The Nature of Economic Development and the Economic Development of Nature

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This paper reviews and in part extends an emerging literature that integrates development and environmental thinking. It focuses on a small part of the literature: economic evaluation, and goes on to develop the notion of sustainable development and construct a unified language for sustainability and policy analyses. It is shown that by economic growth we should mean growth in *wealth* – which is the social worth of an economy's entire set of capital assets – not growth in gross domestic product nor the many ad hoc indicators of human development that have been proposed in recent years. The concept of wealth invites us to extend the notion of capital assets and the idea of investment well beyond conventional usage. The author also shows that by sustainable development we should mean development in which wealth (per head) adjusted for its distribution does not decline. This has radical implications for the way national accounts are prepared and interpreted. The author then provides an account of a recent publication that has put the theory to work by studying the composition of wealth accumulation in contemporary India. The study reveals that the entire architecture of contemporary development thinking is stacked against nature. 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.

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> The best policies for alleviating malnutrition and poverty are those which increase growth and the competitiveness of the economy, for a growing and competitive economy facilitates a more even distribution of human capital and other assets and ensures higher incomes for the poor. Progress in the battle against malnutrition and poverty can be sustained if, and only if, there is satisfactory economic growth.
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> – World Bank, *World Development Report*, 1986, p 7.
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> ...long run economic growth is often slowed by widespread chronic food insecurity. People who lack energy are ill-equipped to take advantage of opportunities for increasing their productivity and output. That is why policymakers in some countries may want to consider interventions that speed up food security for the groups worst affected without waiting for the general effect of long-run growth.
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> – S Reutlinger and H Pellekaan, *Poverty and Hunger: Issues and Options for Food Security in Developing Countries*, World Bank Publication (1986: 6).

1 The Development Orthodoxy

A central message of modern development economics is the importance of income growth, by which is meant growth in gross domestic product (GDP). In theory, rising GDP creates employment and investment opportunities. And as incomes grow in a country where GDP was once low, households, communities, and government are able increasingly to set aside funds for the production of things that make for a good life. Today GDP has assumed such a significant place in the development lexicon, that if someone mentions "economic growth", we know they mean growth in GDP.[1]

But if GDP is to grow, the state must establish conditions that create incentives to households, firms, communities, charities, and various layers of government to allocate goods and services in productive uses. The role of the state in economic development is thus both active (maintaining the rule of law and producing other public goods; investing in physical infrastructure, primary healthcare, and education) and passive (permitting markets to operate; supporting freedom to express oneself). No doubt GDP growth in itself doesn't guarantee a reasonable distribution of incomes, but that only provides a case for including taxes and transfers on the government's agenda. Or so the argument would have it.

1.1 Contrasting Views

There are, however, two contrasting positions even within that argument, which are reflected in the quotations at the head of this article. That the publications from which the passages have been taken are from the same institution (The World Bank) and appeared in the same year (1986) is worth noting, because the views have been the source of a seemingly

unending controversy. They have been revived once again in two recent books (Bhagwati and Panagariya 2013; Dreze and Sen 2013) in which the authors assess India's economic performance since the early 1990s. Because the framework in which the pair of views has been constructed in the two books – more generally the argument itself – should have by now been retired, it will pay to recount them here.

There is general appreciation that the programme of economic liberalisation and structural reforms the Government of India initiated in the early 1990s gave rise to unprecedented economic growth for nearly two decades. During the first decade of this century GDP grew at an annual rate of 7.5%. That was accompanied by improvements in a number of other economic indicators. For example, the proportion of people whose incomes are below the country's official poverty line declined from 45% in the early 1980s to 28% in 2005. The decline is impressive, but the latter figure tells us that the country still harbours widespread deprivation.

Over the years the persistence of inequities in India in the distribution of health and education has been a reason for complaint among social commentators. As the World Bank noted recently, 45% of children under five are underweight and 25% of women are illiterate, figures that are worse than the corresponding ones in a number of countries that are poorer in terms of GDP per head. So, if you look at changes that have taken place in the indicators of the quality of life in India since the early 1990s, the country would appear to be a winner. On the other hand, if you study the current figures in the country for the same indicators and compare them to those in some countries where GDP per head is lower, India would seem to be a loser. Depending on your perspective, the proverbial glass would appear to be either half full or half empty.

Bhagwati and Panagariya (2013) begin by exposing a number of myths (their term) that critics have created about the country's recent performance in health, education, and the distribution of income. They recount that economic growth has come allied to improvements in a number of measures of education, health and poverty. They go on to claim that the reforms necessary for successful economic development over the long run constitute two stages. First, there are to be what the authors call "Track I reforms", aimed at GDP growth, which enable the poor to pull themselves up in the income ladder. Changes aimed at providing healthcare, education, and other forms of support for the poor, all of which would be made possible by the increased tax revenues from higher incomes, are Track II reforms. Without the former phase, the authors argue, there would be no finance to produce the latter benefits. They see the fast growth rates emanating from Track I reforms since the early 1990s as enabling the Indian government to move more fully to Track II in due course.

The target in Dreze and Sen (2013) is the neglect by successive governments of health and education, which the authors interpret as having given rise to the enormous inequities in human "capabilities" that characterise the Indian economy. In contrast to Bhagwati and Panagariya, who study changes over time in India's socio-economic indicators, Dreze and Sen compare the current state of affairs in India with other poor countries and find India wanting. For Dreze and Sen the sequencing of Track I and Track II reforms is repugnant. They insist a far better pattern of economic development would have been one where GDP growth was to an extent traded off for more rapid improvements in health and education. The authors sift evidence from the experiences of Japan, South Korea, and Taiwan among other successful countries to argue that the "extent" is in principle a lot less (and may even be negative) than what Bhagwati and Panagariya imagine, because improvements in health and education raise human productivity and so raise growth rates in GDP. The authors are exasperated with the patience the country's poor have displayed while waiting for better times, so the concluding chapters of their book are on the role deliberative democracy could play in stirring the electorate into action.[2]

1.2 Absent Nature

Despite the vastly contrasting readings of the Indian experience, the analyses in the two books are based on a shared belief, one that is hallowed by tradition but should now be acknowledged to be utterly misconceived. They are built on a model which presumes that in any institutional setting, a combination of labour (more broadly human capital), knowledge, and reproducible capital is the basis of production, exchange, and consumption. Nature doesn't get a look in except as a bit player, nor is there a possibility that population pressure could contribute via habitat destruction to the persistence of poverty and hunger.

Nature is life's support and promoting system, but orthodox development thinking is oblivious of its role as a capital asset. When the absence is noticed, those who advocate the priority of GDP growth in development policy say that nature is a luxury that can wait to be taken care of until the economy generates sufficient incomes. Intellectual support for the viewpoint was offered in the World Bank's *World Development Report 1992*, where the authors used data on air quality in urban sites to conclude that there is a U-shaped relationship between GDP and environmental quality. The relationship was christened, inevitably perhaps, as the "environmental Kuznets curve". The problem is, air quality is able to carry very little of nature's load. Air particulates blow away to other places within days, whereas a broken reef would take centuries to recover. Damage to natural capital is all too frequently irreversible. That is why as a metaphor for development prospects the environmental Kuznets curve should be rejected.[3]

An entirely novel justification for excluding natural capital from economic models has been put forward implicitly by Dreze and Sen. They write (p 42), "(i)f development is about enhancing human freedoms and the quality of life...then the quality of the environment is bound to be part of what we want to preserve and promote". The authors would appear to regard that truth to be a licence to ignore the economics of the natural environment. Devoting all of three pages to sustainable development, their remarks on the subject don't go beyond what is to be found routinely in Sunday supplements. They say, for example, that the Indian government has a plan to construct

more than 600 dams on the Ganges and its tributaries. The authors don't like it, but don't tell us why, other than that there would be adverse environmental consequences. In a book that contains 35 pages explaining why education is good for us, readers should expect a paragraph or two explaining why dams are bad for us. The reasoning would seem to be that because nature is vital to the development of human capabilities, its worth is so deeply embodied in the value of those capabilities that it doesn't require unearthing.[4]

To state the position is to see what is wrong with it. It's all well and good to write eloquently, as Dreze and Sen do, about the role deliberative democracy can play in furthering economic development, but of what instrumental use is it if the basis on which citizens deliberate is innocent of the role a degraded nature plays at the poverty, population, and environment nexus? There are trade-offs between pretty much all we do and strive to be. They include trade-offs between goods and services, which have to be assessed if one is to conduct economic evaluation. How else are we to judge whether draining a wetland to make way for a shopping mall is likely to promote human capabilities in the future, or whether cutting down upstream forests for timber and minerals is worth the heightened risk of severe floods downstream?

GDP is incapable of recording those trade-offs. Recall that GDP is the market value of the flow of final goods and services in a year. The rogue word in the acronym is "gross", which means that the depreciation of capital assets isn't counted. If the wetland is drained to make way for the mall, the construction of the latter contributes to GDP but the destruction of the former goes unrecorded. Intuition tells us that if the social worth of the mall were less than the social value of the wetland, the economy's productive base would decline, which would then have adverse consequences for the current and future generations (we confirm the intuition in Section 3 and Appendix 1, p 51). But GDP would signal otherwise. The seemingly more humane Human Development Index (HDI) of the United Nations misleads in the same way. An economy's GDP could be made to grow and its HDI made to improve for a time by "mining" natural capital (decimating forests, damaging soil, destroying fisheries, depleting rechargeable aquifers, reducing biodiversity). The good times couldn't go on forever though, because no economy can survive without natural capital. So both GDP and HDI would decline in due course. GDP does have an important role in economic analysis and policy (Appendix 2, p 51), but not as a welfare index.

1.3 Environmental Externalities

Bhagwati and Panagariya see government restrictions everywhere and Dreze and Sen can't take their eyes off health and education; but it's hard for some of us not to help noting also the pervasiveness of *externalities*, which are the unaccounted for consequences for others (including future people) of decisions made by each one of us on reproduction, consumption, production and use of the natural environment. In recent years the externalities present in the chain linking poverty, population growth, and degradation of the local natural-resource base in poor countries have been studied both theoretically and empirically. None of the three factors has been found to be a direct cause of the others; rather, each would appear to influence and be in turn influenced by the others. For example, a deterioration in the way a community manages the local woodland and water source or the way the government adjudicates property rights over forest land may mean an increase in the need for "hands" in each household, which then puts further pressure on the woodland and water source; and so on, in a cycle. Empowering women and expanding education certainly help to reduce fertility, but the externalities or spillover effects just alluded to are a potent presence.[5]

Over the past few decades a number of economists have worked to introduce nature into economics in a seamless way. It has required of them to rework the economics of the household, communities, and other non-market institutions, recast national accounting, reconstruct the theory of macroeconomic development and public and trade policy, and revise the theory of collective action. The literature integrates development and environmental economics.[6]

Studies have uncovered connections between the spatially-localised persistence of rural poverty in the Indian subcontinent and the habitat destruction accompanying growth in GDP and population. The socio-environmental processes defining those links have been found to depend on the site and context. That means to borrow lessons from the development experience at one site, let alone one country, in order to inform policy in another is unreliable. The processes have been found also to be non-linear, in many cases significantly so. That in turn means such linear extrapolations of empirical data, as in the claim that "every 1 per cent increase in GDP per head reduces poverty by around 1.7 percent" (*The Economist*, 1 June 2013: 24), are misleading. It also means that the processes can harbour tipping points that portend a collapse of the natural resource-base and a sudden dramatic reduction in a community's economic prospects. The sources of such catastrophes can be population pressure and unprotected property rights over fragile resources. Imagine what would happen to a city's inhabitants if the infrastructure connecting it to the outside world were to break down without notice. Vanishing sources of water, deteriorating grazing fields, desiccated slopes, wasting mangroves, and bleached coral reefs are spatially confined instances of a corresponding breakdown among the rural poor. Civic strife and migration are often related phenomena. As the literature is informed by theory and increasingly validated by empirics, there is now cause to revise the orthodox view of economic life in both the small and the large.[7]

This new literature has also increased our understanding of the strengths and limitations of collective action, household attitudes toward risk, and a number of salient socio-environmental processes (for example, the dynamics of open-access resources). Space forbids discussing them further. My aim here is a lot more limited. It is to review the way the literature has reconstructed the foundations of economic evaluation. In what follows, readers could interpret an "economy" alternatively as

a household, a village, a community, a district, a state, a nation, or indeed the entire world. But data are often compiled and published at the national level. So, when I come to report an empirical study on sustainable development, the economy is taken to be a nation, namely, India.[8]

1.4 Nature as a Regenerative Asset

Contemporary models of economic growth and development regard nature to be a fixed, indestructible factor of production (Barro and Sala-i-Martin 2003; Helpman 2004). The problem with the assumption is that it is wrong. Nature is a mosaic of degradable assets. Agricultural land, forests, watersheds, fisheries, freshwater sources, estuaries, wetlands, the atmosphere – more generally, *ecosystems* – are assets that are self-regenerative, but can suffer from deterioration or depletion through human use. (Oil and natural gas are at an extreme; they are non-renewable.) The term "self-regenerative" shouldn't be taken to mean that natural resources regenerate in isolation when left untouched by humans. Nature, or *natural capital*, is an interconnected body of assets undergoing change over time in size and character. The regenerative capacity of one depends on the mosaic of which it is a part. The processes driving those changes differ in spatial scales, operate at different speed, and are almost invariably non-linear. It should be no cause for surprise that nature is "complex".

Human activities affect nature's processes just as nature's processes influence the options we humans face and the choices we make. The mutual influence is so powerful today that to many scientists, talk of "nature's processes" makes little sense. To them "socio-environmental processes" is a more appropriate term. A few broad principles are understood, but the Devil lies in the details; and the details affect the daily lives of households everywhere. Substitution possibilities between reproducible capital and human capital, on the one hand, and vital forms of natural capital, on the other, become increasingly limited as the latter dwindles in size and quality (Ehrlich and Goulder 2007). Unfortunately the cost of recovering those dwindling assets also increases, which is another way of saying that the processes suffer from hysteresis (worse, irreversibility). This is as true of village waterholes and mangrove forests as it is of carbon concentration in the atmosphere.

Some ecological stresses are global, while many are spatially localised; some occur slowly and may therefore miss detection until it's too late, while others are all too noticeable and a cause of persistent societal stresses. That may be why there is tension among the senses of urgency people express about carbon emissions and acid rains that sweep across regions, nations, and continents; on the stresses communities face when grasslands transform into shrub-lands; and on declines in firewood, biodiversity, water sources, and soil productivity that are specific to the needs and concerns of the poor in small, village communities.

Because socio-environmental processes are imperfectly understood, environmental problems present themselves in different ways to people. Some identify environmental problems with population growth, while others identify them with wrong sorts of economic growth; then there are those who view the problems through the spectacle of poverty in poor countries. Each of those visions is correct. There is no single environmental problem; there is an innumerable collection of them.

2 Natural Capital

Why are environmental externalities pervasive and quantitatively significant? One reason is that property rights to prominent classes of natural capital are difficult to define and enforce (forest patches, open seas). By property rights I mean not only private rights, but communitarian and public rights too. And one reason property rights are difficult to define, let alone to enforce, is natural capital's tendency to move. The wind blows, particulates diffuse, rivers flow, fish swim, birds and insects fly, and even earth worms are known to move. In extreme cases the market price of natural capital is nil even when they have considerable social worth. "Green" taxes would be a way to close the difference.

The gap between the market price and social worth of natural capital has meant that technological innovations are biased against nature. Entrepreneurs, understandably, seek innovations that economise on expensive factors of production, not those that are cheap. It should be no surprise then that modern technology has proved to be rapacious in its use of nature's services. In the absence of green taxes, public subsidy for the development of green technologies is a straightforward implication of this reasoning (Dasgupta 2004).

Natural capital is of direct use in consumption (fisheries), of indirect use as inputs in production (oil and natural gas; ecosystem services), and of use in both (air and water). The value of natural capital can be "utilitarian" (as a source of food or as a keystone species – many economists call it "use-value"); it can be aesthetic (places of scenic beauty), religious (sacred groves), intrinsic (primates); or it may be all those things (biodiversity). Their worth to us could be from extraction (timber, gum, honey, leaves and barks, fish) or from their presence as a stock (forest cover, marshes, and reefs), or from both (watersheds). The stock could be an index of quality (air quality) or quantity. Quantity is sometimes expressed as a pure number (population size); in various other cases it is, respectively, (bio)mass, area, volume, depth. Even quality indices are often based on quantity indices, as in "parts per cubic centimetres" for measuring atmospheric haze.

The above classification is useful in economic evaluation because it is based on the reasons we value nature. For understanding the changing landscape in contemporary economies, however, the classification in MEA (2005a-d) is more useful. Natural capital was classified in those publications in terms of the kinds of services they provide. Moreover, the focus was on ecosystems.[9]

2.1 Valuing Ecosystems

Apart from fisheries as sources of fish and forests as sources of timber, ecosystems have until recently been neglected by environmental and resource economists and national income statisticians. An ecosystem is a complex of the a-biotic

environment and plant, animal, fungi, and microorganism communities, interacting as a functional unit. Among the visible products of ecosystems are food, fibres, fuel, and freshwater, but many remain hidden from view. Ecosystems maintain a genetic library, preserve and regenerate soil, fix nitrogen and carbon, recycle nutrients, control floods, mitigate droughts, filter pollutants, assimilate waste, pollinate crops, operate the hydrological cycle, and maintain the gaseous composition of the atmosphere. As those services aren't visible, it is all too easy to overlook them.

Ecosystems offer joint products. Wetlands recycle nutrients and purify water; mangrove forests protect coastal land from storms and are spawning grounds for fish; and so on. Unhappily, social tensions arise in those many cases where an ecosystem has competing uses (farms versus forests versus urban development; forests versus agro-ecosystems; coastal fisheries versus aquaculture). Ultimately, a balance has to be struck among those demands, but the balance that's struck needs to be informed of the unseen benefits human societies enjoy from natural capital. That is why economic evaluation is a vital exercise. A much-publicised example of informed public discussion is the one that took place on the Catskill watershed in New York State, which operates as a natural filter, providing drinkable water to New York City. By the early 1990s, urbanisation upstream had degraded the watershed to an extent that the city's water supply was found to be deteriorating. Purifying the water by means of a filtration system (reproducible capital) would have cost 6-8 billion dollars. Restoration of the watershed (investing in natural capital), which was the chosen alternative, cost 1-1.5 billion dollars. This was a case where the ecosystem could be revived at a relatively low cost. Many other cases, such as large-scale destruction of coral reefs, are to all intents and purposes irreversible.

Because ecosystems are a mosaic of natural resources, the scope of an ecosystem is fashioned by the problem being studied. Some have an extensive reach ("biomes", such as the Savannah), there are those that cover regions (river basins), many involve clusters of villages (micro-watersheds), while others are confined to the level of a single village (the village pond). In each example there is an element of indivisibility. Divide an ecosystem into parts by creating barriers, and the sum of the productivities of the parts will typically be found to be lower than the productivity of the whole (other things being equal of course). The tropics house some of the most fragile ecosystems. MEA (2005a-d) provided an account of the stresses being experienced currently by both global and local ecosystems. Of the 24 that were investigated for the report, 15 were found to be either degraded or used in an unsustainable way.

The social worth of a piece of natural capital is its shadow price, familiar in cost-benefit analysis. An asset's shadow price is the present discounted value (PDV) of the flow of social benefits from the services it is forecast to provide. Measuring shadow prices thus requires (i) an understanding of the relevant socio-environmental processes (the dynamical system), (ii) knowledge of the size of assets (initial condition), and (iii) a conception of social well-being (ethical values). Here we focus on cases where the PDV is the sum of the asset's market price and the externalities arising from its use. If the market price is zero, the entire burden of estimating shadow prices falls on quantifying the relevant externalities.

By *social well-being* in this article I mean a numerical aggregate that is built on individual well-beings but reflects in addition not only fairness in the allocation of goods and services among members of any given generation, but also among members of different generations. The conception is thus responsive to both intra- and inter-generational efficiency and intra- and inter-generational equity.

Social well-being is sometimes referred to as "aggregate well-being", to highlight the special case where it is the weighted sum of individual well-beings (e g, as in total utilitarianism). Policy analysis is usually undertaken in terms of an aggregate measure. That is why, when introducing the idea of sustainable development I work with an aggregate (Propositions 1-2). Later in Section 3, however, I show that sustainability analysis invites us to work with social well-being, averaged over people across the generations (e g, as in average utilitarianism; see footnote 15). The move has no bearing on policy analysis (e g, project evaluation) if population forecasts are independent of marginal changes in policy, but otherwise it has a deep significance even there. Propositions 3-6 are cast in terms of the average measure of social well-being.

Requirements (i)-(iii) tell us that estimating shadow prices involves comparing hypothetical perturbations to an economy to the status quo, as in the question, "What would the contribution to social well-being be if an extra unit of an asset were made available to the economy free of charge?" That means shadow prices can't be calculated merely on the basis of the shape of things to come; the exercise also requires forecasts of the shapes of things that would come if the current portfolio of assets were to be otherwise. Forecasts therefore require thinking through counterfactuals. Good forecasts are no mere guesses. Conditions (i)-(ii) are the key to economic forecasts. Condition (iii) has a separate, though related status; it enables the evaluator to place a value on perturbations.

Shadow prices simultaneously reflect the asset trade-offs an economy would face if social well-being were to be held fixed. Which is why deriving shadow prices is one of the hardest empirical problems in economics. Shortcuts have been tried – by soliciting people's willingness to pay for conserving natural capital (the "stated preference" approach), studying how much people actually pay to enjoy their services (the "revealed preference" approach), and so on. Those methods are useful in the case of environmental amenities (e g, places of scenic beauty) but not of factors of production (forest cover). More empirical studies of the value of ecosystem services are now sorely needed.[10]

2.2 Pollution vs Conservation

Pollutants are the reverse side of natural capital. One way to conceptualise "pollution" is to consider the depreciation of capital assets. Acid rains damage forests; industrial seepage and discharge reduce water quality in streams and underground reservoirs; sulphur emissions corrode structures and harm

human health; and so on. The damage inflicted on each type of asset (buildings, forests, fisheries, human health) should be interpreted as depreciation. The task then is to estimate the depreciation amounts.

Corrosion of buildings and structures is frequently estimated by their replacement cost. This is an imperfect procedure. The correct way would be to estimate the loss in output owing to the corrosion. But that can prove to be hard. As another example, consider that damage to health should be estimated by (a) loss in human productivity, (b) the direct loss in well-being in experiencing pain and discomfort, and (c) reduction in life expectancy. It is fortunate for humanity that good health offers the three benefits more or less as joint products. But to the best of my knowledge, no one has estimated all three losses in studies of the damage environmental pollution causes to human health. The point remains though that there is no reason to distinguish resource management problems from pollution management problems. Roughly speaking, "resources" are "goods", while "pollutants" (the degrader of resources) are "bads". Pollution is the reverse of conservation.

The mirror-symmetry between conservation and pollution is well illustrated by the atmosphere, which is both vital for human activity and a sink for pollutants. The atmosphere is a public good (if air quality is improved, we all enjoy the benefits, and none can be excluded from enjoying the benefits). It is also a common pool for pollution. That it is a public good means the private benefit from improving air quality is less than the social benefit. Without collective action there is underinvestment in air quality. In contrast, as the atmosphere is a common pool into which pollutants can be deposited, the private cost of pollution is less than the social cost. Without collective action, there is an excessive use of the pool as a sink for pollutants. Either way, the atmosphere suffers from the "tragedy of the commons".

3 Economic Evaluation

Economic evaluation isn't a prerogative of people fortunate enough to live in well-ordered societies. Even in the most dysfunctional of polities there are concerned citizens who would like to weigh matters sympathetically, but judiciously, before assessing the performance of their economy and arriving at a view on what policies should be pursued. The theory I develop below accommodates such people. There is no presumption that the world they inhabit functions equitably or efficiently.

I shall refer to the person doing the evaluation as the "social evaluator". The social evaluator could be a citizen (thinking about things before casting her vote on political candidates), he could be an ethicist employed by government to offer guidance, she could be a public servant, and so on.

Economic evaluation involves comparing perturbations to an economy to the status quo (called "business as usual"). It comes in two forms: *sustainability analysis* and *policy analysis*. What are they and how do they differ?

An object is "sustained" when it doesn't diminish over time. So, sustainability analysis involves evaluating the change an economy undergoes across the passage of time. This is to be contrasted with the more familiar policy analysis (e g, project evaluation), which involves evaluating the perturbation to an economy caused by a policy change (e g, an investment project) at a moment in time. In what follows I don't specify the ethical basis of economic evaluation. The idea of social well-being, introduced earlier, has a wide reach. The social evaluator could be someone wedded to one of a wide variety of utilitarian theories, or to an empirical notion of happiness, or to a theory that pays particular attention to human rights, and so on. I want to keep the interpretation of social well-being unspecified because the foundations of sustainability and policy analysis don't depend on it.

3.1 Sustainable Development

In his interview in the August 2013 Issue of *Prospect* magazine, Amartya Sen asked, "Is growth inescapably damaging to the environment?" and mused, "I don't think so". Fortunately, we have the required grammar for going beyond speculation.

World Commission (1987), commonly known as the Brundtland Commission Report, defined "sustainable development" to be "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Stated another way, the requirement is for each generation to bequeath to its successor at least as large a productive base, relative to their populations, as it had itself inherited.

The requirement is derived from a relatively weak notion of social well-being. 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?

An economy's productive base is a means to protecting and promoting well-being across the generations. What we want is a measure of the base whose movements over time mimic those of social well-being. It transpires 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 call the total worth of assets, *wealth*.

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

$$W(t) = {}_i\Sigma[P_i(t)K_i(t)] \qquad \ldots(1)$$

$W(t)$ is the economy's wealth at t.[11]

If an economy's institutions are weak or simply bad, the shadow prices of those same assets would be small, and that 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 go to define wealth.

Identifying assets is no simple matter. The social evaluator is 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. As equality in the distribution of well-beings among contemporaries is a desired objective of social policy, assets should be identified also 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 social well-being constant, they provide the required link between an economy's productive base and well-being across the generations. It would mean that the shadow price of a property belonging to someone poor is 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 has proved to be 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 inequalities across the generations and include a separate index of inequality among contemporaries. The Gini coefficient of wealth inequality suggests itself.

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

$$\Delta W(t) = {}_i\Sigma P_i(t)\Delta K_i(t).^{12} \qquad \ldots(2)$$

Let $V(t)$ be an 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 social 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 $\Delta V(t)$. In Appendix 1 it is shown that

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

Equation (3) can be summarised as

Proposition 1: Social well-being increases during a short interval of time if and only if wealth increases.

The Proposition says that if we interpret sustainable development to require that social well-being shouldn't decline over time, we should be asking whether wealth is increasing and is likely to increase in the future.[13] 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 such aggregate indices as HDI are ad hoc; they aren't rooted in any well-defined notion of social well-being. That is why they are of no use in the study of sustainable development.[14]

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

Proposition 2: Social well-being increases during a short interval of time if and only if aggregate consumption does not exceed net domestic product.

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.

3.2 Population Growth

Even though Propositions 1-2 are intuitively appealing, they have a disquieting feature. Imagine that wealth grows at 1% a year while 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 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 and interpret the Propositions accordingly, which is how Propositions 1 and 2 should be read. Another way is to reconstruct social ethics in terms of the well-being of the average person across the generations.[15]

Fortunately under certain simplifying assumptions Proposition 1 can be reconstructed in terms of wealth per capita.

Proposition 3: Social 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.[16]

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

Proposition 4: Social well-being increases during a short interval of time if and only if consumption per head does not exceed net domestic product per capita.

Even though they are only approximations to Proposition 1, Propositions 3 and 4 are 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 by *intra*-generational inequality we should mean inequality in the distribution of wealth, not income; and by poverty a paucity of wealth, not low income. The aim shouldn't be to *maximise* the rate of wealth accumulation; it should be to *optimise* 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. By a judicious choice policy it may be possible to accumulate wealth *per capita* and enjoy modest increases in GDP per head for a while. Only further work in wealth accounting will show whether that is the case today. The empirical work on sustainable development reported in Section 4 is suggestive of the possibility.

3.3 Policy Analysis

Policy analysis (e g, 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 they 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

$$\Delta W(t) = {}_i\Sigma[P_i(t)\Delta K_i(t)]. \quad \ldots(4)$$

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 ($\Delta K_i(t) < o$ in the activity from which i is to be displaced, and $\Delta K_i(t) > o$ 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. That could seem odd, in as much as the conventional criterion for evaluating investment projects is the PDV of the flow of social profits. But it can be shown 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.[17]

Proposition 5 is intuitively appealing. Being 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 correspondingly the assets that have been inherited from the past are so deployed in an optimising economy 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 social well-being is at the heart of normative development economics.

3.4 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, it gives rise to an additional flow of consumption, the present discounted value of which can be realised in the market. And third, the good can be alienated (transferred to another individual) with no change in value.[18]

For economic evaluation this is too narrow a point of view. Propositions 1-5 tell us that by assets we should mean the state variables of the socio-environmental processes driving the economy. Health and education possess the first two features but not the third. That may be why neither is regarded as an asset in national accounts, where they appear as consumption expenditure. 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. Leaving aside questions of aggregation, the social evaluator faces a choice. It may, for example, seem natural to regard "knowledge" to be an asset (as in "knowledge capital"). But if knowledge is an output of domestic Research and Development (R&D), the capital inputs in R&D (scientific equipment, human capital) could substitute for knowledge itself. In contrast, suppose 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, otherwise known as the "residual", which is the portion of GDP growth that cannot be accounted for by growth in the factors of production in use. Note though that the residual is a mathematical transform of the passage of time, which means time itself is an asset. If that seems non-intuitive, an alternative would be to embed knowledge in the quality of other assets and measure the latter in efficiency units. In theory it makes no difference which route is 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), knowledge (the arts, humanities and sciences), and natural capital (ecosystems, sources of water, the atmosphere, land, sub-soil resources). In Section 4 we make use of this classification.

3.5 The Idea of Investment

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

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

When applied to Proposition 3, equation (5) reads as

Proposition 6: Social well-being averaged over people across the generations increases if and only if investment per head, adjusted for the distribution of investment across contemporaries, is positive.

If Proposition 6 reads oddly, it is 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 levelling the ground and tarmac being laid. 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.[19]

That suggests 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, it enables them also to be more productive in the future and to live longer. Because their human capital increases, the additional food intake should count also as investment. Note though that food intake by the well-nourished doesn't alter their nutritional status, which means 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. This 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. Such expenditure enters 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 in a given year it invests 40 billion dollars in reproducible capital, spends 20 billion dollars on primary education and healthcare, and depletes and degrades its natural capital by 70 billion dollars. The economy's System of National Accounts (SNA) would record the 40 billion dollars as investment ("gross capital formation"), the 20 billion dollars as consumption, and remain silent on the 70 billion dollars of loss in stocks of natural capital. Proper accounting methods in contrast would reclassify the 20 billion dollars as expenditure in the formation of human capital ("investing in the young", as the saying goes) and the 70 billion dollars as depreciation of natural capital. Aggregating them and assuming that expenditure on education is a reasonable approximation to 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 dollars; and that's before taking note of 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 programme of accumulation can be sustainable and be a burden on the current generation.

3.6 Trade, Externalities, and Wealth Transfers

Proposition 3 tells us also to curb our enthusiasm for free trade in a distorted world.[20] 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 stabilise both soil and water flow and are a habitat for insects and birds (in the words of MEA (2005a-d), these are "regulating services"), deforestation erodes soil and increases water run-off downstream and reduces pollination and pest control in nearby farms. If the law recognises the rights of those who suffer damage from deforestation, the timber company would 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, their geography matters. Moreover, downstream farmers may not even realise that the decline in their farms' productivity is traceable to logging upstream. The timber company's operating cost would in those circumstances 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 straightened circumstances. The subsidy is hidden from public scrutiny, but Proposition 3 says that it amounts to a transfer of wealth from the exporting to the importing country. Ironically, some of the poorest people in the exporting country would be subsidising the incomes of the average importer in what could well be a rich country. That can't be right. Compensation to downstream farmers, financed by a (Pigouvian) tax on timber harvests would be the right policy.

4 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 UNU-IHDP/UNEP (2012) have made 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.

4.1 Wealth in India: Estimates

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.[21] The choice of countries was in part designed to reflect different stages of economic development and in part to focus on particular resource bases. Because of an absence of data, the authors didn't study wealth inequality within countries. In what follows I summarise the steps they took to enquire 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)-(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)-(3)); and natural capital (row (4)).

Table 1: Per Capita Wealth and Its Growth in India (1995-2000; 2000 $)

	1995 Stock (1)	2000 Stock (2)	Change (1995-2000) (3)	Growth Rate (% Per Year) (4)
(1) Reproducible capital	1,530	2,180	650	7.30
(2) Human capital, 1 (education)	6,420	7,440	1,020	3.00
(3) Human capital, 2 (health)	5,00,000	5,03,750	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	5,10,250	5,15,650	5,170	0.20
(8) TFP				1.84
(9) Wealth per capita				2.04

Source: Arrow et al (2012), Table 5 (modified).

The value of reproducible capital in 1995, amounting to $1,530 per head, was calculated from government publications on past capital investments. The implicit assumption was that prices used by the government to record expenditures are reasonable approximations of shadow prices. Using the methods summarised in Klenow and Rodriguez-Clare (2005), the value of education per person ($6,420) was 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 labour productivity and current well-being. For that reason the authors studied longevity only. Its shadow price was 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 VSL in India is approximately $5,00,000. Arrow et al (2012) showed that under a set of simplifying assumptions VSL equals the value of health per person (row (3), column (1)). They then estimated the value of a statistical life-year and used that to value the increase in life expectancy between 1995 and 2000 (row (3), column (2)).

Four categories of natural capital were 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 was interpreted to be an "enabling" asset, which is why it is excluded from columns (1) and (2) but included in the estimate of the change in wealth over the five year period.

The value of land was taken from World Bank (2011). Using market prices for timber and oil and minerals, the shadow value of natural capital in 1995 was estimated to be $2,300 per person (row (4), column (1)). Because of the lack of relevant data, the figure 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. Adding the figures, wealth *per capita* in 1995 was found to be $5,10,250 (row (5), column (1)).

Population in India grew at an average annual rate of 1.74%. Column (3) records changes in *per capita* capital stocks over the period in question; and column (4) presents the corresponding annual rates of change. The former is embellished by two factors. Firstly, 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, which was calculated to be $140 per person (row (5), column (3)). Secondly, during 1995-2000 global carbon emissions into the atmosphere was over 38 billion tonnes. At current levels of concentration (380 parts per million in 1995) carbon is a global "public bad". The theory of public goods says that the loss to India over the period would have been global emissions times the shadow price of carbon specific to India. In their base case Arrow et al (2012) took the global shadow price to be minus $50 per tonne. Using the estimates of Nordhaus and Boyer (2000), the loss to India per tonne of carbon emissions was taken to be 5% of the global shadow price, which is minus $2.50. This amounted to a loss per person of $90 (row (6), column (3)).

Row (7) records the change in wealth *per capita* in India over the period 1995-2000. It translates to 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) modelled the latter as "enabling assets" and interpreted improvements in them as growth in total factor productivity (TFR), which in India has been estimated to be 1.84% a year (row (8)). Based on a formula the authors derived for including the residual in wealth calculations, row (9) records the annual rate of growth of wealth per head in India during 1995-2000 as having been 2.04%.

4.2 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 20th century. It is as well to highlight the most striking:

(1) Of the four types of capital comprising measured wealth, reproducible capital is the smallest. Even though the value of natural capital in both years is in all likelihood a serious underestimate, it was considerably greater in 1995 than reproducible capital.

(2) The rapid growth of reproducible capital (7.30% a year), as against a 0.15% annual rate of decline of natural capital meant that by 2000 their stocks were pretty much the same.

(3) In 1995 human capital in the form of education was over four times that of reproducible capital. But the ratio declined over the five-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 of the study 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 reproducible capital. There was no basis for a prior expectation of what the finding would be once health was placed in the same normative footing as other forms of wealth. Health dominates because of the high figure for VSL reported in the empirical literature. Longevity matters to people everywhere and matters greatly. In democratic societies that should count.[22]

(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 scepticism, because they are based on models that

don't include natural capital as factors of production. If natural capital were to decline 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 as increases in knowledge and improvements in institutions. Worse still, the greater is the under-coverage of natural capital, the greater is the bias in the estimate of TFP growth. By plundering Earth TFP could be raised by as much as the authorities like.

5 Green National Accounts

The literature I have sketched in this paper has revealed that the entire architecture of contemporary growth and development economics is stacked against nature. No matter where you look in official models of economic 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 realise 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 have 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 probably a serious underestimate. When national accounts are better prepared, health and natural capital will in all probability be found to be much 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. Kumar (2010) is a pioneering set of studies on the value of ecological services, and in a remarkable research programme called the Natural Capital Project, Gretchen Daily of Stanford University and Steve Polasky of the University of Minnesota are jointly directing the mapping and valuing of ecosystem services in a large number of sites in the world. 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 non-timber forest products), Ferraro et al (2011) have found 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 one of uncertainty about the role natural capital plays in production and consumption possibility, it is 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 in the foreseeable future wealth estimates should be attempted only at the sector level (as in rows (1)-(4) in Table 1), and that too within bands; they 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.

NOTES

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1 An example is the recent interchange between Jagdish Bhagwati and Amartya Sen, in their letters to *The Economist* on 13 and 20 July 2013, respectively. Both refer to economic growth without finding it necessary to explain that they mean growth in GDP.

2 A mistake is to claim that in contrast to the views of Dreze and Sen, the ones put forward by Bhagwati and Panagariya are "right-wing". The mistake is made by Lawrence Haddad, Director of the Institute of Development Studies, Sussex, in his blog in July 2013. Authors of both books are anxious to discover the best route to *long-term* development. The pairs differ in their assessment of what that route should be. To invoke a "left-right" distinction in this context is sophomoric.

3 For an early questioning of the environmental Kuznets curve, see Arrow et al (1995). For a questioning of the statistical fit of even air quality and GDP, see Stern (2004). Bhagwati and Panagariya do not appeal to any such curve for justifying their neglect of natural capital. In developing their Track I and Track II sequence theoretically, they assume the various layers of government are taking account of environmental matters (Preface: xvi). But when applauding the structural reforms in India since the early 1990s, they don't ask whether their assumption is justified. I return to this issue in Section 3.4.

4 In a response to a reprint in Brad DeLong's blog of 27 July 2013, of passages from my review (Dasgupta 2013) of the Bhagwati-Panagariya and Dreze-Sen books, Ashok Rao stated the position explicitly. He wrote that as Dreze and Sen are concerned with extreme poverty and human development, they "...certainly address the environmental and social sustainability of growth". Rao also found ecology to be "a recurrent motif", in a book that says nothing

about ecology nor how we are to measure the worth of ecosystems in supporting and promoting life.

5 Dreze and Sen do touch upon externalities (pp 90-94), but only in connection with the consequences of mining and burning coal, and with the dangers posed by nuclear reactors.

The temptation to overreach when publicising one's views would seem to be irresistible. In an interview published in the August 2013 issue of *Prospect*, a current affairs magazine in the UK, Sen said in a rejoinder to the Bhagwati-Panagariya book that he knows of "no example of unhealthy, uneducated labour producing memorable growth rates". But by the reckoning advanced in his book with Dreze, India since the early 1990s is an example: GDP growth rates in the region of 6-8% a year over a 20-year period should be regarded memorable when compared to the "Hindu growth rate" of 3.5% a year that characterised the country's performance during the four previous decades. In the interview Sen also remarked that "China's low fertility rates can be explained entirely by widespread education of girls and widespread economic independence of women". Are we to take it then that the Chinese government's "one child" policy was entirely pointless, or are we to regard the resulting bias in the gender ratio a goal of the government?

6 The empirical literature on the pairwise links between population growth, poverty, and degradation of the local natural-resource base is now substantial. See in particular Jodha (1986, 2001), Agarwal and Narain (1989), Chopra, Kadekodi and Murty (1989), CSE (1990), Ostrom (1990, 1992, 1996), Somanathan (1991), Repetto et al (1992), Baland and Platteau (1996), Cavendish (2000), Kadekodi (2004), Ghate, Jodha and Mukhopadhyay (2008), Pattanayak and Pfaff (2009) and Barbier (2010). The links between all three factors have been investigated by Chopra and Gulati (1998), Aggarwal, Netanyahu and Romano (2001), and Filmer and Pritchett (2002). Revisions to the theory of international negotiations over climate change have been made by Barrett (2003), and on national environmental policy, by Sterner (2003). For a review of the empirical literature on the population-poverty-environment nexus and the development of their theoretical underpinnings, see Dasgupta (1993, 2000, 2005, 2010). Since its inauguration in 1996, the journal *Environment and Development Economics*, under the successive editorships of Charles Perrings and Anastasios Xepapadeas, has published many of the most significant empirical studies in this field by, among others, young economists associated with the South Asian Network for Development and Environmental Economics (SANDEE).

7 On the ubiquity of non-linearity in systems involving human-nature interactions and the hysteresis (in the extreme, irreversibility) inherent in the corresponding processes, see Dasgupta (1982, 2004), Brander and Taylor (1998), Carpenter (2001), Dasgupta and Mäler (2003), Steffen et al (2004), Lenton et al (2008), and Scheffer (2009). A symposium in the *Proceedings of the National Academy of Sciences* in 2011 studied links between biodiversity loss and poverty traps in sub-Saharan Africa.

8 The discussion is based on Dasgupta (1982, 1993, 2004, 2005, 2010), Dasgupta and Mäler (1991, 2000), and Dasgupta and Ehrlich (2013). The required re-structuring of national economic accounts can be found in Repetto et al (1989), Mäler (1991), Vincent et al (1997), Hartwick (2000), Arrow, Dasgupta, and Mäler (2003a, b), UNU-IHDP/UNEP (2012), and the Report submitted by an Expert Group convened by the Government of India, on greening India's National Accounts (Anant et al 2013). The case study I summarise in Section 4 is taken from Arrow et al (2012).

9 Theirs is a four-way classification of ecosystem services: (i) provisioning services (food, fibre, fuel, fresh water); (ii) regulating services (protection against natural hazards such as storms; the climate system); (iii) supporting services (nutrient cycling, soil production); and (iv) cultural services (recreation, cultural landscapes, aesthetic or spiritual experiences). Notice that cultural services and a variety of regulating services (such as disease regulation) contribute directly to human well-being, whereas others (soil production) contribute indirectly (by providing the means for growing food crops). Bateman et al (2013) have used this classification to study the changing patterns of UK's landscape.

10 On eliciting people's preferences over environmental resources from, respectively, what they say in response to questions asked of them and from what they are observed to do, see Smith (1997) and Freeman (2002). Haque, Murty and Shyamsundar (2011) is an excellent collection of studies on valuation of ecosystem services. Barbier (2000), Pattanayak and Butry (2005), Das and Vincent (2009), Kumar (2010), and Kareiva et al (2011) are pioneering studies estimating the value of ecosystem services that are inputs in production. However, in two reviews of the literature, Pattanayak and Pfaff (2009) and Ferraro et al (2012), conclude that we are still far from understanding even apparently simple human-nature interactions. For further empirical studies, see various issues of *Environment and Development Economics*. A key characteristic of ecosystems is their biodiversity. For a comprehensive account of the ecology and economics of biodiversity, see Perrings (2014).

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

12 $P_i(t)$ is held constant in the formula because by definition it is a measure of the value of a unit change in $K_i(t)$.

13 Equation (3) represents the equivalence between changes in wealth and social well-being, respectively, 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).

14 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) has shown that under the version of HDI proposed in UNDP (2010), the value of longevity in Zimbabwe is 0.51 dollars per year. That means if Zimbabwe's authorities were to make a policy change that increases national income by a mere 0.52 dollars per person per year at the cost of reducing average life expectancy by one year (other things remaining the same), the country will have promoted human development. That simply can't be right.

15 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 where δ (≥ 0) is the rate at which future U's are discounted and social well-being at date t is taken to be

$V(t) = {}_t\int^{\infty}[\sum_j U_j(s)\exp(-\delta(s-t))]ds.$

Then social well-being averaged over people across the generations would be

$V(t)/\{{}_t\int^{\infty}[N(s)\exp(-\delta(s-t))]ds\} = {}_t\int^{\infty}[\sum_j U_j(s)\exp(-\delta(s-t))]ds/\{{}_t\int^{\infty}[N(s)\exp(-\delta(s-t))]ds\}.$

16 For proofs of the equivalence, in increasing generality, see Hamilton and Clemens (1999), Dasgupta and Mäler (2000), Dasgupta (2004, 2009) and Arrow, Dasgupta and Mäler (2003a, b). The technically minded reader will know that averaging social well-being over people across the generations does not change the formulation of intergenerational ethics that is generally in use in policy analysis (e g, Chakravatry 1969). But it makes a difference, for the better, in sustainability analysis.

Wealth is the dynamic counterpart of income. The welfare significance of national income was explored by Hicks (1940), Samuelson (1961), Mirrlees (1969), and Sen (1976), among many others. As the authors confined themselves to perturbations of timeless economies, their findings have no empirical import. Only Samuelson addressed the problems a dynamic economy poses for the national accountant. In the final page of his article Samuelson speculated that something like a wealth index is needed for economic evaluation, but provided no argument.

17 For details see Dasgupta (2004: Appendix).

18 I am grateful to Kenneth Arrow for discussions on the idea of capital.

19 What we are calling "net investment" has been called "genuine saving" by Hamilton and Clemens (1999) and "inclusive investment" by UNU-IHDP/UNEP (2012). Note also that 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.

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

21 UNU-IHDP/UNEP (2012) used the same framework to measure wealth in 120 countries.

22 Becker, Philipson and Soares (2005) included 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.

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Appendix 1

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 $K(t)$ the vector denoting the stocks of the economy's entire set of assets. Thus we write

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

Social well-being at t depends on the productive base $K(t)$ and the socio-environmental processes that are forecast to drive the economy beyond t. Denoting the socio-environmental processes symbolically by M, we may write $V(t)$ as $V(K(t),M)$. M reflects not only the ecological processes the economy is subject to, but also the workings of institutions. If institutions are thought to co-evolve with the level of economic development, M reflects that too. In most case studies M is formulated in terms of a set of differential equations reflecting the dynamics of socio-environmental processes (for illustrations, see Dasgupta 2004: Appendix; Sengupta 2013).

For the technically minded reader, we recall the theory of dynamic programming and note that $V(K(t),M)$ is a "value function". It is a reduced form of an entire dynamical system. For constructing V the social evaluator needs to represent the socio-environmental 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.) It should be noted that there is no presumption that M is a socially optimum socio-environmental process.

For simplicity of exposition, I am supposing that the socio-environmental system under study is autonomous, implying that V is not an explicit function of t. M is a parameter in sustainability analysis, not a variable. In policy analysis M is a choice variable. Acceptance of a proposed investment project changes M ever so slightly. A sequence of acceptances amounts to a sequence of improvements to M.

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 $V(K(t),M)$ should not decline. In our notation, $V(K(t),M)$ changes by $\Delta V(K(t),M)$. Because Δ represents a small change,

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

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

$$P_i(t) = \partial V(K(t),M)/\partial K_i(t). \quad ...(A2)$$

Using equation (A2) in equation (A1) and dividing both sides of the resulting equation by Δt, yields

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

Write

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

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

Appendix 2

The Salience of GDP

In the text it was shown that GDP is not an index of social well-being. That should come as no surprise. The construction of GDP wasn't meant to serve the purposes of economic evaluation over the long run. GDP is a measure of market activity and was designed for use in a world where a significant proportion of people were unemployed and resources lay idle (Kuznets 1941). The index allows economists to estimate the gap between potential output and actual output. Moreover time series of GDP enable macroeconomists to study household and corporate behaviour. In addition, as national income is the source of government taxation, Finance Ministers are drawn to GDP forecasts. And finally, estimating depreciation and obsolescence introduces errors, which is why GDP is appealing to the national income statistician. As a criterion for evaluating short run economic policy, GDP has served admirably. However, ignoring depreciation of reproducible and human capital and degradation of natural capital is indefensible practice in economic evaluation concerning the long run.

Nevertheless, GDP is so attractive that without international cooperation it would be hard for any government on its own to abandon it as an index of economic progress. Why?

GDP is the market value of final goods and services. Those goods and services can be deployed so as to gain advantage in the international sphere. Never mind if a country enjoys a large GDP by depleting its natural capital; GDP can be (and is routinely) used by governments as a strategic weapon in a world where nations compete against one another for economic and political influence. Not only does a nation's status in the world rise if it enjoys GDP growth, high GDP enables a nation to tilt the terms of trade with the rest of the world to its advantage. History is replete with examples that demonstrate the strategic advantages of GDP growth.

The competitive advantages associated with GDP growth lead to a to-date unexplored form of the "tragedy of the commons": nations vie with one another for competitive advantage by bolstering GDP, thereby jeopardising future well-being within each of their borders. As in classic instances of the tragedy, international recognition of the wasteful nature of such a form of competition is a needed first step in shifting national economic policies toward the accumulation of wealth. National accounts shouldn't abandon GDP, but to call for GDP growth and demand sustainable development at all times is to seek two incompatible desires.