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Sustainable development: conceptualizations and measurement

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The paper builds up from a review of some expected, but other quite surprising results regarding country estimates for the year 2000 of **genuine saving**, a sustainability indicator developed by a World Bank research team. We examine this indicator, founded on neoclassical welfare theory, and discuss one of its major problems. Theoretical developments from ecological economics are then considered, together with insights from Georgescu-Roegen's approach to the production process, in search for an alternative approach. A model with potentially fruitful contributions in this direction is reviewed; it points the course efforts could take enable sustainability evaluations based on a more realistic set of interrelated monetary and biophysical indicators.

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INTRODUCTION

Five years after the Millennium Declaration, with development goals for the first 15 years of the XXI century, the World Bank issued a report (World Bank, 2005a) evaluating the 7th of these goals: that of ensuring environmental sustainability. Based on results of the work of a research team of the Bank (WBRT) headed by Kirk Hamilton (see World Bank, 2005b), the report heralded progress

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regarding this target. According to the WBRT estimates for 2000, there was a clearly unsustainable group of poor countries and oil producing countries, but surprisingly, most developed countries and many of the emerging countries — including major contributors to greenhouse-gas emissions — were found to be sustainable. The World Bank, 2005a report ignores the results for the latter group; after all, it was probing the sustainability of the developing world, the main focus of the Millennium Goals. Moreover, World Bank 2005b claims that the construction of sustainability indicators is an ongoing process, subject to improvement. But the message of the report evaluating the 7th Millennium Goal is that, for global sustainability to be achieved, it is enough to give a hand to very poor countries and to persuade oil producers to stop consuming their natural wealth.

In order to unravel this paradox, this paper focuses the WBRT methodology in light of economic conceptualizations of sustainability. Section 2 sketches the WBRT sustainability indicator; section 3 discusses its main theoretical foundation — the neoclassical concept of substitutability. Based on Georgescu-Roegen's approach to the production process, section 4 considers the degree to which we can expect substitutability between broad categories productive assets. The analysis of this author allows us to recognize nature not only as a supplier of inputs for use in production but also an important provider of basic services. Based on this distinction, section 5 discusses when, in assessing sustainability, it is legitimate to assume substitutability or complementarity relationships. Section 6 elaborates on this, based on contributions from ecological economics. Section 7 reviews a systems analysis model as an alternative to the **genuine saving** approach. Section 8 contains concluding comments.

THE WBRT METHODOLOGY

World Bank, 2005b presents the WBRT estimates of wealth, broadly defined, of a large set of countries. Sustainable development is considered from the perspective of a process of asset management,¹ the idea being that the welfare of a society is determined by its total wealth, which must be conserved. That is, a country is sustainable only if it conserves its total endowment of productive capital, **K**, broadly defined to include categories such as '*manufactured capital*, *natural capital*, *human capital* and *institutional or social capital*. The WBRT has estimated **K** for a large set of countries for which data were available, and there are results for a number of years.

¹ For the methodology see Hamilton, 2002; Hamilton and Clemens, 1999, and World Bank, 2005b. Arrow et al., 2004, evaluate the methodology.

But the country sustainability indicator for 2000, used in World Bank, 2005a, was obtained somewhat differently.² Since changes in a society's wealth over a given period, ΔK , are analogous to its saving in the period, the WBRT estimated the **genuine saving** — saving broadly defined to include changes in the major components of K — of each of the focused countries. These estimates included: the value of the change in *manufactured capital*, ΔK_m (the national accounts net saving); in human capital, ΔK_h (education expenditures, net of investment in buildings and equipment; this is part of ΔK_m); and in natural capital, ΔK_n (obtained by the sum of the values of energy and mineral depletion, of net forest depletion, of damages from CO₂ emissions, and from particulate emissions). Thus, a country's **genuine saving**, S_g , was calculated as: $\Delta K = (\Delta K_m + \Delta K_h + \Delta K_n)$.

Note that, although ΔK_m and ΔK_h are usually positive, ΔK_n is always negative; thus S_g can be either positive or negative. A country with a negative **genuine saving** is a country that did not invest in reproducible assets K_m and K_h , the rents from the depletable natural resources assets it runs down. Consuming a portion of these rents, it fails to maintain its productive base. Here, the WBRT report employs the Hartwick-Solow-sustainability concept,³ which specifies that to be sustainable an economy must invest the rents from the extraction and use of its depletable resources in reproducible capital.

Examples of the **genuine saving** estimates for the year 2000 are in Table 1. The countries included are: Brazil, a large emerging economy; the United States, a major developed country; two oil exporting countries (Saudi Arabia and Venezuela); and two very poor countries (Ethiopia and the D.R. of Congo).

Table 1: Genuine Saving in Selected Countries, 2000
(as a % of GDP).

Country	Change in manufactured capital (ΔK_m)	Change in human capital (ΔK_h)	Change in natural capital (ΔK_n)	Genuine saving ($S_g = \Delta K$)
Brazil	6.8	3.7	-3.3	7.2
United States	5.7	4.2	-1.8	8.1
Saudi Arabia	19.5	7.2	-53.2	-26.5
Venezuela	21.3	4.4	-28.4	-2.7
Ethiopia	4.5	4.0	-13.3	-4.8
Congo D.R.	-11.5	0.9	-4.0	-14.6

Source: World Bank, 2005b, Appendix 3.

² For details, see World Bank, 2005b, Appendix 1.2.

³ See Solow, 1986, Hartwick, 1977. More on this below.

The **genuine saving** of these countries is composed of changes as a proportion of GNP, in manufactured capital, human capital and natural capital. All countries have negative changes in **Kn**; regarding **Kh**, all exhibit positive, although in a case, very modest, variations. And all but one of the countries had positive ΔK_m ; the exception is in one of the poor countries which ‘consumed’ not only **Kn**, but also part of its manufactured capital. The last column presents the algebraic sum of the changes in the three categories of the productive base, the year 2000 **genuine saving** estimates.

The negative estimates for the very poor countries and the oil exporting countries are as expected. But we see positive **genuine savings** for Brazil and the United States. These two countries were to be considered sustainable; this is surprising, given that both are often criticized for major unsustainable practices. To help to unravel this paradox, next section examines the theoretical foundations of the **genuine saving** approach.

THEORETICAL FOUNDATIONS OF THE GENUINE SAVING APPROACH

Each area of science focuses its object of study based on particular foundations, assumptions and logical structure; hence, economists, ecologists and philosophers have different understandings of sustainability. The same is true with different schools of thought in economics, and the distinction is particularly striking regarding the analysis of sustainable development. The **genuine saving** methodology is founded on theoretical propositions of neoclassical economics. We sketch below the neoclassical approach to sustainability.

Acknowledging that sustainability has to do with intergenerational equity, the neoclassical approach relies on the efficiency criterion. It assumes a market economy composed of individuals acting independently, each striving to maximize his/her wellbeing (utility); wellbeing stems from the consumption of goods and services. It also assumes a *social welfare function*, an aggregate of individual utility functions.

Consumption, in turn, is made possible by the output from society’s productive assets, **K**. These assets can be taken to include ‘*manufactured*’ capital (**K_m**: machines, buildings, etc); *natural capital* (**K_n**: natural resources; services of nature); *human capital* (**K_h**: the knowledge and skills embodied in society’s population),⁴ **K_k** (society’s disembodied knowledge); **K_{in}** (institutional capital).⁵ In short, at a point in time a society’s productive base can be represented as:

⁴ Pearce and Atkinson (1993, 1995) pioneered in defining broadly society’s productive assets.

⁵ See Dasgupta and Serageldin, 2000; **K_k** and **K_{in}** were included at the suggestion of an anonymous referee.

$$K_t = Km_t + Kh_t + Kn_t + Kk_t + Kin_t$$

The addition of these different capital categories is justified as follows: a society's wealth is the total worth of its entire capital base, and the value of each component can be estimated in monetary terms, using accounting (or shadow) prices; thus, they can be added up. Note, however, that each component comprises an amalgam of different items; for some there are market prices and thus benchmarks for determining efficiency prices, but others require considerable effort of measurement, and for still others this may be virtually impossible.⁶ Overlooking these problems, the neoclassical approach goes on to assume that, as some components of K become increasingly scarce, other components can substitute for them; this occurs, especially, with non reproducible natural resources. There is an aggregate production function, an important attribute of which is that of *substitutability* between the various productive assets used to manufacture goods and services.

The neoclassical concept of intergenerational equity relies on the present value approach; it is used by social welfare theory to establish conditions for the efficient allocations of resources over time, and to select among such efficient allocations, that which maximizes social welfare.⁷ It assumes that a welfare function can be erected to guide in the determination of the welfare maximizing intergenerational allocation of resources. Social welfare in a given moment is determined by the utility (the wellbeing) individuals in society derive from consumption, broadly defined to include public consumption, at that moment. In principle there are many paths of efficient intergenerational allocation but only one maximizes welfare.

An allocation of resources generates a level of income, part of which is employed in the maintenance of the productive base; the remainder is consumed and used to enlarge society's productive assets. In the analysis of efficient allocation, we can employ the notion of Hicks' income (Hicks, 1946): this is the maximum real consumption in a period consistent with maintaining the productive base of the same magnitude in the end as it was in the beginning of the period. It can be obtained deducting from the gross national income, suitably defined, the depreciation of the assets that yield that income.

Of course, not all of the Hicks income is consumed; part can be saved. In establishing society's living standard, consumption determines social welfare. But this changes over time, and the main engine of change is investment. Investing part of the Hicks income society expands its productive base. At each period decisions are made regarding both consumption and saving and, if gross saving

⁶ As argued, for instance by Ayres, 1993.

⁷ For details, see Toman et al., 1995; Dasgupta and Maller, 2001; and Arrow et al., 2004.

is larger than the depreciation of productive assets, the economy can be considered to be growing sustainably.

The relevant neoclassical welfare function at a given moment is an expression of society's preferences, regarding not only present consumption but also the consumption that is expected to result in the future from changes in the productive base (and in the technological menu). More accurately, social welfare at a given moment is the **discounted** value of the flow of consumption, from this moment into infinity. Future is discounted at a positive and constant rate of time preference, determined by society's preferences regarding thrift and by its marginal productivity of capital, broadly defined.

Since a discounted outcome has to do with preferences of the generation existing in a given moment, there has been debate regarding the discount rate. In theory there is a 'right' value for that rate. If it is too high, future welfare will weigh little and present consumption will be excessive; saving and investment will be insufficient. The reverse is the case if the rate is too low. But, since it is difficult to estimate the 'right' social rate of discount, there has been a controversy on what rate to use, with many arguing for a very small rate in discounting the distant future.⁸

Remember that the neoclassical approach assumes a decentralized market economy operating under clearly defined property rights, competitive markets, the absence of externalities, of distorting governmental interference, and a complete set of future markets (bridges between present and future). Maximizing society's intergenerational welfare function under these assumptions, an efficient path of consumption — and of saving — would be determined. Essential in establishing this path is a set of efficiency prices. For the present value approach, if economic agents are confronted with the full social cost of all components of the productive base, reflected on the set of shadow prices derived from the maximization outcome, the intertemporal equilibrium path of resource allocation — and of consumption and saving/investment — will be efficient. Efficiency prices are thus essential for the equilibrium solution. However, in real life many components, especially of natural capital, are not transacted in markets and do not have market prices; in applications such as cost-benefit analysis, substantial effort is made to estimate their shadow prices. And the same is the case with the **genuine saving** methodology.

An essential question at this point is: can we say that an efficient solution is sustainable? Answering we should keep in mind that present value efficiency is measured from the standpoint of the present generation, and that the solution is not constrained by non-decreasing changes in the welfare of future generations.

⁸ Under a zero rate of discount the utility of any future generation would have the same weight as that of the present generation. A summary of the discount argument is in Arrow et al., 2004, pp. 149-50.

But the sustainable development criterion involves a specific constraint: the welfare of future generations must not be lower than that of the present generation. Therefore, intergenerational efficiency is not equivalent to sustainability (Arrow et al., 2004).

Focusing sustainable development, since future welfare is determined by future consumption made possible by the asset base, a sustainable economy is that in which:

$$dK_t/dt \geq 0.$$

As indicated, $K_t = Km_t + Kh_t + Kn_t + Kk_t + Kin_t$, and there are no restriction on the sign of change of individual categories as long as there are compensating variations in other categories. Since by producing and consuming the economy uses depletable natural resources and generates harmful environmental impacts, $dKn_t/dt < 0$; but the reproducible components of K_t can be increased to compensate the reduction in natural capital.

What should the variation of the reproducible components be? The neoclassical answer to this relies on the Hartwick saving rule.⁹ Based on Hotelling (1931), Hartwick demonstrated that — under certain strict assumptions¹⁰ — for an economy to be on a sustainable path, it must invest in reproducible assets the rents from the depletable resources it uses, thus maintaining its productive base. Doing this the economy will preserve at least constant its real consumption.

How does the **genuine saving** fit into this picture? Recall that sustainability has to do with social behavior regarding the accumulation of **genuine wealth**. In a given period, this results from society's gross saving (S_t) less the depreciation of the overall productive base (δK_t).¹¹ Sustainability requires that $(S_t - \delta K_t) \geq 0$. The WBRT calls $(S_t - \delta K_t)$ **genuine saving**, to disengage the concept from that of the national accounts saving. But again, sustainability does not require non negative changes of all components of K_t . In fact, since $\Delta Kn < 0$, other components of K_t have to expand to compensate for this reduction; the Hartwick saving rule establishes the magnitude of this compensating change.

GEORGESCU-ROEGER ON PRODUCTION AND SUBSTITUTABILITY

Substitutability is central in the **genuine saving** methodology. However, in line with the neoclassical approach to production, it is treated casually by the

⁹ See Hartwick, 1977, and Solow, 1993.

¹⁰ For how strict, in fact, are Hartwick's assumptions, see Perman et al., 1996, pp. 63-70.

¹¹ δ is the rate of depreciation. But since each capital category which composes K_t has a different form of depreciation, the assumption of an overall rate involves a substantial simplification.

methodology. And more: due to the lack of data, natural capital, the substitutability of which is stressed, includes mostly raw materials and a few natural assets for which prices can be found or estimated; major services provided by nature are left out. This treatment of substitutability is far from convincing.

To allow a more realistic treatment of substitutability, we review briefly Georgescu-Roegen's analytical conceptualization of the productive process. In his review of the conventional theory of production, a major pillar of economic analysis, Georgescu-Roegen reproached neoclassical economics for failing to raise "*the same kind of epistemological questions about the production function as those that have continuously tormented the students of consumer's behavior*" (Georgescu-Roegen, 1969, p. 498). In fact, he was not the first to advance such criticism; earlier, Joan Robinson had chastised the neoclassical approach for instilling in generation after generation of economists sloppy habits of thought (Robinson (1953-54), p. 81). Note that such criticism came at a time when production theory was considered complete and perfect in its analytical structure.

Analyzing the production process Georgescu-Roegen (1969; 1971) begins carefully specifying the logical foundations of his approach; he then argues that, in describing a production process we must assume that production is carried out in a steady state — in the sense that whatever the production process does, can be repeated identically time and again. Without this premise, at the conclusion of each production sequence we would have not only products and residuals, but also the structure of the process altered by wear and tear of machines and by the exhaustion of workers. But, despite the steady state assumption, production has a temporal dimension, since it takes time to be executed; production occurs along a time interval. Moreover, as a rule, factors of production and inputs do not go into the production process together when production begins and participate continuously in the process — an exception being the case of production in line.

Georgescu-Roegen considers basically two categories of factors of production: *fund factors*, the agents of transformation in production; and *flow factors*, the energy, materials and components that are transformed as the process unfolds. In the execution of production, fund factors operate over flow factors, generating *products* and *wastes*. Inspired in the classical economists the author classifies the fund coordinates of the production process as:

- L = Ricardian land (physical space in which production occurs);
- K = Manufactured capital goods (machines, tools, constructions);
- H = Labor force.

In the context of our discussion, we add another basic fund factor: factor **Kns** the services provided by nature to production (this is discussed further below).

Georgescu-Roegen stresses that, as production is executed, the fund factors are not integrated physically into the products; all operate providing only services to production. Ricardian land — basically space, typically inert — has fundamental roles in production, but it is not incorporated into products. The machines and

tools used in the transformation of inputs in products are also not incorporated into products.¹² The same is true with **Kns**; workers are crucial for production, but no part of the worker should integrate the product.¹³

For the *flow factors*, Georgescu-Roegen suggests the following categories:

R = Inputs from nature; we call these **Kni** (see below);

I = Inputs from other production processes;

M = Inputs for maintenance.

In **Kni** are include inputs such as solar energy, minerals, fossil fuels, nutrients contained in the soil,¹⁴ among many others. Flow factors **I** comprise inputs from other production processes: parts and components. And **M** includes the inputs for the maintenance of machines and tools employed in production.¹⁵ If maintenance is not correctly executed the steady state assumption is violated.

Fund factors enter the boundary of the production process as production unfolds, participating in the process at various moments and with different intensities; the same occurs with the *flow factors*. And at the end of the execution of production, we observe that the process will have generated two distinct classes of outputs:

Q = Products;

W = Wastes (residuals, pollution).

Q is the main object of the production process; but there are also waste outflows, **W**, generated at various stages of the execution of production.

An important distinction between the conventional and the Georgescu-Roegen approach is that it considers explicitly the waste outflows, absent from the conventional approach. These outflows are at the core of today's sustainability problems, but neoclassical environmental economics deals with this awkwardly, making pollution an input to production, with marginal productivity and other attributes of inputs, instead of what they really are, residuals!¹⁶

The pattern of use of the services of fund factors in the transformation of flow factors in products and wastes varies, in accordance with the needs of each phase of the production process. At some moments a given machine, a tool, a specific worker may lay idle, but in other moments they are intensively used. And the inflow of the various types of flow factors usually takes place at specific

¹² As illustrated by Georgescu-Roegen (1971) a needle used to manufacture a shirt should not be incorporated into it. If this accidentally occurs, the buyer of the shirt will surely complain.

¹³ There are protestations when a strand of the cook's hair is found in the soup served by a restaurant.

¹⁴ Agricultural soil is both a fund factor (Ricardian land, space to capture sun light for vegetable production), and a supplier of inputs (nutrients to be incorporated into plants), flow factors.

¹⁵ Georgescu-Roegen acknowledges the need of maintenance (restoration) of the labor force but he assumes that this to occurs outside the production process (e.g., in the workers home).

¹⁶ For an instance of such treatment, see Fisher, 1981.

moments during the execution of production. Production involves, therefore, a definite temporal pattern of participation of factors of production. Based on this Georgescu-Roegen argues that an accurate representation of a production function requires a formula of the following type:

$$Q(t) = F\{L(t), K(t), H(t), E(t); R(t), I(t), M(t), W(t)\}$$

$\begin{matrix} T & T & T & T & T & T & T & T & T \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}$

This is a functional, that is, a relation between a set of functions (those expressing temporal patterns of factor uses and of waste emission, along the production interval $[0, T]$) to one function (the outflow of production in this interval). As shown by Georgescu-Roegen (1971, p. 236), this is a far cry from the conventional production function, a point function — a relation between a set of numbers (the inputs) to one number (the output). The author shows that this functional can be approximated by a conventional production function only exceptionally: in the case of production in line, that is, when all fund factors can be arranged in line so that their services are uninterruptedly used in the transformation of continuous flows of inputs into continuous output and waste streams.

It is important to stress, at this point, a basic difference between *stocks* and *funds of services*. It is well known that a stock is a quantity accumulated of something at a point in time. Over a given period, the magnitude of the stock is altered by flows entering and leaving the stock. Georgescu-Roegen (1971, ch. 9) shows, however, that when we state that a country's *fixed capital* — a set of fund factors — has accumulated by so much in a year, something different takes place. It is true that the country's fixed capital comprises, so to speak, a stock of fund factors; but the connotation of 'stock' in this case is different from that of the country's stock of parts and components at this point in time (in fact, the system of national accounts measures the variation of this stock). The difference is that, when a portion of the stock of components becomes used in production, it is physically 'consumed'. But the economy's 'stock' of fund factors encompass, so to speak, reserves of services, which may or may not be used; and if they are used, contrary to what happens with the components, the services of the fund factors are not 'consumed', not in the same way as the 'consumption' of components.

In other words, "A machine does not come into existence by the accumulation of the services it provides as a fund. [...] Services cannot be accumulated as the dollars in a saving account or the stamps in a collection can" (Georgescu-Roegen, 1971, p. 227). Moreover, contrary to what occurs with the components, the services of the machine not used in a given period are wasted. This is the tragedy of a recession.

The different nature of stocks of components and funds of productive services is especially relevant to the discussion of sustainability that follows.

SUSTAINABILITY IN THE LIGHT OF THE GEORGESCU-ROEGEN APPROACH.

The degree of optimism regarding the attainability of sustainable development is usually related to the extent with which reproducible assets are assumed to be substitutes for depletable natural resources. Those who believe that substitutability is, and will remain, extensive are usually optimists; those who consider that the substitutability of certain elements of natural capital is limited, are often pessimistic.

The optimistic view on substitutability is reflected in the so called *weak sustainability* outlook (Pearce and Atkinson, 1995). It considers sustainability basically from the point of view of the extraction of depletable resources such as fossil fuels and minerals. By definition, the use of these items of natural capital reduces their availability, but it is believed that the productive base can be maintained by increases in reproducible components; they will substitute the depletable resources in a process enhanced by technical change. But this outlook tends to ignore elements of natural capital such as life support functions of nature.

The *strong sustainability* outlook, in turn, is critical of the *weak sustainability* assumptions and modeling. It considers that there is more to the total value of a natural system than the mere sum of values of its components, and that substitutability may be an issue (Pearce and Atkinson, 1995, p. 169). If consumption is to be at least maintained over time, basic services of natural capital must be preserved. *Complementarity* is an important attribute of certain components of **Kn**; there may be substitutability between depletable elements of natural capital and reproducible capital, but those are not regarded the more important cases.

An inspection of the arguments of the sustainability controversy reveals an often casual treatment, with beliefs prevailing over well founded reasoning. Reproducible capital and natural capital are treated as somewhat homogeneous categories, and the discussion is about the substitutability of one for the other. Complex relationships between nature and the economy are hidden.

There is much to be gained by focusing substitutability based on insights from the Georgescu-Roegen approach. Beginning with manufactured capital, for the national accounts the change **Km** over a given period (the **investment**) is composed of two completely different parts: the value of the change in fixed capital — machines, buildings, roads; and the value of changes in the stocks of components and of final goods not yet sold by firms. The national accounts record the value of these two sets of elements separately, but the sum of the two is often treated as a uniform entity. We should bear in mind, however, that the manufactured capital changed by investment, is made up both of **funds** of productive services, and of **stocks** of goods in process. A crucial difference between these categories is that the **fund** of fixed capital (we call it **Kms**) provides services

in the transformation of components into products; but in doing so the machines and equipment that make up this fund of services are not physically incorporated into the products. With adequate maintenance, at the end of a given period they leave the productive process in condition to efficiently provide further productive services. Regarding the inventories, however, (we call them **Kmi**), their components are available to be transformed by **Kms**, in association with other agents of production, into products. But once a portion of the inventories is used, it ceases to exist as such; it becomes incorporated into products and into the waste steam. An implication of this decomposition of **Km** into **Kms** and **Kmi** is that there are usually different substitutabilities between and within these two categories.

A similar decomposition, particularly relevant for our discussion, can be made regarding **Kn**. Natural capital comprises a very important category of *funds of services* of nature, **Kns**, usually overlooked by the *weak sustainability* approach; and a category of *stocks* of natural resources, **Kni**, available to be extracted for use in production. If **Kn** is assumed to be mostly of the latter kind, however, it is not difficult to expect considerable substitutabilities between **Km** and the depletable elements of natural capital (but there surely are some complementarities between the two categories). And technical change will usually facilitate such substitution.

Regarding **Kns**, the funds of services from nature, they provide to the human society important services, not only for production and consumption, but also in safeguarding life. They include, for instance, functions of nature such as the regulation of climate, the maintenance of biogeochemical cycles fundamental for life; or the resilience of ecosystems in face of human impacts. But although fundamental, many of the services of **Kns** are free and it is very difficult to attach property rights to most of them, and estimate meaningful efficiency prices for the services they provide (Ayres, 1993); and some cannot be replaced once destroyed.

The latter point should be stressed: it is true that **Kms** and **Kns** are both funds of services, but machines can usually be rebuilt; this is not the case with certain elements of **Kns**.

WHY SHOULD WE BE CONCERNED WITH KNS?¹⁷

A casual posture regarding the fund of services of natural capital can be expected when sustainability is evaluated based on an epistemology that is blind to the properties of natural systems. These services are then regarded as stemming from a submissive system which can, to a large degree, be impacted by the economy

¹⁷ This section is based on Mueller, 2001.

with no major consequences. It is agreed that the economy can mishandle nature, but the ensuing effects are only seen as important if they adversely impinge on social welfare. Moreover, events generating these effects tend to be considered amenable to fairly easy rectification, through the imposition of corrective charges.

This is not a suitable approach to the analysis of the interactions between our economy and vital natural systems. An alternative would be to recognize at the outset, that sustainable development is development that lasts, and treat development as an **evolutionary** process. Sustainable development would, therefore, be associated with the **stability** of evolution; and the underlying forces connecting **development** and **stability** would be reflected in the state of **quasi-equilibrium** of natural systems. Quasi-equilibrium is a state involving “*a process of ongoing change [with] stable patterns or parameters*” (Boulding, 1991, p. 23).

Unsustainable development can, however, result in changes, some potentially catastrophic, in evolutionary parameters. An evolutionary catastrophe is an “*improbable event, whether an external catastrophe or some improbable mutations [resulting in drastic change, creating] new niches, new species, and perhaps widespread extinction of old species...*” (Boulding, 1980, p. 187). There are instances of human induced catastrophes which altered evolutionary parameters. *Homo sapiens* has “*shifted evolution on this planet into a new gear and proved ecologically catastrophic for many older species*” (Boulding, 1991, pp. 23-4).

This approach can be used to bring into the analysis of sustainability the funds of services from nature. Natural systems are treated, not as benign, self restoring space, but as a set of dynamic, interdependent and vulnerable systems. They operate through processes involving “*a closed-loop system of material cycles in which matter is continuously recycled*” by a steady dissipation of solar energy (Binswanger, 1993, p. 221). These biologically assisted material cycles contribute to the auto-regulation and self-maintenance of natural systems; they are essential in sustaining life.

Stability can be focused assuming our globe as an all encompassing natural system; for Ayres,¹⁸ for instance, our planet is a dynamic, self organizing system, operating through a series of physical and chemical processes, thanks to which it “*... maintains itself in a dynamic pattern of continuous change, within a stable envelope. [...] In certain respects, [the global system] is like an individual organism: it is maintained in a stable state, far from [...] thermodynamic equilibrium, by a steady supply of external energy from the sun.*” Solar energy drives a system of biochemical processes that provide support to our oxygen-nitrogen atmosphere and to other biochemical cycles, all crucial in supporting life. But “*... every closed cycle [...] is an inherently non-equilibrium phenomenon*”, and the stability far from equilibrium requires an adequate operation of the ecocycles (Ayres, 1993,

¹⁸ See, for instance, Ayres, 1993; 1994; 1999.

pp. 202-4). However, our economy has been functioning largely outside this cycling mechanism.

The question, then, is: until when will the global system endure increasing human aggression? For the *weak sustainability* approach, the answer is forever, but for the *strong sustainability* approach this is far from being the case. We should, therefore, explicitly focus the effects of anthropogenic interferences on environmental functions, elements of **Kns**, which are vital for the stability of the global system.

A strategy for sustainability would involve the protection of the resilience of systems on which humanity depends, with its implementation monitored with the aid of pertinent sustainability indicators, built based on a methodology that explicitly considers the destabilizing human impacts on natural systems.

THOUGHTS ON AN ALTERNATIVE APPROACH

Discussing substitutability, some neoclassical scholars recognize human threats to global stability. For Toman et al., (1995, p. 143), for instance, substitutability “*also involves the ability to offset a diminishing capacity of the natural environment to provide waste absorption, ecological system maintenance, and aesthetic services. Questions of substitution and technical progress versus thresholds and catastrophe risks are especially relevant when addressing large-scale damages to natural systems whose ecological functions remain poorly understood.*” But “*behind these questions are exceedingly complex issues*” (Toman et al., 1995, note 6); and since we do not know how to deal with them, sustainability should continue to be focused in the usual fashion.

Another instance is, to some extent, in the analysis by Arrow et al., 2004, of the WBRT preliminary results. The tone and the conclusions of the paper, authored by a group of prominent economists and environmentalists, are similar to those of the World Bank, 2005b report. However, the final sections of the paper discuss elements of instability and unsustainability that cannot be captured by the **genuine saving** (the paper labels it **genuine investment**) methodology. Thresholds and catastrophe risks are acknowledged but the overall message is that, since ecological economics has not yet produced satisfactory tools to deal with them (Arrow et al., 2004, p. 152), **genuine saving** type methodologies should continue to be used.

In attempting to develop an alternative approach, some totally reject such methodologies. For Wackernagel (1999, pp. 13 and 15), for instance, sustainability evaluations should entirely shun monetary indicators; they should, instead “*be grounded in biophysical assessments*”. [...] This is so because once “*biophysical limits are explicitly recognized, [...] it becomes more difficult to avoid the hard questions of sustainability*”, concealed in **genuine saving** indicators. But the author

advocates the use of another unidimensional sustainability indicator: the ecological footprint, the total amount of land necessary for a city, a region, a country to function (Wackernagel and Rees, 1996).

Common and Perrings (1992) argue, however, that modifications in a general equilibrium model can be made to take into account threshold elements; to this extent they combined concepts of economics and of ecology in a sustainability model in which the ‘efficient’ allocation of resources is constrained by threats to the stability of the global system. We present a sketch of their model.

Common and Perrings (for short, C&P) criticize *present value* Solow/Hartwick models for their failure in addressing biophysical properties of the global system in which the economy is embedded; the problem is that such models ignore “*essential properties of the real phenomena modeled*” (C&P, 1992, p. 22). They show that the stability derived from such models — they call it *Solow stability* — depends basically on values and prices, especially of natural resources of the **Kni** type, leading to *weak sustainability* assessments. For the authors the most pressing sustainability problems arise from feedbacks between the economy and biophysical systems involving threats of irreversible changes in their organizational structure.

For C&P, sustainability is basically an economic problem; they focus the interdependence between natural systems and the economy with a systems approach, which includes objectives, instruments and constraints (C&P, 1992, pp. 23-8); and the constraint set draws from “*the properties of the biophysical system within which economic activity takes place.*” It has “*its own internal dynamics*”, which is “*sensitive to the stimuli offered*” by the economy in the form of resource extraction and of the deposition of wastes from production and consumption (C&P, 1992, p. 22). They emphasize the interdependence, brought in by the constraint set, between the economy and the larger system in which it is embedded.

Their model also has a social welfare function. Welfare — discounted — is made to vary along a specific planning period, defined as the time interval along which the relationship between social preferences and the state of the global system can be taken as unchanged. “*It depends on the range of institutional, technological, cultural and ethical factors that regulate*” the welfare function and its arguments (C&P, 1992, p. 24). Welfare is derived both from the income resulting from the exploitation of the resource base and, importantly, from the benefits obtained by the present generation “*from the state of the system it bequeaths to future generations*” (p. 24).¹⁹ Welfare optimization constraints emphasize, therefore, the dynamics of the global system.

¹⁹ As pointed out by an anonymous referee, the C&P model assumes stable preferences. It would be more appropriate to work with preferences which vary with changes in values — in our case, especially those related to environmental issues. The problem, however, is in specifying how preferences regarding this change.

Their treatment of sustainability has to do with the way the dynamics of the global system is incorporated into decision-making; for this they rely on the ecologist C.S. Holling (1986) sustainability concept. *Holling sustainability* is linked to the resilience of the biophysical system, that is, to its capacity to maintain its functional stability in face of disturbances, especially those resulting from impacts of economic decisions.

Exploring the efficiency conditions in the context of the sustainability constraint, C&S find that, differently from the of *weak sustainability* modeling, “(t)he discounted marginal benefit of the allocation of economic resources is reduced by the impact of that allocation on the index of system stability. Similarly, the marginal foregone benefits of the allocation of economic resources are augmented by the indirect effects of economic resource allocation on the rate of growth/decay of resources through their effects on the (biophysical) system parameters” (p. 28).

They stress the need to search for a resource allocation that will not threaten the stability of key components of the global system. Important in this is the role of ecological health on the preferences of the present generation, affecting their legacy to the future. If the preferences of those living now downplay ecological health, efficiency prices will lead to unsustainability; if, however, preferences favor the maintenance of ecological health, efficiency prices may lead to sustainability (C&P, 1992, p. 29). In other words, consumer sovereignty — a central element of neoclassical modeling — may or may not be conducive to sustainability.

Since efficiency prices alone do not assure sustainability, single dimension indicators based on them can be misleading. A more consistent evaluation requires that we consider the links between the economy and the global system impacting on the resilience of the larger system. C&P reject *genuine saving* type unidimensional monetary indicators of sustainability; they argue that *Holling-sustainability*, a major component of their model, “is a physical concept deriving from a condition for the stability of ecosystems.” Therefore, relevant indicators regarding this should involve “a set of physical measures”, especially “indicators of the responsiveness in the distribution of the system parameters to perturbation in resources stock” (pp. 30-1).

CONCLUDING COMMENTS

The WBRT efforts to estimate sustainability indicators deserve praise and wishes for continued improvement. There are, however, problems with their estimates. We saw that they revealed the unsustainability in terms of **Kni** of the world’s poorest countries and of large oil exporters, but it would be especially

fruitful if we could also correctly identify features of sustainability and unsustainability of developed and of large emerging countries which are downplayed in the WBRT estimates. For this it would be necessary to develop a working methodology that focuses both on changes in the value of inventory type natural resources (in **Kni**), and on complex economy-environment interactions associated with the growing abuse of basic services from nature (of **Kns**). Of course, accomplishing this is not easy. It requires getting rid of the obsession of measuring sustainability with unidimensional monetary indicators, and working to erect a set of biophysical indicators that reflect elements of Holling-unsustainability resulting from the interaction between the economy and the global system.²⁰ A substantial multidisciplinary collaborative effort would be required just to build an overall workable model. But if this could be achieved, it might be the base for the configuration of a system of combined monetary and biophysical sustainability indicators.

Moreover, since the system would have to deal with large individual economies, it should contain links to capture transboundary externalities; the **genuine saving** methodology treats occurrences in a country as if they did not impact the rest of the world. But, as Arrow et al. (2004, pp. 166-8) concede, the consumption of countries which import large amounts of resource-based products is often subsidized by exporting countries, usually of the developed world. Means of capturing such interactions should be devised.

Similarly, the **genuine saving** methodology does not capture the global effects of the expansion of large economies, such as those contributing to climate change. The methodology assumes that the negative effects of increasing CO₂ emissions associated with welfare creation in a large industrialized country are basically felt within the country; in World Bank, 2005b (p. 40), this is taken care of by a charge (added to the value of negative change in natural capital) of US\$ 20 per ton of CO₂ emitted annually. This charge is from an estimate by Frankhauser (1995); but it is disputed by Pearce (1999, p. 496), who feels that the charge should be at least the double. However, more to the point, the cost of CO₂ emissions — a transboundary externality — should not only be considered to impact the whole world, but also taken to be rapidly increasing, with the potential of becoming very high if, as it is feared, thresholds in the world climate system are approached. Green house gas emissions and the ensuing climatic effects taken out of the **genuine**

²⁰ An anonymous referee asked for instances of the biophysical indicators. This would be a central task in the development of an alternative methodology. It would include indicators regarding global problems of climate change, of biodiversity reduction, of toxic emissions, among others. For an instance of what has been done in the field there is the much less ambitious attempt of the Netherlands NAMEA system (Keuning, 1996).

saving segment of a system devised to evaluate sustainable development and made part of Holling sustainability physical indicators.

Given the large uncertainties regarding ecosystem dynamics and, especially, concerning the determination of accurate threshold levels, it would be naïve to assume that it is easy to erect an overall, interlinked model for use in assessing sustainability. But a guiding model, composed of separate blocks could perhaps be conceived, with links between the blocks being established by indicators of the scale and growth of the global economy. Complexity and uncertainty should not be an excuse for throwing the economy-environment interactions in the *ceteris paribus* pool and working with highly simplified, unrealistic models.

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