

## **The Concept of Natural Capital\***

by

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Macroeconomic models of long-run economic possibilities are for the overwhelming part built on the assumption that an economy's assets comprise (i) manufactured capital (roads, buildings, machines), (ii) human capital (health, education, skills), (iii) knowledge (the differential calculus), and (iv) institutions (the legal infrastructure, social norms of behaviour). Nature is almost always absent from the models. Accounting for Nature, if it comes into the calculations at all, is usually an afterthought to the real business of "doing economics". When pressed, we economists defend ourselves by suggesting that Nature is indeed present in macroeconomic models, but that it appears in a hidden way, as a fixed, indestructible factor of production. (The great Classical Economist, David Ricardo called that factor, "land".) The problem with viewing Nature in that manner is that it is wrong: soil, forests, watersheds, fisheries, fresh water sources, river estuaries, and the atmosphere - *ecosystems* generally - are self-regenerative, but suffer from depletion or deterioration when they are over-used. (In the extreme are exhaustible natural resources like oil and natural gas). Despite the neglect, a number of economists in recent years have been trying to include Nature into economic models in a seamless way. These Notes offer a very brief introduction to the way we have done that.

### **Classification of Natural Capital**

So as to remind ourselves that these Notes are on economic modeling, I shall refer to Nature as *natural capital*. Like manufactured capital, natural capital is of direct use in consumption (as in the case of fisheries); of indirect use, as inputs in production (timber); or of use in both (fresh water). The value of a resource is often derived from its usefulness (as a source of food, or as an essential actor in ecosystems - e.g., a keystone species); but there are resources whose value is aesthetic (places of scenic beauty), or intrinsic (primates, blue whales, sacred groves), or a combination of all three (biodiversity). The worth of a natural resource could be based on what is extracted from it (forest products, fisheries), or on its presence as a stock offering service (coral reefs, mangroves, wetlands, forest cover), or on both (watersheds). The stock may be an index of quality (air quality) or of quantity (sometimes pure numbers (as in population size); at various other times they were (bio)mass, area, volume, quality, depth, and so forth). But even quality indices are most often based on quantity indices ("parts per million").

An important type of natural capital goes by the name "ecosystem". Ecosystems provide innumerable services to us. Among the visible products are food, fibres, fuel, and fresh water, but many remain hidden from view. Among other things, 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 are not visible, it is easy to overlook them (see below). However, with some ingenuity it is possible to estimate the benefits we enjoy from them (see below).

Ecosystems offer joint products. For example, wetlands recycle nutrients and produce purified 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 developments; forests versus agro-ecosystems; coastal fisheries versus aquaculture). As natural capital is a mesh of resources, what one means by an ecosystem is usually influenced by the scope of the problem we ecological economists study. A number of ecosystems have a near global reach ("biomes", such as the Savannah), some cover entire regions (river basins), many involve clusters of villages (micro-watersheds), while others are confined to the level of a single village (the village pond). It is possible to trace the location of world poverty in part to the fact that the tropics harbour some of the most fragile natural environments. The notion of "fragility" is something to which I return (see example (iii) below).

Environmental pollutants are the reverse of natural resources. In some cases the emission of pollutants amounts directly to the depreciation of reproducible capital (corrosion of material infrastructure). In others it means a degradation of ecosystems (eutrophication of lakes). Roughly speaking "resources" are "goods", many being sinks into which pollutants are discharged (rivers, the atmosphere, and the oceans are among the sinks); while "pollutants" (the degrader of resources) are "bads". Pollution is the other side of conservation.

Ecosystems are driven by interlocking non-linear processes that run at different speeds and operate at various spatial scales. That is why ecosystems harbour multiple basins of attraction. The global climate system is now a well known example. But small-scale ecosystems also harbour multiple basins of attraction, for similar reasons. So long as phosphorus run-off into a fresh water lake is less than the rate at which the nutrient settles at the bottom, the water column remains clear. But if over a period of time the run-off exceeds that rate, the lake collapses into a eutrophic state (see example (iii) below). Usually, of course, the point at which the lake will collapse is unknown. That means the system is driven by non-linear stochastic processes.

So, flips in the capacity of ecosystems to supply useful service to us share three important characteristics: (a) they are frequently irreversible (or at best they take a long time to recover); (b) except in a very limited sense, it isn't possible to replace degraded ecosystems by new ones; and (c) ecosystems can collapse abruptly, without much prior warning. Imagine what would happen to a city's inhabitants if the infrastructure connecting it to the outside world was to break down without notice. Vanishing water sources, deteriorating grazing fields, barren slopes, wasting mangroves, and bleached coral reefs are spatially confined instances of a corresponding breakdown among the rural poor. Ecological collapse, such as the one that has been experienced in recent years in Rwanda, the Horn of Africa, and the Darfur region of Sudan, can also trigger rapid socio-economic decline.

### **Shadow Prices and Inclusive Wealth**

Recently it has been shown that the correct indicator of an economy's progress over a period of time is the change in *wealth*, normalized for population growth.<sup>1</sup> The notion of wealth here is an inclusive one. By *inclusive wealth* we mean the sum of the social worth of *all* the capital assets an economy relies on. An asset's social worth is called its *shadow price*, to contrast it from its market price, to which the shadow price may bear little relationship. Formally, *an asset's shadow price is the contribution an additional unit of it would make to human well-being.* (A pollutant's shadow price would be negative.) By human well-being we mean not only the well-being of people today, but also of those who are yet to be born. So, in order to estimate an asset's shadow price we need two pieces of information: (a) a conception of intergenerational well-being, and (b) a reasoned forecast of the economy into the indefinite future. That means shadow prices depend both on "values" and "facts". We note in passing that consumption discount rates relate the shadow prices of current and future stocks of assets.

There are cases where shadow prices can be approximated by market prices; but for most environmental resources they differ greatly from market prices. Environmental and resource economists have devised ingenious methods for estimating the shadow prices of particular types of natural capital, but there is a long way to go before we have a reasonably complete set of shadow prices with which to estimate the inclusive wealth of economies. A systematic assault on such estimation exercises should now be a priority among national and international economic

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<sup>1</sup> I have given a brief account of the argument in Dasgupta (2010). For a detailed account, see Dasgupta (2001). The publications contain references to the original literature.

organizations.

That said, we will never get shadow prices entirely "right". That's because both deep values (what value should we place on the blue whales?) and deep facts (what would be the consequences of an increase in global mean temperature by 3°C?) are involved. But that's not to say we may not be able to arrive at *ranges* of figures. For example, the shadow price of a forest in the uplands of a watershed would include, among other things, the contribution it makes to the economic well-being of farmers downstream (reducing water runoff and siltation). Pattanayak (2004) and Pattanayak and Butry (2005) have arrived at crude estimates of the contribution Malaysian forests in the uplands make to downstream farmers' economic profits.

Formally, imagine that an economy possesses  $N$  types of capital assets. Let  $P_i(t)$  be the shadow price of capital asset  $i$  and  $S_i(t)$  the stock of asset  $i$  *per capita*, at time  $t$ . Inclusive wealth at  $t$ , which I write as  $W(t)$  is:

$$W(t) = \sum_i P_i(t) S_i(t). \tag{1}$$

One can prove the following result concerning *sustainable development*:

**"Intergenerational well-being increases if and only if  $\sum_i P_i(t) dS_i(t)/dt$  is positive."**

Notice that the statement is an equivalence result. It makes clear why and how  $P_i(t)$  depends on both values and facts (items (a) and (b) above). The finding gives formal expression to the primacy of inclusive wealth in economic evaluation.

We can now appreciate how it can be that an economy accumulates wealth in the form of manufactured capital, human capital, and knowledge, perhaps even improves the character of some of its institutions, but decumulates its natural capital to such an extent that its inclusive wealth declines. But if natural capital doesn't enter national statistics, no one in the statistical office will notice that inclusive wealth has declined. They will record that GDP has increased. In the mean time, the economy will have been following an unsustainable development path. Very crude estimates of movements in inclusive wealth during the past three decades suggest that this may well have happened in the countries of South Asia (see Dasgupta, 2010).

Many people would appear to be convinced that technological advances and the accumulation of manufactures capital and growth in human capital can overcome diminutions in natural capital. But the environmental sciences tell us that the extent to which manufactured and human capital can substitute for natural capital is limited. It may have been understandable to assume that Nature doesn't need to be counted at a time when natural resources were abundant

relative to the demand that was made of them (meaning that its shadow price was small), but it isn't understandable in models of development possibilities open to the world today. The stance taken in modern growth models is questionable also because property rights to natural capital are often either vaguely defined or weakly enforced, implying that natural capital is underpriced in the market (see below). Official statistics on national income certainly give the impression that natural capital is of small importance; but official statistics are built on market prices, not shadow prices. Studies of local ecosystems suggest that if shadow prices were to be used in economic statistics, the decomposition of national income into its various components would look quite different. For example, Repetto et al. (1989), and Vincent and Ali (1997) estimated the declines in forest cover in Indonesia and Malaysia, respectively. They found that when depreciation is included, national accounts there look quite different: net saving rates are some 20-30% lower than recorded rates. In their work on the depreciation of natural resources in Costa Rica, the World Resources Institute some years ago found that the depreciation of three resources — forests, soil, and fisheries — amounted to about 10% of GDP and over a third of capital accumulation.

Distortions in the pricing of primary factors of production filter down to influence research and development. The latter in turn influences the character of technological change. Because Nature's services are underpriced in the market, innovators have little reason to economize on their use. We shouldn't be surprised when new technologies are rapacious in the use of natural capital.

### **Lack of Property Rights to Natural Capital**

The Millennium Ecosystem Assessment (MEA, 2003) classified ecosystem services into four types: (i) provisioning services (food, fiber, fuel, genetic resources); (ii) regulating services (climate, natural-hazard regulation, disease regulation); (iii) cultural services (places of recreation, sacred groves); and (iv) supporting services (nutrient cycling, soil production).

Why don't market prices reflect the social worth of those services? If natural capital really is becoming scarcer, wouldn't their prices have risen, signaling that all is not well?

The problem is that if prices are to reveal social scarcities, markets must function well. However, for many types of natural capital - most especially ecological resources - markets not only don't function well, often they don't even exist. In some cases they don't exist because relevant economic interactions take place over large distances, making the costs of negotiation

too high (e.g., the effects of upland deforestation on downstream farming and fishing activities); in other cases they don't exist because the interactions are separated by large temporal distances (e.g., the effect of carbon emission on climate in the distant future, in a world where forward markets don't exist because future generations are not present today to negotiate with us). Then there are cases (the atmosphere, aquifers, open seas) where the migratory nature of the resource keeps markets from existing - they are called "open access resources", and they experience the tragedy of the commons.

Each of the above examples points to a failure to have secure *property rights* to natural capital. We can state the problem thus: ill-specified or unprotected property rights prevent markets from forming or make markets function wrongly when they do form.

By "property rights" I don't only mean private property rights, I include communal property rights (e.g., over common property resources, such as woodlands, in South Asia and sub-Saharan Africa)) and state property rights. At an extreme end are "global property rights", a concept that is implicit in current discussions on climate change. But the concept isn't new. That humanity have collective responsibility over the state of the world's oceans used to be explicit in the 1970s, when politicians claimed that the oceans are a "common heritage of mankind".

The failure to establish secure property rights to natural capital typically means that the services natural capital offers us are underpriced in the market, which is another way of saying that the use of Nature's services is implicitly subsidized; which is yet another way of saying that shadow prices exceed their market prices. At the global level what is the annual subsidy? One calculation suggested that it is 10% of annual global income. My reading is that the margin of error in that estimate is very large. But it's the only global estimate I have come across. MEA (2003) and Hassan, Scholes, and Ash (2005) contain quantitative information that could be used to generate more reliable estimates of nature's subsidies. International organizations such as the World Bank have the resources to undertake that work. But they have so far been reluctant to do so.

### **Formal Models**

It may help to have a formal account of the way economists work with models of natural capital.

Formally, let  $S(t)$  denote the stock of a particular type of natural capital at time  $t$ . Suppose that the natural regenerative rate of the stock is  $H(S)$ , so that at time  $t$  it is  $H(S(t))$ . As natural

capital comprises an interactive set of natural resources, the regenerative rate of  $S$  in most cases is a function of the stocks and flows of other capital assets, not just  $S$  itself. But for expository ease, I take those other factors that influence  $H$  as given.

Here are a couple of examples of  $H(S)$ :

(i) Exhaustible natural resources (oil and natural gas):

$$H(S) = 0. \quad (2)$$

(ii) Simple Ecosystems (the  $r$ - $K$  model):

$$H(S) = r(S - S^2/K), \quad \text{where } r, K > 0. \quad (3)$$

For simplicity imagine that  $S$  is an extractive resource. Then, if  $R(t)$  is the rate at which the resource is extracted for use in the economy, the resource dynamics would be given by the equation,

$$dS(t)/dt = H(S(t)) - R(t). \quad (4)$$

The asset depreciates if  $R(t) > H(S(t))$  in equation (4); it accumulates if  $R(t) < H(S(t))$ .

Equation (4) shows that to assume away the depreciation of capital assets is to draw a wrong picture of future production and consumption possibilities open to a society. Nevertheless, such a distorted view of production and consumption possibilities has been so successful, that if someone exclaims, "Economic growth!", no one needs to ask, "Growth in what?" - we all know they mean growth in gross domestic product (GDP). When asked, economists acknowledge Nature's existence, but many have until recently denied she is worth much. I have heard professional colleagues remark at seminars that the services nature provides amount at best to 2-3% of an economy's output, which is the share of agriculture in the gross domestic product (GDP) of the United States. Why, they ask, should one incorporate a capital asset of negligible importance in macro-economic models of growth and distribution? I have already provided a reply to the question in these Notes, namely, an absence of property rights implies that shadow prices can be large even while market prices are nil. Note that the rogue word in GDP is "gross". Since GDP is the total value of the final goods and services an economy produces, it doesn't deduct the depreciation of capital that accompanies production - in particular, it doesn't deduct the depreciation of natural capital.

Pollution is the reverse of conservation. So, then here is an example of a model of pollution:

(iii) Phosphorus in shallow freshwater lakes.

Let  $S$  be the amount of phosphorus in the water column of a shallow fresh water lake. Here is a much-used functional form:

$$H(S) = aS^2/(1 + S^2) - bS, \quad \text{where } a, b > 0. \quad (5)$$

Notice that  $H(S)$  is a convex-concave function. (As phosphorous encourages algae bloom in what may be a lake offering water sport,  $S$  in equation (5) is an economic "bad", not a "good"!) Let  $R$  be the phosphorus runoff into the lake from neighbouring farms. Then we have

$$dS(t)/dt = aS^2/(1 + S^2) - bS + R(t). \quad (6)$$

To illustrate tipping points, suppose the lake's owner has no control over  $R$ , and that  $R$  changes very slowly. It is easy to confirm (Carpenter, Ludwig, and Brock, 1999; Carpenter, 2001; Dasgupta, 2001) that the system defined by equation (6) contains multiple stationary points. In particular, when  $a/b$  is large, the lake would be doomed if  $S$  were ever to exceed a critical level given by the parameters  $a$  and  $b$ .

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