Measuring the Wealth of Nations

Partha Dasgupta

Frank Ramsey Professor Emeritus of Economics, University of Cambridge, Cambridge CB3 9DD, United Kingdom, and Fellow, St. John's College, Cambridge CB2 1TP, United Kingdom

Annu. Rev. Resour. Econ. 2014. 6:17–31

First published online as a Review in Advance on April 17, 2014

The *Annual Review of Resource Economics* is online at resource.annualreviews.org

This article's doi:
10.1146/annurev-resource-100913-012358

Keywords

environment, health, education, ecosystems, value of statistical life

Abstract

In this article, I review—and to an extent further develop—a normative theory that offers a unified language for both sustainability and policy analyses. The theory shows that by economic growth we should mean growth in wealth, which is the social worth of an economy's entire stock of capital assets, not growth in GDP or improvements in the many ad hoc indicators of human development that have been proposed in recent years. Concurrently, the theory shows that by poverty we should mean a low level of wealth, not income, and that the distribution of well-being ought to be judged in terms of the distribution of wealth, not income or education or the many indicators that are currently in use. I show that the concept of wealth invites us to extend the notion of assets and the idea of investment well beyond conventional usage. This perspective has radical implications for the way that national accounts are prepared and interpreted. I then sketch a recent publication that has put the theory to work by studying the composition of wealth accumulation in contemporary India.

INTRODUCTION

Twentieth-century economics was in large measure detached from the environmental sciences. Judging by our profession's writings, we economists have regarded nature at best as a backdrop from which resources can be considered in isolation. Moreover, macroeconomic forecasts almost always exclude natural resources. Accounting for nature, if it comes into the calculus at all, is an afterthought to the real business of "doing economics." We have been so successful in this enterprise that if someone today exclaims, "Economic growth!", no one will need to ask, "Growth in what?"; we all know that growth in gross domestic product (GDP) is meant.

CONFLICTING INTUITIONS

The practice of judging the progress and regress of nations in terms of GDP growth (or even in terms of the United Nations's Human Development Index) has given rise to a puzzle. On the one hand, if we look at specific examples of natural resources (freshwater, ocean fisheries, the atmosphere as a carbon sink—more generally, ecosystems), there is strong evidence that the rates at which we are currently utilizing them are unsustainable. During the twentieth century, world population grew by a factor of four to more than 6 billion, industrial output increased 40-fold and the use of energy increased 16-fold, methane-producing cattle population grew on pace with human population, fish catch increased 35-fold, and carbon and sulfur dioxide emissions increased 10-fold. The application of nitrogen to the terrestrial environment from the use of fertilizers, fossil fuels, and leguminous crops is now at least as great as that from all natural sources combined. Ecologists have estimated that 40–45% of primary production owing to terrestrial photosynthesis is currently being appropriated for human use. These figures put the scale of our presence on Earth in perspective and reveal that humanity has created an unprecedented disturbance in nature in a brief period of a century or so.

On the other hand, it is often argued that, just as earlier generations in the West invested in science and technology, education, and machines and equipment so as to bequeath to the present generation the ability to achieve high income levels, the current generation is now in turn making investments that will assure still higher living standards in the future. It has been argued as well that the historical trend in the prices of marketed natural resources, such as minerals and ores, has been so flat that there is no reason for alarm. Economic growth has allowed more people to have access to potable water and to enjoy better protection against water- and airborne diseases. The physical environment inside the home has improved beyond measure with economic growth (although cooking in the Indian subcontinent continues to be a major cause of respiratory illnesses among women). Moreover, natural resources can be shifted round today such that dwindling resources in one place can be met by imports from another. Intellectuals and commentators use the term globalization to imply that location per se doesn't matter. This optimistic view emphasizes the potential of capital accumulation and technological improvements to compensate for environmental degradation. This view probably explains why contemporary societies are obsessed with cultural survival and are on the whole dismissive of any suggestion that we need to find ways to survive ecologically.

PLAN OF THE ARTICLE

In this article, I review a theory that enables one to weigh the conflicting intuitions in a consistent manner. The approach is normative. The theory offers a unified language for sustainability and policy analyses. It shows that by economic growth we should mean growth in wealth—which is the social worth of an economy's entire stock of capital assets—not growth in GDP or the many ad hoc indicators of human development that have been proposed in recent years. Concurrently, the theory shows that by poverty we should mean a low level of wealth, not income, and that the distribution of well-being ought to be judged in terms of the distribution of wealth, not income or education or the many indicators that are currently in use.

The concept of wealth invites us to extend the notion of capital assets and the idea of investment well beyond conventional usage. The theory shows that by sustainable development we should mean development in which wealth (per head) adjusted for its distribution does not decline. I show that this theory has radical implications for the way national accounts are prepared and interpreted.[1] I then sketch two recent publications that put the theory to work by studying the composition of wealth accumulation in contemporary India (Arrow et al. 2012, 2013). Although the studies' authors paid much attention to the measurement of natural capital, due to a paucity of data they acknowledge that the value of natural capital is underestimated, in all probability by a large margin. These are still early days in the measurement of the wealth of nations, but both theory and the few empirical studies we now have at our disposal should substantially alter the way we interpret the progress and regress of nations.

THE BRUNDTLAND PROPOSAL

The starting point for reconciling the conflicting intuitions sketched above is the notion of sustainable development. The term became commonplace after the publication of a report by the World Commission on Environment and Development (World Commission 1987), widely known as the Brundtland Report, which defined sustainable development as "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The idea is that, relative to its demographic base, each generation should bequeath to its successor at least as large a productive base as it inherited from its predecessor. If each generation were to do so, the economic possibilities facing the successor would be no worse than those it faced when it inherited productive assets from its predecessor.

The requirement is derived from a relatively weak notion of economic development. Sustainable development in the Brundtland Commission's sense demands that members of future generations have no less of the means to meet their needs than we do ourselves; it demands nothing more. (It doesn't require, for example, that development be optimal.) But how is a generation to judge that it is leaving behind an adequate productive base for its successor? Moreover, shouldn't sustainable development be defined in terms of social well-being rather than an economy's productive base?

WEALTH AS A MEASURE OF PRODUCTIVE BASE

An economy's productive base is a means to protect and promote well-being (that is, social well-being) across the generations. We want a measure of the base whose movements over time mimic those of well-being across the generations. We show below that the required measure is the social worth of an economy's stock of capital assets. An asset's social worth is its shadow value. So it is natural to refer to the total worth of assets as wealth.

---

[1]That national accounts should be revised to include environmental natural resources was emphasized by economists some time before the literature I summarize here was fashioned. See, for example, Repetto et al. (1989), Mäler (1991), Vincent et al. (1997), and Hartwick (2000). But the realization that wealth is the object of interest in economic evaluation has exposed the need for still further revisions to national income accounts. I discuss them below.

Formally, let $K_i(t)$ be the economy's stock of asset i at t and $P_i(t)$ its shadow price. Write

$$W(t) = {}_i\Sigma\left[P_i(t)K_i(t)\right]. \tag{1}$$

$W(t)$ is the economy's wealth at t.[2]

If an economy's institutions were weak or simply bad, the shadow prices of those same assets would be small, which would translate into a low value of wealth. Institutions (more broadly, social capital) can be thought of as enabling assets, contributing to the social worth of those durable goods that define wealth.[3]

Identifying assets is no simple matter. We are obliged to go beyond usual classifications of goods and services. Because the size and composition of present and future populations are built into the notion of social well-being, they should be included in the list of assets. Moreover, material assets should be identified not only by their physical and chemical attributes, but also by location, date, and contingency. Because equality in the distribution of well-being among contemporaries is a desired objective of social policy, assets should also be identified by the identities of people who have claims to them. As shadow prices are the rates at which assets can be traded off against one another while keeping intergenerational well-being constant, they provide the required link between an economy's productive base and well-being across the generations.

If equality in the distribution of assets were taken to matter, the shadow price of a property belonging to someone poor would be higher than that of the same property if it were owned by someone wealthy. Differences between those shadow prices are distributional weights whose use, however, is controversial in social cost-benefit analysis. A rough and ready alternative to naming assets in terms of their ownership is to keep inequality in the distribution of well-being among contemporaries separate from inequality across the generations and to include a separate index of inequality among contemporaries. The Gini coefficient of wealth inequality is one possibility.

WEALTH AND SOCIAL WELL-BEING

To see why wealth is the index we are looking for in sustainability analysis, let ΔX denote a small change in any variable X. Consider a short interval of time Δt that begins at t. We write the change in K_i over the interval by $\Delta K_i(t)$. From Equation 1, it follows that the change in wealth over the interval is

$$\Delta W(t) = {}_i\Sigma P_i(t)\Delta K_i(t). \tag{2}$$

[$P_i(t)$ is held constant in the formula because, by definition, it is a measure of the social value of a unit change in $K_i(t)$.] Let $V(t)$ be a numerical index of the well-being of people alive at t and the potential well-being of those who are forecast to be alive after t. $V(t)$ is intergenerational well-being at t. By sustainable development over the period $[t, t + \Delta]$, let us mean that V at end of the period should be no less than what it was at the start of the period, which is to say, $V(t + \Delta t) \geq V(t)$. We denote the difference by $\Delta V(t)$. The Appendix shows that

[2]What we are terming "wealth" has been named in turn "inclusive wealth" by IHDP-UNU/UNEP (2012) and "comprehensive wealth" by Arrow et al. (2012, 2013). The adjectives remind readers that the list of assets contains many goods that are typically absent from national accounts.

[3]Wealth is the dynamic counterpart of income. The welfare significance of national income is explored by Hicks (1940), Samuelson (1961), Mirrlees (1969), and Sen (1976), among many others. As these authors confine themselves to perturbations of stationary states, their findings have no empirical import. Only Samuelson addresses the problems that a dynamic economy poses for the national accountant. In the final page of his article, Samuelson speculates that something like a wealth index is needed for economic evaluation, but provides no argument.

$$\Delta V(t) = \Delta W(t) = {}_i\Sigma P_i(t)\Delta K_i(t). \quad (3)$$

Equation 3 can be summarized as

> **Proposition 1**: Intergenerational well-being increases during a short interval of time if and only if wealth also increases.[4]

Proposition 1 says that if we interpret sustainable development to require that intergenerational well-being not decline over time, we should be asking whether wealth is increasing and is likely to increase in the future.[5] Proposition 1 also says that, in sustainability analysis, assets should be valued at their shadow prices. In contrast, the trade-offs postulated among the components of aggregate indices such as HDI are ad hoc; they aren't rooted to any well-defined notion of intergenerational well-being. That is why they are of no use in the study of sustainable development.[6]

Define net domestic product (NDP) as GDP minus the depreciation of capital assets. It is an easy matter to prove that wealth increases during a short interval of time if and only if aggregate consumption does not exceed NDP. So we have the following:

> **Proposition 2**: Intergenerational well-being increases during a short interval of time if and only if aggregate consumption does not exceed NDP.

Proposition 2 shows that sustainable development displays a particular form of prudence. It requires that resources be set aside for the future so as to expand the productive base.

ADJUSTING FOR POPULATION GROWTH

Even though Propositions 1 and 2 are intuitively appealing, they have a disquieting feature. Imagine that wealth grows at 1% a year, whereas population grows at an annual rate of 2%. The economy's wealth would be growing even though individuals would be getting poorer. To ignore the latter is unseemly. The problem here resembles the classic tension between total utilitarianism and average utilitarianism. That earlier literature, however, studied timeless societies. Here we have a dynamic system in need of ethical repair. One way out of the dilemma is to include population as a separate capital asset in Propositions 1 and 2. Another way is to reconstruct social ethics in terms of the well-being of the average person across the generations.[7]

---

[4]For proofs of the equivalence, see, in increasing generality, Hamilton & Clemens (1999), Dasgupta & Mäler (2000), Dasgupta (2004, 2009), and Arrow et al. (2003a,b).

[5]Equation 3 represents the equivalence between changes in wealth and social well-being in a short interval of time. The idea of sustainable development over the long run can be obtained by summing both sides of the equation over short intervals. For details, see Dasgupta (2004, 2009).

[6]HDI is a weighted combination of GDP per head, life expectancy at birth, and literacy. The weights aren't derived from any known welfare considerations. Ravallion (2012) shows that, under the version of HDI proposed in UNDP (2010), the value of longevity in Zimbabwe is US\$0.51 per year. That means if Zimbabwe's authorities were to make a policy change that increased national income by a mere US\$0.52 per person per year at the cost of reducing average life expectancy by 1 year (other things remaining the same), the country would promote human development. That simply can't be right.

[7]To illustrate, let time be continuous and denoted by s and t ($s \geq t$). We label people at each moment by j. Denote the flow of well-being to person j at time s as $U_j(s)$, and let $N(s)$ be population size at s. Consider, by way of example, an ethical viewpoint in which δ (≥ 0) is the rate at which future Us are discounted and social well-being at date t is taken to be $V(t) = {}_t\int^{\infty}[{}_j\Sigma U_j(s)\exp(-\delta(s-t))]\mathrm{d}s$. Then social well-being averaged over people across the generations would be $V(t)/\{{}_t\int^{\infty}[N(s)\exp(-\delta(s-t))]\mathrm{d}s\} = {}_t\int^{\infty}[{}_j\Sigma U_j(s)\exp(-\delta(s-t))]\mathrm{d}s/\{{}_t\int^{\infty}[N(s)\exp(-\delta(s-t))]\mathrm{d}s\}$. The technically minded reader will know that averaging social well-being over people across the generations doesn't change the formulation of intergenerational ethics that is commonly in use in policy analysis (e.g., Arrow & Kurz 1970), but it makes a difference, for the better, in sustainability analysis. For details, see Dasgupta (2004).

Fortunately, under certain simplifying assumptions, Proposition 1 can be reconstructed in terms of wealth per capita (Dasgupta 2004):

> **Proposition 3**: Intergenerational well-being adjusted for the distribution of wealth in each generation and averaged over people across the generations increases over a short period of time if and only if wealth per capita increases.

Similarly, to allow for population growth, Proposition 2 under those same simplifying assumptions can be reconstructed as

> **Proposition 4**: Intergenerational well-being averaged over people across the generations increases during a short interval of time if and only if consumption per head does not exceed NDP per capita.

Propositions 3 and 4 are only approximations to Proposition 1 but are nonetheless enormously useful, because by measuring assets in per capita terms, the social evaluator is able to avoid regarding population as a separate asset. Proposition 3 says that by economic growth we should mean growth in wealth, not growth in GDP. Similarly, it says that by intragenerational inequality we should mean inequality in the distribution of wealth, not inequality in income, and that by poverty we should mean a paucity of wealth, not low income. The aim shouldn't be to maximize the rate of wealth accumulation; it should be to optimize the rate. Estimating stocks is no doubt hard work, but it shouldn't be avoided. Because GDP doesn't record the degradation of natural capital, the term green GDP is an utter misnomer.

In a severely distorted economy, a government may be able to have its proverbial cake and eat it too. A judicious choice policy may allow for both the accumulation of wealth per capita and the enjoyment of modest increases in GDP per head for a while. The empirical work on sustainable development reported below is suggestive of the possibility.

POLICY ANALYSIS

Policy analysis (e.g., that of appraising investment projects) involves evaluating perturbations to an economy at a point in time. Consider a proposal for an investment project to be initiated at date t. The project involves transferring assets at t to the project from those activities in which such assets would be deployed under the status quo. The transfers amount to a perturbation to the economy with long-run consequences. If the project is small relative to the size of economy, the social value of the perturbation is

$$\Delta W(t) = {}_i\Sigma\left[P_i(t)\Delta K_i(t)\right]. \tag{4}$$

The perturbation doesn't affect shadow prices because the project is small. The social evaluator would be required to estimate consumer surpluses if the project were not small. In Equation 4, the $\Delta K_i(t)$s are the quantities of assets transferred from one set of activities to another. Of course, in a closed economy, their physical magnitudes at t wouldn't change [$\Delta K_i(t) < 0$ in the activity from which i would be displaced, and $\Delta K_i(t) > 0$ in the project to which i would be placed]. But as i's shadow price in the two activities would differ, $\Delta W(t)$ is not zero.

Equation 4 says that the coin on the basis of which we should evaluate the project is wealth. The claim could seem odd inasmuch as the conventional criterion for evaluating investment projects is the present discounted value (PDV) of the flow of social profits. But one can show that the PDV in question is the project's impact on wealth (Dasgupta 2004). Formally, we have

Proposition 5: The PDV of social profits from a project is positive if and only if the project gives rise to an increase in wealth.[8]

Proposition 5 is intuitively appealing. As the (weighted) sum of social profits, a project's PDV has the dimensions of stock. Wealth also has the dimensions of stock. The proposition says that a project's PDV is the change in wealth occasioned by it. In an optimally managed economy, the PDV of the marginal investment project would be zero. Proposition 5 says that the assets that have been inherited from the past are deployed in an optimizing economy such that wealth is at its maximum at each date. Taken together, Propositions 1 and 3 tell us that the criterion we should use for economic evaluation is wealth. The equivalence between wealth and intergenerational well-being is at the heart of normative development economics.

ENLARGING THE SCOPE OF ASSETS

Historically, assets were taken to possess three features shared by commonplace durable goods such as land, buildings, and machines. First, the good is an input in production. Second, the good gives rise to an additional flow of consumption, the PDV of which can be realized in the market. And third, the good can be alienated (transferred to another individual) with no change in value.

For economic evaluation, this point of view is too narrow. Propositions 1–5 tell us that by assets we should mean the state variables of the socioenvironmental processes driving the economy. Health and education possess the first two features, but not the third. That may be why health and education are not regarded as assets in national accounts, in which they appear as consumption expenditures. But both education and health are state variables in any plausible account of the processes that drive an economy. That is why they should be entered as capital assets.

What one means by a state variable is also in part a matter of discretion. If one leaves aside questions of aggregation, the person engaged in economic evaluation faces a choice. It may, for example, seem natural to regard knowledge as an asset (as in knowledge capital). But if knowledge were an output of domestic R&D, the capital inputs in R&D (scientific equipment, human capital) could substitute for knowledge itself. In contrast, suppose that the economy freely applies knowledge that is produced elsewhere. Growth of knowledge in the domestic economy would then be exogenous, and increases in knowledge would be recorded as growth in total factor productivity (TFP), otherwise known as the residual. However, the residual is a mathematical transform of the passage of time, which means that time itself is an asset. If that seems nonintuitive, an alternative is to embed knowledge in the quality of other assets and measure the latter in efficiency units. In theory, either route could be taken (Arrow et al. 2013). A coarse partition of assets in Proposition 3 would comprise reproducible capital (roads, ports, cables, buildings, machines, equipment), human capital (education, health), and natural capital (ecosystems, sources of water, the atmosphere, land, subsoil resources). This classification is used in the empirical study I report below.

THE IDEA OF INVESTMENT

Equation 2 denotes the change in wealth caused by a perturbation to the economy. Suppose that the perturbation is the passage of time. Divide both sides of Equation 2 by Δt to obtain

[8]For details, see the appendix in Dasgupta (2004).

$$\Delta W(t)/\Delta t = {}_i\Sigma P_i(t)\Delta K_i(t)/\Delta t. \quad (5)$$

When applied to Proposition 3, Equation 5 reads as

> **Proposition 6**: Intergenerational well-being adjusted for the distribution of well-being in each generation and averaged over people across the generations increases if and only if investment per head (adjusted for the distribution of investment across contemporaries) is positive.

Proposition 6 may read oddly because the word investment carries with it a sense of robust activism. When the government invests in roads, the picture that is drawn is of bulldozers leveling the ground and tarmac being laid by men in hard hats. But the notion of capital extends beyond reproducible assets to include human capital, knowledge, and natural capital. So we need to stretch the notion of investment, which in Proposition 6 includes the growth of renewable natural resources such as ecosystems. To leave a forest unmolested would be to invest in the forest, to allow a fishery to restock under natural conditions would be to invest in the fishery, and so on.[9]

The above examples suggest that investment amounts to deferred consumption, but the matter is subtler. Providing additional food to undernourished people via, say, food guarantee schemes not only increases their current well-being but enables them to be more productive in the future and to live longer. Because these people's human capital increases, the additional food intake should also count as investment. However, food intake by the well nourished doesn't alter their nutritional status, which means that the intake is consumption, not investment. Equation 5 says that by net investment in an asset we should mean the value of the change in its stock, which has a number of implications for national income accounting (Anant et al. 2013). It means, for example, that defensive expenditures (i.e., resources deployed to mitigate environmental pollution) should be deducted from investment figures (Mäler 1991). Such expenditures enter GDP in a positive light, but they don't add to wealth.

To illustrate Proposition 6 further, consider a closed, egalitarian economy with constant population. Suppose that in a given year the economy invests \$40 billion in reproducible capital, spends \$20 billion on primary education and health care, and depletes and degrades its natural capital by \$70 billion. The economy's system of national accounts would record the \$40 billion as investment (gross capital formation) and the \$20 billion as consumption and would remain silent on the \$70 billion of loss in stocks of natural capital. Proper accounting methods, in contrast, would reclassify the \$20 billion as expenditure in the formation of human capital ("investing in the young," as the saying goes) and the \$70 billion as depreciation of natural capital. Aggregating them and assuming that expenditure on education is a reasonable approximation of gross human-capital formation, we would conclude that, owing to the depreciation of natural capital, the economy's wealth will have declined over the year by \$10 billion, and that figure does not take into account the depreciation of reproducible and human capital. The moral we should draw is that development was unsustainable that year.

Sustainable development is different from optimum development. One can imagine a sustainable development path involving excessively high rates of investment. The idea of sustainable development is of immense value as a check against profligacy by the current generation, but a program of accumulation can be sustainable and can be a burden on the current generation.

[9]What we are terming "net investment" has been termed "genuine saving" by Hamilton & Clemens (1999) and "inclusive investment" by IHDP-UNU/UNEP (2012). Additionally, net investment per capita in Proposition 6 should be interpreted as the rate at which per capita wealth changes; it is not net aggregate investment divided by population size. Economic evaluation requires estimates of stocks.

TRADE, EXTERNALITIES, AND WEALTH TRANSFERS

Proposition 3 also tells us to curb our enthusiasm for free trade in a distorted world.[10] To illustrate why, imagine that timber concessions have been awarded in an upstream forest of a poor country by its government so as to raise export revenue. As forests stabilize both soil and water flow and are the habitat for birds and insects (in the words of MEA 2005a–d, these services are "regulating" and "provisioning"), deforestation erodes soil, increases water runoff downstream, and reduces pollination and pest control in nearby farms. If the law recognizes the rights of those who suffer damage from deforestation, the timber company will be required to compensate downstream farmers. But compensation is unlikely when the cause of damage is many miles away and the victims are scattered groups of farmers. Problems are compounded because damages are not uniform across farms; geography matters. Moreover, downstream farmers may not even realize that the decline in their farms' productivity is traceable to logging upstream. In those circumstances, the timber company's operating cost would be less than the social cost of deforestation (the latter, at least as a first approximation, would be the firm's logging costs and the damage suffered by all who are adversely affected). So the export would contain an implicit subsidy (the externality), paid for by people downstream. And I haven't included forest inhabitants, who now live under even more straitened circumstances. The subsidy is hidden from public scrutiny, but Proposition 3 says that the subsidy amounts to a transfer of wealth from the exporting country to the importing country. Ironically, some of the poorest people in the exporting country would be subsidizing the incomes of the average importer in what could well be a rich country. That can't be right.

SUSTAINABILITY ANALYSIS: EMPIRICS

Proposition 1 is the sustainability theorem in its pristine form. If we are to apply it, assets will have to be reclassified so as to conform to limitations of data. Proposition 3 is an approximation of Proposition 1. Empirical work requires further approximations, and analysts are forced to cut corners. Proposition 1 is nevertheless essential for even the most hard-boiled empiricist. If national income statisticians were to remain unaware of it, they wouldn't know what corners they would be obliged to cut.

Arrow et al. (2012, 2013) and IHDP-UNU/UNEP (2012) make an initial try at applying Proposition 3. Their publications are like reconnaissance exercises. They explore the land mostly in the dark; you know they've got it wrong, but you have reasons to believe they're in the right territory.

Wealth in India

Arrow et al. (2012) put Proposition 3 to work by estimating the change in wealth per capita over the period 1995–2000 in Brazil, China, India, United States, and Venezuela.[11] The choice of countries is designed in part to reflect different stages of economic development and in part to focus on particular resource bases. Because of an absence of data, the authors do not study wealth inequality within countries. In what follows, I summarize the steps they take to inquire whether economic development in India was sustained during the five years in question. Details can be found in their paper.

Table 1 provides estimates of wealth per capita in 1995 and its growth during the following five years. Columns 1 and 2 provide estimates of stocks per capita for 1995 and 2000, respectively, for three categories of assets: reproducible capital (row 1); human capital, divided into education and health (rows 2 and 3); and natural capital (row 4).

[10]The example is taken from Dasgupta (1990) and from the empirical substantiation in Pattanayak & Butry (2005) and Kareiva et al. (2011).

[11]IHDP-UNU/UNEP (2012) uses the same framework to measure wealth in 20 countries.

Table 1 Per capita wealth and its growth in India, 1995–2000 (2000 US$)

	(1) 1995 stock	(2) 2000 stock	(3) Change (1995–2000)	(4) Growth rate (percent per year)
(1) Reproducible capital	1,530	2,150	650	7.30
(2) Human capital (education)	6,420	7,440	1,020	3.00
(3) Human capital (health)	500,000	503,750	3,750	0.14
(4) Natural capital	2,300	2,280	−20	−0.15
(5) Oil (net capital gains)			−140	
(6) Carbon damage			−90	
(7) Total	510,250	515,650	5,170	0.20
(8) TFP				1.84
(9) Wealth per capita				2.04

From Arrow et al. (2012), table 5 (modified).

The value of reproducible capital in 1995, amounting to $1,530 per head, is calculated from government publications on past capital investments. The implicit assumption is that prices used by the government to record expenditures are a reasonable approximation of shadow prices. By using the methods summarized in Klenow & Rodriguez-Clare (2005), the value of education per person ($6,420) is estimated on the basis of a functional relationship between wage differences and differences in levels of education.

No data are currently available for calculating the contribution of health to labor productivity and current well-being. For that reason, Arrow et al. (2012) study longevity only. Its shadow price is estimated from the value of a statistical life (VSL), which is commonly obtained from the willingness to pay for a marginal reduction in the risk of death. Recent work suggests that VSL in India is approximately $500,000. Arrow et al. show that, under a set of simplifying assumptions, VSL equals the value of health per person (**Table 1**, row 3, column 1). They then estimate the VSL year (see **Table 1**, row 3, column 2) and use that figure to value the increase in life expectancy between 1995 and 2000.

Four categories of natural capital are included in the study: forests (valued for their timber), oil and minerals, land, and carbon concentration in the atmosphere. Like institutions and knowledge, atmospheric carbon is interpreted to be an enabling asset and is therefore excluded from columns 1 and 2 of **Table 1** but included in the estimate of the change in wealth over the 5-year period.

The value of land is taken from World Bank (2011). By using market prices for timber and oil and minerals, the shadow value of natural capital in 1995 is estimated to be $2,300 per person (**Table 1**, row 4, column 1). Because of the lack of relevant data, this number doesn't include the value of all the many ecological services that forests provide. Moreover, ecosystems such as fisheries, wetlands, mangroves, and water bodies are missing from **Table 1**. That means $2,300 is an underestimate, in all probability seriously so. By adding the figures, wealth per capita in 1995 is found to be $510,250 (**Table 1**, row 7, column 1).

Population in India grew at an average annual rate of 1.74% from 1995 to 2000. In **Table 1**, column 3 records changes in per capita capital stocks over the period in question, and column 4 presents the corresponding annual rates of change. Numbers in the former column are embellished by two factors. First, India is a net importer of oil, whose real price rose during the period. The capital losses owing to that increase amounted to wealth reduction in India that is calculated to be $140 per person (**Table 1**, row 5, column 3). Second, from 1995 to 2000 global carbon emissions into the atmosphere were more than 38 billion tons. At 1995 concentration levels (380 parts per million), carbon is a global public bad. The theory of public goods says that the loss to India over the period was global emissions times the shadow price of carbon specific to India. In their base case, Arrow et al. (2012) take the global shadow price to be −$50 per ton. By using the estimates of Nordhaus & Boyer (2000), the loss to India per ton of carbon emissions is taken to be 5% of the global shadow price, which is −$2.50. This calculation amounts to a loss per person of $90 (**Table 1**, row 6, column 3).

Row 7 of **Table 1** records the change in wealth per capita in India from 1995 to 2000. This change is 0.20% a year, a figure so near to zero as to be alarming. However, the estimate doesn't include improvements in knowledge and institutions. Arrow et al. (2012) model the latter as enabling assets and interpret improvements in them as growth in TFP, which in India has been estimated to be 1.84% a year (**Table 1**, row 8). On the basis of a formula Arrow et al. (2012) derive for including the residual in wealth calculations, row 9 of **Table 1** records the annual rate of growth of wealth per head in India during 1995–2000 as 2.04%.

Wealth in India: Commentary

The composition of wealth in **Table 1** doesn't have direct implications for policy. A mere study of the relative magnitudes of the different forms of wealth wouldn't tell us their relative importance. Suppose, for example, that the value of asset *i* swamps all other forms of capital by a factor of 1,000. That doesn't mean investment ought to be directed at further increases in *i*, for we don't know the costs involved in doing so. Only social cost-benefit analysis, using the same shadow prices as are estimated for sustainability analysis, would tell the evaluator which investment projects are socially desirable.

Taken at face value, **Table 1** reveals a number of interesting characteristics of India's economic development during the final years of the twentieth century. I highlight the most striking of these characteristics:

1. Of the four types of capital composing measured wealth, reproducible capital is the smallest. Even though the value of natural capital in both years is likely a serious underestimate, it was considerably greater than reproducible capital in 1995.
2. The rapid growth of reproducible capital (7.30% a year), compared with a 0.15% annual rate of decline of natural capital, meant that by 2000 stocks of the two assets were pretty much the same.
3. In 1995, human capital in the form of education was more than four times that of reproducible capital. But the ratio declined over the 5-year period owing to a slower growth in education.
4. Health swamps all other forms of wealth. That it is some two orders of magnitude larger than all other forms of wealth combined in what was in 1995 a low-income country is unquestionably the most striking result and will no doubt come as a surprise to readers. That the finding is a cause for surprise is, however, no reason for dismissing it. Health has been much discussed in the development literature but hasn't been valued within the same normative theory as has reproducible capital. There was no basis for a prior expectation of what the finding would be once health was placed on the same normative footing as other forms of wealth. Health dominates because of the high VSL reported in the empirical literature. Longevity matters greatly to people everywhere. In democratic societies, that should count positively.[12]

[12]Becker et al. (2005) include longevity increase in estimates of the growth of income per head to show that the economic performance of developing countries in recent decades was considerably superior to that of rich countries.

5. Growth in wealth per capita in India has been in great measure a consequence of TFP growth (the residual). But contemporary estimates of the residual should be treated with the utmost skepticism, based as they are on models that don't include natural capital as factors of production. If the use of natural capital were to increase over a period of time, TFP growth obtained from regressions based on those models would be overestimates. The implication is more than just ironic. The regressions would misinterpret degradation of the environment through rising use of natural capital as increases in knowledge and improvements in institutions. Worse still, the greater the undercoverage of natural capital, the greater would be the bias in the estimate of TFP growth. By plundering Earth, TFP could be raised by as much as the authorities liked.

GREEN NATIONAL ACCOUNTS

The literature I sketch in this article reveals that the entire architecture of contemporary growth and development economics is stacked against nature. No matter where you look in official models of growth and development, you will find an assumption that eliminates natural capital from human activities. It should be no surprise that intuitions built on the basis of those models are at odds with the experiences of rural households and communities in poor countries.

Theory guides and helps to shape empirical research. The absence of natural capital in growth and development models has meant that contemporary national accounts continue to be prepared without mention of the environmental resource base. Although the United Nations statistical office has constructed satellite accounts that include natural capital, few countries treat them as anything more than the proverbial footnote.

These are early days in the preparation of wealth accounts. But it is sobering to realize that 60–70 years ago estimates of national incomes were subject to uncertainties of a magnitude people are minded to think no longer exists in current estimates. In any event, we take contemporary estimates of national incomes too much at face value. Official estimates are silent on the proportion of incomes that has gone unrecorded. Estimates of transactions falling outside the market system or operating within a black market system suggest that the errors in official estimates of national income are substantial.

The value of natural capital in **Table 1** is a serious underestimate. When national accounts are better prepared, health and natural capital will in all probability be found to be the most significant component of the wealth of nations. That is also why official ignorance of the state of an economy's stock of natural capital assets should now be a matter of embarrassment to governments.

Estimating shadow prices is no easy matter. It requires (*a*) an understanding of the relevant socioenvironmental processes (the dynamical system), (*b*) knowledge of the size of assets (initial condition), and (*c*) a conception of intergenerational well-being (ethical values). Kumar (2010), Kareiva et al. (2011), and Bateman et al. (2013) are pioneering studies on the value of ecological services. But they are only a beginning, and their coverage is such as to be unusable in the study of the wealth of nations. Moreover, in a review of the empirical literature on forest services (carbon storage, ecotourism, hydrological flows, pollination, health, and nontimber forest products), Ferraro et al. (2012) find little that can be reliably used in wealth estimates.

But even if figures for natural resource stocks were available, the deep problem of imputing values to them would remain. Market prices may be hard facts, but shadow prices are soft. The issue isn't merely that the role that natural capital plays in production and consumption possibility is uncertain, but also that people differ in their ethical values. The sensitivity of wealth estimates to shadow prices should become routine exercise in national accounts. An expert group convened by the Government of India has recommended in its report on greening the country's national accounts (Anant et al. 2013) that for the foreseeable future wealth estimates should be attempted only at the sector level (as in rows 1–4 in **Table 1**), within bands; such estimates should not be presented as precise figures. Shadow prices are far too fragile to support point estimates.

That people may never agree on the wealth of nations is, however, no reason for abandoning wealth as the object of interest in sustainability analysis. Our ignorance of the economic worth of natural capital remains the greatest barrier to an understanding of the history of economic development. Until that ignorance is lifted, policy analysis will remain crippled, and sustainability will continue to be a notion we admire but cannot put into operation.

APPENDIX: PROOF OF PROPOSITION 1

To review the welfare properties of wealth formally, denote by $V(t)$ a scalar index of social well-being at date t. Let $K_i(t)$ be the economy's stock of asset i at t and $\boldsymbol{K}(t)$ the vector denoting the stocks of the economy's entire set of assets. Thus, we write

$$\boldsymbol{K}(t) = \{K_1(t), K_2(t), \ldots, K_i(t), \ldots\}.$$

Social well-being at t depends on the productive base $\boldsymbol{K}(t)$ and on the socioenvironmental processes that are forecast to drive the economy beyond t. Denoting the socioenvironmental processes symbolically by $\boldsymbol{M}$, we may write $V(t)$ as $V(\boldsymbol{K}(t), \boldsymbol{M})$. $\boldsymbol{M}$ reflects not only the ecological processes the economy is subject to, but also the workings of institutions. If institutions are thought to coevolve with the level of economic development, $\boldsymbol{M}$ reflects that too. In most case studies, $\boldsymbol{M}$ is formulated in terms of a set of differential equations reflecting the dynamics of socioenvironmental processes (for illustrations, see Dasgupta 2004, appendix).

Let ΔX denote a small change in any variable X. Now consider a short interval of time Δt starting at t. Sustainable development over the interval $[t, t + \Delta]$ would demand that $V(\boldsymbol{K}(t), \boldsymbol{M})$ should not decline. In our notation, $V(\boldsymbol{K}(t), \boldsymbol{M})$ changes by $\Delta V(\boldsymbol{K}(t), \boldsymbol{M})$. Because Δ represents a small change,

$$\Delta V(\boldsymbol{K}(t), \boldsymbol{M}) = {}_i\Sigma\left[\partial V(\boldsymbol{K}(t), \boldsymbol{M})/\partial K_i(t)\right]\Delta K_i(t). \tag{A1}$$

Let $P_i(t)$ be asset i's shadow price at t. By the definition of shadow prices, we know that

$$P_i(t) = \partial V(\boldsymbol{K}(t), \boldsymbol{M})/\partial K_i(t). \tag{A2}$$

Using Equation A2 in Equation A1 and dividing both sides of the resulting equation by Δt yield

$$\Delta V(\boldsymbol{K}(t), \boldsymbol{M})/\Delta t = {}_i\Sigma P_i(t)\Delta K_i(t)/\Delta t. \tag{A3}$$

Write

$$W(t) = {}_i\Sigma\left[P_i(t)K_i(t)\right]. \tag{A4}$$

$W(t)$ is the economy's wealth at t. From Equations A3 and A4, we conclude that social well-being increases during $[t, t + \Delta]$ if and only if wealth increases during $[t, t + \Delta]$.[13]

[13]For the technically minded reader, we recall the theory of dynamic programming and note that $V(\boldsymbol{K}(t), \boldsymbol{M})$ is a value function. It is a reduced form of an entire dynamical system. To construct V, the analyst needs to represent the socioenvironmental processes in question by, say, a system of differential equations; has to know what the initial asset stocks are; and has to specify the social well-being function with which to conduct the evaluation. (For illustrations, see Dasgupta 2004, appendix.) There is no presumption that $\boldsymbol{M}$ is a socially optimal socioenvironmental process. For simplicity of exposition, I suppose that the socioenvironmental system under study is autonomous, implying that V is not an explicit function of t. In sustainability analysis, $\boldsymbol{M}$ is a parameter, not a variable. In policy analysis, $\boldsymbol{M}$ is a choice variable. Acceptance of a proposed investment project changes $\boldsymbol{M}$ ever so slightly. A sequence of acceptances amounts to a sequence of improvements to $\boldsymbol{M}$.

DISCLOSURE STATEMENT

The author is not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

LITERATURE CITED

Anant TCA, Basu K, Chopra K, Dasgupta P, Desai N, et al. 2013. *Green national accounts in India: a framework*. Rep., Expert Group Convened by the National Statistical Organization, Ministry of Statistics and Programme Implementation, Government of India. **http://mospi.nic.in/mospi_new/upload/Green_National_Accouts_in_India_1may13.pdf**

Arrow KJ, Dasgupta P, Goulder LH, Mumford KJ, Oleson K. 2012. Sustainability and the measurement of wealth. *Environ. Dev. Econ.* 17(3):317–55

Arrow KJ, Dasgupta P, Goulder LH, Mumford KJ, Oleson K. 2013. Sustainability and the measurement of wealth: further reflections. *Environ. Dev. Econ.* 18(4):504–16

Arrow KJ, Dasgupta P, Mäler K-G. 2003a. Evaluating projects and assessing sustainable development in imperfect economies. *Environ. Resour. Econ.* 26(4):647–85

Arrow KJ, Dasgupta P, Mäler K-G. 2003b. The genuine savings criterion and the value of population. *Econ. Theory* 21(2):217–25

Arrow KJ, Kurz M. 1970. *Public Investment, the Rate of Return and Optimal Fiscal Policy*. Baltimore, MD: Johns Hopkins Univ. Press

Bateman IJ, Harwood AR, Mace GM, Watson RT, Abson DJ, et al. 2013. Bringing ecosystem services into economic decision-making: land use in the United Kingdom. *Science* 341:45–50; doi:10.1126/science.1234379

Becker GS, Philipson TJ, Soares RS. 2005. The quantity and quality of life and the evolution of world inequality. *Am. Econ. Rev.* 95(1):227–91

Dasgupta P. 1990. The environment as a commodity. *Oxf. Rev. Econ. Policy* 6(1):51–67

Dasgupta P. 2004. *Human Well-Being and the Natural Environment*. Oxford, UK: Oxford Univ. Press. 2nd ed.

Dasgupta P. 2009. The welfare economic theory of green national accounts. *Environ. Resour. Econ.* 42(1):3–38

Dasgupta P, Mäler K-G. 2000. Net national product, wealth, and social well-being. *Environ. Dev. Econ.* 5(1):69–93

Ferraro PJ, Lawlor K, Mullan KL, Pattanayak SK. 2012. Forest figures: ecosystem services valuation and policy evaluation in developing countries. *Rev. Environ. Econ. Policy* 6:20–44

Hamilton K, Clemens M. 1999. Genuine savings rates in developing countries. *World Bank Econ. Rev.* 13(2):333–56

Hartwick J. 2000. *National Accounting and Capital*. Cheltenham, UK: Edward Elgar

Hicks JR. 1940. The valuation of social income. *Economica* 7(2):105–24

IHDP-UNU/UNEP. 2012. *Inclusive Wealth Report 2012: Measuring Progress Toward Sustainability*. Cambridge, UK: Cambridge Univ. Press

Kareiva PK, Tallis H, Ricketts TH, Daily GC, Polasky S, eds. 2011. *The Theory and Practice of Mapping Ecosystem Services*. Oxford, UK: Oxford Univ. Press

Klenow PJ, Rodriguez-Clare A. 2005. Externalities and growth. In *Handbook of Economic Growth*, Vol. 1A, ed. P Aghion, S Durlauf, Chapter 11, pp. 817–61. Amsterdam: North Holland

Kumar P, ed. 2010. *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Washington, DC: Earthscan

Mäler K-G. 1991. National accounts and environmental resources. *Environ. Resour. Econ.* 1(1):1–15

Millennium Ecosystem Assessment (MEA) (Hassan R, Scholes R, Ash N, eds.). 2005a. *Ecosystems and Human Well-Being*, Vol. 1: *Current State and Trends*. Washington, DC: Island

MEA (Carpenter SR, Pingali PL, Bennet EM, Zurek MB, eds.). 2005b. *Ecosystems and Human Well-Being*, Vol. 2: *Scenarios*. Washington, DC: Island

MEA (Chopra K, Leemans R, Kumar P, Simmons H, eds.). 2005c. *Ecosystems and Human Well-Being*, Vol. 3: *Policy Responses*. Washington, DC: Island

MEA (Capistrano D, Samper CK, Lee MK, Randsepp-Hearne C, eds.). 2005d. *Ecosystems and Human Well-Being*, Vol. 4: *Multiscale Assessments*. Washington, DC: Island

Mirrlees JA. 1969. The evaluation of national income in an imperfect economy. *Pak. Dev. Rev.* 9(1):1–13

Nordhaus WD, Boyer J. 2000. *Warming the World: Economic Models of Global Warming*. Cambridge, MA: MIT Press

Pattanayak SK, Butry DT. 2005. Spatial complementarity of forests and farms: accounting for ecosystem services. *Am. J. Agric. Econ.* 87(4):995–1008

Ravallion M. 2012. Troubling tradeoffs in the Human Development Index. *J. Dev. Econ.* 99(3):201–9

Repetto R, Magrath W, Wells M, Beer C, Rossini F. 1989. *Wasting Assets: Natural Resources and the National Income Accounts*. Washington, DC: World Resour. Inst.

Samuelson PA. 1961. The evaluation of "social income": capital formation and wealth. In *The Theory of Capital*, ed. FA Lutz, DC Hague, Chapter 3, pp. 32–57. London: MacMillan

Sen A. 1976. Real national income. *Rev. Econ. Stud.* 43(1):19–39

UN Dev. Prog. (UNDP). 2010. *Human Development Report*. New York: UN

Vincent JR, Ali RM, and Associates. 1997. *Environment and Development in a Resource-Rich Economy: Malaysia Under the New Economic Policy*. Cambridge, MA: Harv. Inst. Int. Dev.

World Bank. 2011. *The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium*. Washington, DC: World Bank

World Commission on Environment and Development (World Commission). 1987. *Our Common Future*. New York: Oxford Univ. Press