

# SUSTAINABLE DEVELOPMENT OF NATURAL RESOURCE CAPITAL

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**Keywords:** natural resources, sustainable development, renewable resources, intertemporal distribution rules, natural capital.

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## Summary

This article tries to bring out the perspectives offered by “weak” and “strong” perspectives on requirements for sustainable development. In essence, the divergencies revolve around different concepts of natural capital and appropriate rules for management of natural capital in the pursuit of long-run sustainability.

## 1. Natural Resource Capital and Sustainable Development

It has, by now, become commonplace to refer to ecological goods and services as deriving from existing stocks of natural resource capital, or more commonly, of “natural capital.” Formally, this involves the simple extension of the well-established economist and accountant notions of a firm’s (company’s) capital as the stocks and equipment capable of delivering flows of money or physical services through time. As Daly (1994) describes it: “Natural capital is the stock that yields the flow of natural resources; the population of fish in the ocean that regenerates the flow of caught fish that go to market, the standing forest that regenerates the flow of cut timber; the petroleum deposits in the ground whose liquidation yields the flow of pumped crude oil.”

Moreover, the economist's concept of opportunity cost seems to apply equally well to ecological goods as to economic goods. The biosphere as a habitat and life-support system is a finite, and in many respects destructible, reservoir of natural capital. Estimating the severity of trade-offs, and the redistributions of economic opportunities, access to environmental benefits, financial and ecological costs, and burdens of risks, thus becomes a major task of ecological economics as a policy science. The fact that current patterns of use of natural capital are environmentally unsustainable, can also threaten economic and social sustainability. In this way, a general precondition for sustainability is the maintenance of those environmental functions which play a major role in sustaining natural ecosystems and which make a substantial contribution to human welfare. The concept of "environmental functions" is here defined as the capacity of natural processes and components to provide goods and services that satisfy human needs. These natural processes and components can in turn be identified as stocks of natural capitals or flows, provided by these natural capitals.

Weak natural capital theory, as will be discussed in Section 2, assumes that welfare is not dependent on a specific form of capital, and that sustainability can be maintained by substituting human-made (manufactured) capital or human capital for natural capital. There are no essential differences between different forms of capital.

Strong natural capital theory, as will be discussed in Section 3, considers that manufactured or human capital cannot be substituted for natural capital. Natural capital is distinct and specific. A single ecosystem or natural resource might fulfill a range of economic production input, recreational, biological and pollution absorption functions, for example, forest and river systems. It is not possible to find ready substitutes for this ensemble of functions fulfilled by a given environmental asset. Nor can technological progress be considered to apply in any uniform way to these functions. The "strong sustainability criterion" for policy then specifies, as a necessary condition for sustainable development, the maintenance of natural capital stocks at or above some threshold levels.

## **2. Weak Natural Capital Theory**

### **2.1 Neoclassical Natural Capital Theory and Sustainability**

Neoclassical natural capital models assume substitutability between natural and produced capitals as (i) inputs for economic capital accumulation, and/or (ii) elements of consumption. These models characterize sustainability as nondecreasing social welfare over time, the social welfare being defined by an aggregate utility function or consumption level.

The mathematical models in this domain are of two main forms. On the one hand are those in the lineage of growth theory, with an aggregate output that can be used in consumption or invested in economic capital accumulation. On the other hand are intertemporal equilibrium models that consider utility as a function of consumption levels and agents' preferences as pioneered by Howarth and Norgaard (1990, 1992); Muir (1996) gives a good overview.

Technological and resource considerations determine whether or not the economy is capable of following a sustainable development time path. These models can be thought of as expressing “social choices,” as signified by population growth, individuals’ preferences and institutional arrangements governing endowment or income distribution, subject to the defined technical and resource constraints. Population change is usually treated as exogenous, so the emphasis is placed on production feasibility (the intertemporal production possibility frontier), and on the social determinants of investment and consumption over time.

On the feasibility side, the growth and/or sustainability potentials for a model economy depend strongly on the specific assumptions made about natural capital renewal rates, about elasticities of substitution between natural and produced capitals, and about technical progress augmenting productivity of capitals. Where “technical progress” and/or elasticities of substitution between natural and produced capitals are made high enough, models can be obtained in which the value of the economy’s capital stock may grow without limit, and thus the “sustainable national income” that is attainable “in the long run” is correspondingly unbounded. In such instances, just as in the 1950s literature on growth, achieving sustainability appears as a problem of savings. In any particular period there is a trade-off between consumption and capital accumulation.

High consumption in a given period means “living off capital” during the period in question, but no permanent damage to “sustainable growth” prospects if this is a transitory phenomenon. The problem becomes serious if the living off capital is repeated period-after-period, becoming a trajectory of economic decline due to inadequate “savings propensity.”

The new feature of the modeling work in the 1970s was the introduction of depletable “natural capital.” Analyses focused on the importance of substitutability and technical progress for relieving growth constraints due to the depletable nature of the natural capital. Three articles appearing just after the 1973/4 OPEC oil crisis, by Dasgupta and Heal (1974), Solow (1974) and Stiglitz (1974), are among the seminal contributions; much recent work follows directly in their line. What was brought out by these early results is the emphasis on feasibility expressed in terms of:

- technical requirements (productivity improvements over time, substitutability between inputs, relative importance of inputs); and
- social parameters (population growth, savings rules).

## **2.2 Sustainability and Intertemporal Distribution Rules**

By now a variety of models have been constructed in which there exists the technological capability for unlimited growth in the value of economic capital over time by substituting away from a renewable or nonrenewable natural capital, but where achievement or not of consumption sustainability is a social choice. Typically, to investigate this problem of “social choice,” solutions are obtained in these models using the criterion of maximizing the present value of “society’s utility” as defined by some intertemporal social welfare function. The generic result is now well known. Where there is a sufficiently high time preference for present consumption over future

consumption, the intertemporal equilibrium path will be characterized, from the outset or after a peak, by monotonically declining values for total capital stock, and correspondingly, per capital utility or consumption levels.

What are the determinants of the distribution over time of consumption? Consumers' preferences can be important in two respects, along with the "social distribution rule" that is applied.

First, where more than one good enters into individuals' utility functions at a given moment and these goods have differing natural capital requirements for their production or supply, the relative intensity of preferences for one good over another influences the pressure on natural capital. This expresses one way that lifestyle changes can work for or against sustainability.

Second, individuals' and society's consumption are distributed over time, and this is partly a time-preference phenomenon. The term "subjective time preference" is used to mean the way that consumers compare the value (in welfare terms to themselves) of consumption at one moment (or period) in time compared with other moments (or periods). But each generation of consumers will have a distinctive, period-based "preference function," and each consumer's rate of time discounting is determined by their particular preference function in conjunction with the consumption opportunity set.

Once the distinction has been made between consumers distributed through time (each with their individual preferences) and "society" (which decides the "distribution rule"), the role of savings is seen to be one of influencing the distribution across successive generations of endowments and of consumption opportunities. Thus, for example as Dixit et al. (1980) observed, a program of investment respecting the Hartwick Rule of reinvesting the value of all "rents" from natural capital, amounts to a policy choice in favor of intertemporal equity.

These issues have been most clearly brought out by models framing the optimal resource use problem as one of intertemporal general equilibrium with utility-maximizing consumers, notably by Howarth (1991), Howarth and Norgaard (1990, 1992), and Muir (1996). These authors' usual model form is a closed economy, and the question of time preference is structured by assuming overlapping generations. The model presented here is adapted from one by Howarth. Each generation lives for two time periods (say  $n$  and  $n + 1$ ), and the  $n^{\text{th}}$  generation maximizes utility ( $U$ ):

$$U_n = U_n(C_{n,y}, C_{n+1,old}) \quad (1)$$

where  $C_{n,y}$  is consumption during period  $n$  when the  $n^{\text{th}}$  generation is young, and  $C_{n+1,old}$  is the consumption during period  $n + 1$  when the generation is old. Within each generation, all individuals are identical so they are treated as one. The emphasis is thus on aggregate consumption each period. (A model in Muir (1996) distinguishes subgroups within each generation and displays interactions between intra-and inter-generational equity.)

Markets for natural capital (resources or environmental amenity), manufactured goods, and labor are assumed to be “competitive” in the sense of equalization of opportunity costs on all margins.

Labor is an initial endowment distributed equally across all generations; each generation “owns” (and thus supplies) labor only while young. Intergenerational transfers are possible through exchange of income for natural capital held as initial endowments.

Technical parameters and initial stock levels determine the intertemporal production possibilities frontier for the economy, and the “optimal” point on this frontier is then selected as either:

- the equilibrium outcome of utility-maximizing consumers’ choices subject to a specified endowment distribution; or
- the optimum of a social welfare function, the latter being formulated in terms of consumption or utility levels through time.

The equilibrium obtained will thus be sensitive to, *inter alia*, the choices made explicitly or implicitly about intertemporal natural capital endowment (property rights) distribution. This exemplifies the Second Welfare Theorem from the theory of general competitive equilibrium, which states that any allocatively efficient model equilibrium can be obtained as a “competitive” equilibrium through suitable choice or “ruling” over initial endowments. A number of important results emerge.

First, sustainability and allocative efficiency are clearly distinct. Sustainability, in the sense of indefinitely nondeclining consumption from one generation to the next, is an intertemporal equity requirement which is not guaranteed by the “competitive” rule of maximizing present value of total consumption over time. When property rights over natural capital are tipped in favor of the “present” generation (still able to be exchanged between generations to enable the old of each period to consume optimally), the typical result is monotonically declining utility levels beyond some period into the future.

Second and conversely, achieving an equilibrium with nondecreasing consumption levels requires, that one way or another, present generations “care enough” about future generations. This caring for the future can be expressed through a variety of mechanisms, notably:

- a maximin social welfare function;
- intertemporal social welfare maximization subject to nonnegative change in representative individuals’ welfare from one period to the next;
- the assumption of a sufficiently high level of individual altruism of each generation towards the generation immediately following;
- the assumption of an obligation on the part of each generation to provide for a utility level of the generation immediately following at least as high as its own, resulting in a “chain of obligation” indefinitely into the future; and
- the explicit award of property rights over natural capital or the benefits obtainable from it as initial endowments distributed equitably to all generations.

Third, the possible model equilibria are each characterized by distinctive trajectories, not just for capital stocks and consumption, but also for relative prices, including the time discount rate (generally itself a function of time, but sometimes time invariant for a given model or class of equilibria). It is often said, that for intertemporal efficiency, the price of natural capital such as minerals or energy resources or fish or forest products, should “correctly” reflect the intertemporal opportunity cost (namely, the user cost). If sustainability is an objective, it is noted, therefore, that this has to be the opportunity costs as evaluated along an intertemporal efficient path that also satisfies the sustainability criterion. This result also applies to the “correct” valuation of an externality, and hence to a Pigovian tax or emission right for internalization.

### 2.3 Defining a Sustainable National Income

The sustainable national income (henceforth *SNI*) for an economy may be defined as the quantity of goods and services, say  $C^*$ , that may be consumed (rather than conserved/reinvested) in a given period while the economy-system still furnishes the capital stock as the basis for providing (at least) the same level of real consumption  $C^*$  in every period through the future. It is important to note that (at least) two somewhat different definitions can be offered for an *SNI*.

- Immediately and thereafter perpetually obtainable income,  $SNI(i)$ , is the highest level of “income” that can be attained immediately, from some given vector of stocks  $X(t = 0)$ , subject to the constraint that the income level during  $t > 0$  is permanently nondecreasing. This is a maximin utility path.
- Later but thereafter perpetually obtainable income,  $SNI(ii)$ , is the highest level of “income” that the economy can continuously attain at and after a finite time, starting from some given vector of stocks  $X(t = 0)$ , subject to the constraint that the income level is permanently nondecreasing.

The Hicksian definition of a person’s (or nation’s) income is the amount that can be consumed during a specified period, while ensuring that personal (or national) wealth at the end of the period is no less than the wealth at the outset. Assume that the value of total capital stocks is  $K$ , measured in money units. Then:

$$K \equiv \pi \bullet X, \text{ where}$$

$X = (M, L, R)$  is the vector of stocks in physical units, and  
 $\pi = (p_1, p_2, p_3)$  is the vector of relative prices.

Then the Hicksian national income will be associated with the rule:  $dK/dt = 0$ . The change in value of capital stock may, generally, be written:

$$dK/dt = d/dt (\pi \bullet X), \text{ and this can be split into two parts:}$$

- the current value of savings,  $\pi \bullet dX/dt$ , and
- the “capital gains” term,  $X \bullet d\pi/dt$

Using the above notation, Hartwick’s Rule is written:

$$\pi \bullet dX/dt \geq 0$$

For a model with constant population,  $dL/dt = 0$ , so this becomes:

$$p1 \cdot \frac{dM}{dt} + p3 \cdot \frac{dR}{dt} \geq 0$$

The first term refers to the value, in current prices, of the change in manufactured capital stock; the second term refers to the value, in current prices, of the change in natural capital stock.

Now suppose the economy is on a time path that maximizes present value of consumption. Then the net national product (henceforth *NNP*) is defined as value of consumption plus net change in the value of capital stocks. If natural capital stocks are included, this is called a “green *NNP*” (*gNNP*), defined as follows:

$$gNNP = p1C + \left( \pi \cdot \frac{dX}{dt} \right) \quad (2)$$

where, as before, *C* is the physical quantity of consumption, *p1* is the current price of manufactured capital (which can be saved or consumed), and  $(\pi \bullet dX/dt)$  is the Hartwick net savings measured in current prices.

It can be noted straight away, that because Hartwick’s Rule does not include the “capital gains” term, the respect of Hartwick’s Rule at any moment in time does not necessarily imply nonnegative change in the value of total capital stocks. So the Hicksian national income and the green net national product (*gNNP*) are evidently not the same thing. Furthermore, the *gNNP* and the *SNI(i)* are not the same thing. As also made plain in the recent work by Asheim (1994) and by Pezzey (1997), the *gNNP* and *SNI(i)* will coincide only if highly restrictive theoretical conditions are fulfilled.

The theoretical work by Solow, Hartwick and others in the 1970s and 1980s showed that, for a closed economy obeying the PVU-max criterion (PVU-max is the maximized present value of utility), a property of the *SNI(i)* “maximin” consumption path is that Hartwick’s Rule is satisfied at all times. It was not initially remarked that respect of Hartwick’s Rule in this context was a necessary but not a sufficient condition. Two complications were not fully appreciated. First, changes in relative prices along a PVU-max path through time will show up in, among other places, the “capital gains” term. Second, different relative prices are associated with each distinct PVU-max solution. Consider the results that may be obtained if price changes are simply neglected. As above:

$$gNNP = p1C + (\pi \bullet dX/dt) \quad (3)$$

According to the Hartwick-Solow results, along a path of constant consumption  $dC/dt = 0$ , Hartwick's Rule is necessarily respected in equality form:  $\pi \bullet dX/dt = 0$  for all  $t$ . Under these conditions,  $gNNP = p1C$  is obtained, and this is the  $SNI(i)$ .

Now, if it were that the prices do not change, the capital gains term would be zero and  $dK/dt = \pi \bullet dX/dt$ .

Thus, along a PVU-max path where Hartwick's Rule is respected at all times, and also there are no capital gains (if such a path can be found), the green net national product  $gNNP$  is a measure of the immediately and perpetually sustainable welfare delivery potential, the  $SNI(i)$ , for the economy and its natural capital stock, and this would also be the "Hicksian national income" at all times.

This is the reasoning that has motivated the estimation of  $(\pi \bullet dX/dt)$  and  $gNNP$  as sustainability indicators. If the above reasoning were valid (which it is not):

- The  $gNNP = SNI(i)$ , and so the  $gNNP$  could be interpreted as an estimate for level of consumption (in money terms) that can be maintained from the present onwards, on a long-term basis, while also maintaining intact the value of the total stock of capital.
- A positive value of the Hartwick term ( $\pi \bullet dX/dt > 0$ ) would signal that the "net savings" of economic plus natural capital, measured in money units, is positive during the period. A negative value ( $\pi \bullet dX/dt < 0$ ) would signal that the "net savings" is negative, or there is "net depreciation" during the period. This yields the Hartwick-Solow "Weak Sustainability Indicator" or "savings rule" as proposed by Solow.

There is one further step for operationalizing the procedures for obtaining "weak" indicators. This is to estimate empirically the components of Eq. 3 on the basis of current period prices and quantities. The "sustainable national income"  $SNI(i)$  is, in empirical practice, estimated by making subtractions away from current GNP ( $p1C$ ) of estimates for  $(\pi \bullet dX/dt)$  representing depreciation during the current period, of capital stocks including manufactured capital and natural capital.

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### **Biographical Sketch**

**Sylvie Faucheux** is currently Professor in Economic Science at the University of Versailles-St Quentin-en-Yvelines (UVSQ) in Paris, France, and Director of the research institute C3ED (Centre d'Économie et d'Éthique pour l'Environnement et le Développement) based at the UVSQ. Since 1992, in addition to teaching, research supervision and other duties as a university professor, Faucheux has been responsible for the leadership and management of contract research at C3ED in the fields of sustainability, ecological economics, environmental policy and scenarios. She has published a large number of scientific papers in French and English, and is associated with several collective publishing ventures. These include: the role of coeditor for the *International Journal of Sustainable Development* which was established in 1998 and publishes a lot of ecological economics contributions; cooperation in the establishment of the *International Library of Ecological Economics* (a new monograph series published by Edward Elgar); and a new series in ecological economics based in Switzerland, to be published in French with translation agreements for English and German. Recently, she has especially concentrated on problems of governance, risks and technological change, and systems of “vigilance-foresight,” with stakeholder-based approaches to the analysis of transitions towards sustainability in European countries. She has worked with several Ministries of the French state, with firms and with the European Commission on these topics, including recently climate policy, nuclear reactor waste management, and futures studies for technological innovation and the environment. As a member of the ISEE Board, Sylvie Faucheux brings a long experience in leadership, organization and resource management for ecological economics activities on an international and multilanguage level. In 1994, she led the organization of a major international conference in Paris on models for sustainable development (participation of 400), and in 1996 she played a central role in organizing the inaugural conference of the European Society for Ecological Economics (ESEE), the European branch of ISEE. She was elected the ESEE's first President in 1996, until stepping down from this position at the end of 1999. Under her leadership, the C3ED research institute has acted as host for the ESEE Secretariat since 1996, and has provided the support needed to establish a regular ESEE Newsletter, to maintain the membership list, and other activities. Sylvie Faucheux has also led initiatives to establish partnerships with universities, ministries and industry in the Middle East and parts of Africa (especially French-speaking North and West Africa), in this way broadening the base of ecological economics networking. She is a member of the European Consultative Forum on the Environment and Sustainable Development as well as reporter of the Climate Change Working Group of the former forum.