*, 2010). This depends on the impact improvements have on crop yields, but it also depends on the rate at which the material becomes available, the extent to which it is diffused—including the rate at which it is allowed to spill over into other jurisdictions—and the capacity of users to exploit it (Piesse & Thirtle, 2010). Projections of future total factor productivity growth in agriculture are much less optimistic, however. In the U.S., for example, total factor productivity growth over the period 2000-2025 is expected to be less than half the rate achieved between 1975 and 2000 (Goettle *et al.*, 2007). One consequence of this is that the growth in food production needed to meet the needs of the growing world population will increase the rate at which land is converted from other uses to agriculture, with all the consequences that has for biodiversity and ecosystem services.

The solution both to the problem of constructing wealth accounts, and to the management of interactions between assets not currently accounted for, is to quantify and value the capital stocks that do affect total factor productivity growth. That is the motivation for adding such stocks as explicit factors of production (Vouvaki & Xepapadeas, 2009).

5. Satellite accounts and the capital accounts in the SNA

The consensus is that changes to the national income accounts needed to address these issues should appear first in satellite accounts. In practice, changes in both natural capital stocks and environmental externalities are addressed via the satellite *System of Environmental and Economic Accounts* (SEEA), still under development by the UN, the EC, the OECD, the IMF and the World Bank. The SEEA (2003) includes measures of the effect of environmental change on capital stocks. Since the SEEA has a capital focus it is, in principle, consistent with the welfare-theoretic approach adopted by Dasgupta et al. That is, it takes changes in aggregate capital as a test of sustainability. Development is regarded unsustainable if it relies on stocks of natural capital, and these are degraded to the point where they are no longer able to adequately provide what are referred to in the SEEA as 'resource', 'service' or 'sink' functions (loosely corresponding to the MA provisioning, cultural and regulating/supporting services). The SEEA comprises four accounts:

- Flow accounts for pollution, energy and materials, recording industry level use of energy and materials as inputs to production along with the generation of pollutants and solid waste.
- Environmental protection and resource management expenditure accounts identifying expenditures incurred by industry, government and households to protect the environment or to manage natural resources (already recorded in the SNA).
- Natural resource asset accounts recording changes in traditional natural resource stocks such as land, fish, forest, water and minerals.

- Valuation of non-market flow and environmentally adjusted aggregates which adjusts aggregates for depletion and degradation costs and defensive expenditures.

By contrast with the definition of natural resources in the SNA (Table 4), environmental assets in the SEEA are defined to be:

Table 5: SEEA Environmental Assets

EA.1 Natural Resources
- EA.11 Mineral and energy resources (cubic metres, tonnes, tonnes of oil equivalents, joules)
- EA.12 Soil resources (cubic metres, tonnes)
- EA.13 Water resources (cubic metres)
- EA.14 Biological resources
  - EA.141 Timber resources (cubic metres)
  - EA.142 Crop and plant resources, other than timber (cubic metres, tonnes, number)
  - EA.143 Aquatic resources (tonnes, number)
  - EA.144 Animal resources, other than aquatic (number)

EA.2 Land and surface water (hectares)
- EA.21 Land underlying buildings and structures
- EA.22 Agricultural land and associated surface water
- EA.23 Wooded land and associated surface water
- EA.24 Major water bodies
- EA.25 Other land

EA.3 Ecosystems
- EA.31 Terrestrial ecosystems
- EA.32 Aquatic ecosystems
- EA.33 Atmospheric systems

Memorandum items – Intangible assets related to environmental issues (extended SNA codes)
- AN.1121 Mineral exploration
- AN.2221 Transferable licenses and concessions for the exploitation of natural resources
- AN.2222 Tradable permits allowing the emission of residuals
- AN.2223 Other intangible non-produced environmental assets

Source: SEEA (2003)

Two aspects of these assets are worth noting.

First, aside from the intangible assets these are all place-based, and involve the conversion and management of, or impact on, ecosystem services associated with a particular place. *In situ* sub-soil resources are not generally associated with biological activity, but their extraction involves production, processing and waste disposal on the surface that frequently has extensive direct and indirect off-site impacts on ecosystem services. Surface 'land' and 'land-based' or 'water' resources are more immediately used to enhance the flow of particular ecosystem services, though this may be at a cost to other services.

Second, there may be a range of property rights applying to environmental assets extending from private ownership (freehold), through time limited use rights (leasehold), common property (common pool resources and public lands) to undefined rights (open access). Within the SNA, only assets subject to well-defined property rights are included, and most changes in environmental assets recorded in the SNA occur as 'other changes in the volume of assets'. The SEEA, by contrast, focuses not property rights but on the physical attributes of assets, and so includes a wider and less well-defined range of environmental assets. The SEEA asset boundary includes not just all land and natural resources, for example, but also ecosystems.

The inclusion of ecosystems is the biggest difference between the SNA and SEEA. It is also quite problematic. The SEEA's ecosystem assets deliberately introduce an element of double counting in the interests of recording each of a number of distinct ecosystem services.[3] Three types of system are recognized: terrestrial, aquatic and atmospheric. Each is recognized to deliver multiple services. An asset identified as EA1 or EA2 can also appear in EA3, if it is associated with any of the services of EA3. As long as ecosystem services are recorded in physical terms the double counting is not an issue, but when the assets are valued, this does not make as much sense.

The designation of ecosystems as assets is motivated by a desirable goal—the inclusion of valuable ecosystem services in the system of national income accounts. However, this may not be the best option for capturing currently non-marketed ecosystem services. Any piece of land will jointly produce a number of goods and services, some of which may generate off-site benefits/costs. The social value of the land as an asset is the discounted flow of all the services it yields, whether marketed or not and whether on-site or not. The on-site benefits should be captured in land prices (where these exist), so the task of the SEEA is to identify the offsite services. The justification provided in SEEA (2003) for citing ecosystems as the source of such services is that "it is not generally the

[3] With the exception of natural resources that provide direct use benefits, the individual organisms and physical features that make up ecosystems are not classified as unique assets in the SEEA. This reflects the fact that it is not generally the components of ecosystems that benefit humans, but the systems as a whole. However, because natural resources are recognised as specific assets, some elements of the environment appear twice in the SEEA asset classification, once as natural assets and again as components of ecosystems. Thus, forests that are used as a source of timber are classified as natural resource assets. Since these same forests provide other benefits as well (carbon absorption for example), they are also classified as ecosystem assets. This reflects the fact that these forests provide more than one kind of benefit. As natural resources, they provide direct use benefits, while as components of ecosystems they provide indirect use benefits. It is necessary to recognise both roles of forests and other biological resources if a complete picture of the benefits provided to humans by the environment is to be captured in the SEEA. Note, though, that the inclusion of ecosystems as a separate category, like that of the inclusion of soil, means that there is an element of double counting in the SEEA classification, deliberately introduced to enable different environmental aspects to be examined. (SEEA 2003: 7.74).

components of ecosystems that benefit humans, but the systems as a whole". But this is simply not correct. The value of any piece of land committed to some use derives from the marginal impact of that use on the flow of all the goods and services from the land. If the service providing benefits, V, is a public good, G, then the marginal value of actions by the i^{th} provider that change the flow of the public good is just the bold term in the following expression: $\frac{\partial V\left(S(t)\right)}{\partial G(t)}\left(\frac{dG_i(t)}{dt}+\sum_{j\neq i}\frac{dG_j(t)}{dt}\right)$. That is what affects the value of the assets held by the i^{th} provider, and is the accounts should record. The contributions of all other providers (the grey terms) affect the value of their own assets. Of course, there may well be assets (defined in terms of property rights) that extend over whole ecosystems. The SEEA water assets, for example, include the Exclusive Economic Zones of countries, and so cover a number of large marine ecosystems. However, in general, asset values derive from the marginal contribution that individual properties make to the flow of all economically relevant ecosystem services.

The SEEA approach to estimating asset values is summarized in Table 6.

Table 6: Methods used to estimate asset values in the SEEA

Data needs for estimating stock values:

Resource rent
Stock of the resource
Life-length or rate of extraction of the resource
Decision on how to record renewals/discoveries
Discount rate for future income

Data for estimating resource rent

1. Appropriation method
    - direct observation
2. PIM based method
    - stock of produced capital (estimated from price decline)
    - net operating surplus
    - rate of return to produced capital
3. Capital service based method
    - stock of produced capital (estimated from efficiency decline)
    - gross operating surplus
    - capital services rendered by produced capital

Source: SEEA (2003)

As in the SNA, multiple methods are used including both perpetual inventory methods and direct estimation of resource rents. For most environmental assets, the resource rent is derived by deducting costs from the market price received for marketed products, the value of the stock being calculated as the net present value of rents. The SEEA suggests that non-market valuation techniques be used for services that do not have a market price. To capture the effect of non-marketed off-site ecosystem services flows what is needed is a measure of the externality involved, and not the addition of ecosystems as an extra category of assets.

What is needed to correct the wealth accounts in the SNA (or the National Income and Product Accounts (NIPAs) in the U.S.A.) is both the extension of the set of stocks measured to comprise all relevant sources of wealth, and the inclusion of the non-marketed impacts of asset use on third parties. The most important single addition to make to the set of stocks measured is undoubtedly human capital. The findings of World Bank (2006) along with numerous studies of total factor productivity growth indicate that the most important driver of wealth creation is the skills and know-how of the population. This is excluded from both the NIPA and the SNA (Jorgenson & Landefeld, 2006; SNA, 2009). The most important *environmental stocks* to add are those currently excluded on grounds that they lack sufficiently well-defined property rights. These are not 'ecosystems' as such, but the many public lands, open access resources, sea areas within the Exclusive Economic Zone that are important components of national wealth, but that do not currently appear in the accounts.

The most important non-marketed impacts of asset use on third parties are off-site ecosystem service flows: environmental externalities. There are four main categories of off-site ecosystem services flows that are currently neglected in the national accounts.

- Hydrologically mediated flows include water pollution, siltation, soil loss, flooding and so on.
- Atmospherically mediated flows include emissions with local (PM10, photochemical smog), regional (sulfur dioxide) and global (carbon dioxide, nitrous oxide, methane) consequences.
- Human travel and transport mediated flows include the transmission of pests and pathogens through local, regional and global goods transport and travel networks.
- Access mediated flows include changes in on-site benefits accessed by people elsewhere. Examples include the external benefits or costs to others of on-site biodiversity conservation/loss. Such flows may involve either information or physical (e.g. travel) movements.

Many local flows might fall into Nordhaus's category of external effects whose impact on asset values are already included in the accounts (Nordhaus, 2006). However, many regional and all global flows are international, and are currently not recorded anywhere in the accounts. Since many of these flows are non-exclusive and non-rival in their effects (they are public goods), whether they are significant enough to be measured and recorded depends on the extent of the public interest affected—the per capita benefits conferred or costs imposed and the size of the affected population. Indeed, this is why a system of triage is needed. Capturing important off-site ecosystem service flows is, however, critical to the correct estimation of the value of the assets involved.

6. Conclusions

The capital accounts in the existing national income accounts do a poor job of tracking changes in wealth. This is partly because of their focus on 'tangible' assets and hence their neglect of human and social capital, but it is also because of the way in which environmental assets are currently recorded. The weaknesses of the approach to environmental assets in the SNA have long been recognized (Pearce & Warford, 1993; Repetto *et al.*, 1989). The World Bank's adjusted net savings measure and its application in *Where is the wealth of nations* is an attempt to estimate the errors involved (World Bank, 2006). The SEEA (2003) is an attempt to generate the environmental data needed to measure environmental wealth. While both move the agenda forward, however, neither resolves the questions of what environmental stocks are important to include, how they should be measured and how they should be valued.

A very large part of the problem lies in the exclusions implied by the property rights focus of the SNA. Since the only admissible assets are those that generate claims to future benefit streams, the SNA excludes a number of natural resources that are important to human wellbeing, but that cannot be privately co-opted. The list of excluded resources includes many in public ownership or that lie beyond national jurisdiction. From a global perspective, it is important that the set of accounts used to measure the growth, equity and sustainability of resource use covers all assets on which human wellbeing depends, including those beyond national jurisdiction. Three points are important.

Firstly, the stocks of 'environmental' assets that need to be recorded comprise all lands that generate off-site benefits or costs as a result of environmental flows, noting that 'land' in this context defines a surficial area associated with the off-site ecosystem service flows described above, i.e. it includes both terrestrial and aquatic properties. Note that this is not the same as the 'ecosystems' referred to in the SEEA. Surficial assets should be defined by ownership. They should cover the full extent of the surface over which the country has rights, and should include all forms of property, whether or not they yield marketed products. If a parcel of land genuinely makes no contribution to human wellbeing, then its shadow value will be zero. But it should be on the list of assets.

Secondly, the lands that generate off-site ecosystem service flows are not restricted to the natural resource categories in either the SNA or the SEEA. There is an increasing appreciation that built environments—urban and industrial areas—create ecosystems that generate benefits and costs to people that are sometimes similar and sometimes different from ecosystems in other areas. They also involve off-site flows that affect wellbeing. For example, urban environments play a critical role in the transmission of infectious diseases, even if the origins of those diseases might lie elsewhere. Urban systems tend to have different thermal properties than other systems. The heat island effect, for example, is an urban phenomenon. They also play a critical role in stimulating demand for ecosystem services within the urban hinterland. Whether assets are classified in the national accounts as natural resources or something else is not important. What is important is that if assets in other classifications have significant off-site environmental effects, then that should impact their value in the accounts.

Thirdly, it is worth repeating that the non-marketed ecosystem services that should be recorded in the accounts are those generating costs or benefits not currently reflected in the rents to asset holders. Specifically, off-site externalities that affect the value of other assets should be recorded. Such externalities can generally be associated with particular types of ecosystem services. So, for example, changes in on-site characteristics that affect the access that others have will frequently be cultural services. Off-site flows, including water pollution, soil loss, siltation, disease transmission and so on will frequently be regulating services. From an accounting point of view, however, it is the effect on the value of other assets and not the classification of the service that matters.

Finally, the relationship between asset holdings, externalities and poverty is important to unravel. The dependence of many people on the non-market exploitation of natural resources in open- or weakly-regulated access common pool resources is not reflected in the national accounts as they now exist. This is partly because of the SNA rules on assets not subject to well-defined property rights, and partly because of the exclusion of environmental externalities. The evidence from the adjusted net savings estimates suggests that the poorest countries have, on average, reduced the value of their assets over the last four decades. In the absence of comprehensive wealth estimates it is, however, difficult to confirm this.

References

Alston, J. M., Andersen, M. A., James, J. J. & Pardey, P. G. (2010) *Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending*, edn. Springer, Dordrecht.

Alston, J. M., Beddow, J. M. & Pardey, P. G. (2009) Agricultural Research, Productivity, and Food Prices in the Long Run. *Science*, **325**, 1209-1210.

Arrow, K. J., Dasgupta, P. & Mäler, K.-G. (2003) The Genuine Savings Criterion and the Value of Population. *Economic Theory*, **21**, 217-225.

Dasgupta, P. (2009) The Welfare Economic Theory of Green National Accounts. *Environmental and Resource Economics*, **42**, 3-38.

Dasgupta, P. & Maler, K.-G. (2000) Net national product, wealth, and social well-being. *Environment and Development Economics*, **5**, 69-93.

Ferreira, S., Hamilton, K. & Vincent, J. R. (2008) Comprehensive Wealth and Future Consumption: Accounting for Population Growth. *The World Bank Economic Review*, **22**, 233–248.

Goettle, R. J., Ho, M. S., Jorgenson, D. W., Slesnick, D. T. & Wilcoxen, P. J. (2007) IGEM, an Inter-temporal General Equilibrium Model of the U.S. Economy with Emphasis on Growth, Energy and the Environment. U.S. Environmental Protection Agency, Office of Atmospheric Programs Climate Change Division, Washington D.C.

Goossens, Y., Mäkipää, A., Schepelmann, P., Van De Sand, I., Kuhndtand, M. & Herrndorf, M. (2007) Alternative progress indicators to Gross Domestic Product (GDP) as a means towards sustainable development. European Parliament: Policy Department, Economic and Scientific Policy, Brussels.

Hamilton, K. (1994) Green Adjustments to GDP. *Resources Policy*, **20**, 155-168.

Hamilton, K. & Clemens, M. (1999) Genuine savings rates in developing countries. *World Bank Economic Review*, **13**, 333-356.

Hartwick, J. (2000) *National Accounting and Capital*, edn. Edward Elgar, Cheltenham.

Hartwick, J. M. (1990) Natural Resources, National Accounting, and Economic Depreciation. *Journal of Public Economics*, **43**, 291-304.

Hartwick, J. M. (1994) National Wealth and Net National Product. *Scandinavian Journal of Economics*, **96**, 253-256.

Hicks, J. R. (1939) *Value and Capital*, edn. Clarendon Press, Oxford.

Jorgenson, D. W. & Landefeld, J. S. (2006) Blueprint for expanded and integrated U.S. accounts: review, assessment and next steps. *A New Architecture for the U.S. National Accounts* (ed. by D.W. Jorgenson & J.S. Landefeld & W.D. Nordhaus), pp 13-112. Chicago University Press, Chicago.

Lindahl, E. (1933) The concept of income. *Economic Essays in Honor of Gustav Cassel (ed. G.* (ed. by G. Bagge), pp 399–407. Allen and Unwin, London.

Markandya, A. (2000) Poverty, Environment and Development. *Frontiers of Environmental Economics,* (ed. by A.R.A.L. Gabel). Edward Elgar, Cheltenham: .

Markandya, A. (2001) Poverty alleviation and sustainable development implications for the management of natural capital, . World Bank, Washington D.C.

Millennium Ecosystem Assessment, M. (2005) *Ecosystems and human well-being: current state and trends: findings of the condition and trends working group*, edn. Island Press, Washington, D.C.

Nordhaus, W. D. (2006) Principles of national accounting for non-market accounts. *A New Architecture for the U.S. National Accounts* (ed. by D.W. Jorgenson & J.S. Landefield & W.D. Nordhaus), pp 143-160. University of Chicago Press, Chicago.

Pearce, D. & Atkinson, G. (1993) Capital Theory and the Measurement of Sustainable Development: An Indicator of Weak Sustainability. *Ecological Economics*, **8**, 103-108.

Pearce, D., Hamilton, K. & Atkinson, G. (1996) Measuring Sustainable Development: Progress on Indicators. *Environment and Development Economics*, **1**, 85-101.

Pearce, D. W. & Warford, J. J. (1993) *World Without End: Economics, Environment, and Sustainable Development*, edn. Oxford University Press, Oxford.

Piesse, J. & Thirtle, C. (2010) Agricultural R&D, technology and productivity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **365**, 3035-3047.

Repetto, R., Magrath, W. B. & Wells, M. (1989) *Wasting assets: natural resources in the national income accounts*, edn. World Resources Institute, Washington D.C.

Samuelson, P. A. (1961) The Evaluation of 'Social Income': Capital Formation and Wealth. *The Theory of Capital* (ed. by F.A. Lutz & D.C. Hague), pp 32–57. St Martins Press, New York.

SNA. (2009) System of National Accounts 2008. European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, World Bank, United Nations, New York.
Stern, D. I. (2004) The rise and fall of the Environmental Kuznets Curve. *World Development*, **32**, 1419-1439.
Systems 4, I., R., Polasky, S., and Tschirhart, J. (1998) Takings, compensation and endangered species protection on private lands. *Journal of Economic Perspectives*, **12**, 35-52.
Vouvaki, D. & Xepapadeas, A. (2009) Total Factor Productivity Growth when Factors of Production Generate Environmental Externalities. *Fondazione Eni Enrico Mattei Working Papers*, **281**.
World Bank. (2006) *Where is the wealth of nations? : measuring capital for the 21st century*, edn. The World Bank, Washington, DC.
World Commission on Environment and Development. (1987) *Our Common Future*, edn. Island Press, Washington D.C.