

Strong versus Weak Sustainability: Economics, Natural Sciences, and "Consilience"

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The meaning of sustainability is the subject of intense debate among environmental and resource economists. Perhaps no other issue separates more clearly the traditional economic view from the views of most natural scientists. The debate currently focuses on the substitutability between the economy and the environment or between "natural capital" and "manufactured capital"—a debate captured in terms of *weak* versus *strong* sustainability. In this article, we examine the various interpretations of these concepts. We conclude that natural science and economic perspectives on sustainability are inconsistent. The market-based Hartwick-Solow "weak sustainability" approach is far removed from both the ecosystem-based "Holling sustainability" and the "strong sustainability" approach of Daly and others. Each of these sustainability criteria implies a specific valuation approach, and thus an ethical position, to support monetary indicators of sustainability such as a green or sustainable Gross Domestic Product (GDP). The conflict between "weak sustainability" and "strong sustainability" is more evident in the context of centralized than decentralized decision making. In particular, firms selling "services" instead of material goods and regarding the latter as "capital" leads to decisions more or less consistent with either type of sustainability. Finally, we discuss the implications of global sustainability for such open systems as regions and countries. Open systems have not been dealt with systematically for any of the sustainability criteria.

I. INTRODUCTION

The meaning of sustainability is the subject of intense debate among environmental and resource economists.¹ Perhaps no other issue separates the traditional

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¹ In this journal, see, for instance, John M. Gowdy and Peg R. Olsen, "Further Problems with Neoclassical Environmental Economics," *Environmental Ethics* 16 (1994): 161–72; Mohammed H. I. Dore, "The Problem of Valuation in Neoclassical Environmental Economics," *Environmental Ethics* 18 (1996): 65–70; and Rudi M. Verburg and Vincent Wiegel, "On the Compatibility of Sustainability and Economic Growth," *Environmental Ethics* 19 (1997): 247–66. See also Wilfred Beckerman, "Sustainable Development: Is it a Useful Concept?" *Environmental Values* 3 (1994): 191–209, with responses by Mick Common, Herman Daly, Salah El Serafy, and Michael Jacobs and a reply by Beckerman, *Environmental Values* 4, nos. 1 and 2 (1995): 49–55, 57–68, 169–79, and vol. 5, no. 1 (1996): 75–82, 83–88. For a recent survey of the economic literature on sustainable

economic view of the natural world from the views of most natural scientists. The debate currently focuses on the substitutability between the products of the market economy and the environment—"manufactured capital" and "natural capital"—a debate captured in the terms *weak* vs. *strong* sustainability. It is increasingly clear that the criteria for weak sustainability, based on the requirements for maintaining economic output, are inconsistent with the conditions necessary to sustain the ecosystem services of the natural world. Weak and strong sustainability each have their own specific valuation approach and thus different ethical perspectives. In the pages below we follow E. O. Wilson in arguing for "consilience" between economics and natural science.² That is, definitions and procedures from one discipline should conform to solidly verified knowledge in other disciplines. If our goal is to preserve necessary features of the natural world, policies designed to insure sustainable economies should be consistent with the requirements for the long-term survival of the human species including maintaining the resilience and stability of ecosystems. Points of conflict between economic theory and natural systems include the economic assumptions of smooth, continuous, and strongly rational human preferences, unlimited substitution, and the differences between global versus regional sustainability.

This article is organized as follows: in section two, we discuss the market-based approach of weak sustainability and examine its implications in theory and practice. In section three, we examine the broader approach of strong sustainability. In section four, we link the sustainability debate to utility and consumption and conclude that lexicographic preferences have not yet received sufficient attention. In section five, we consider monetary valuation of ecosystems in the context of sustainability. In section six, we present natural science-based perspectives on sustainability and compare these to economics based ones. In seven we argue in favor of approaches to sustainability that aim for consistency among the basic understandings of social and natural sciences.

II. WEAK SUSTAINABILITY

The concept of weak sustainability has come to dominate discussions of natural resource and environmental policy. According to Brekke, "A development is said to be *weakly* sustainable if the development is non-diminishing from generation to generation. This is by now the dominant interpretation of 'sustainability.'"³ Dominant, that is to say, among economists, not ecologists and most other natural scientists.

development, see Jeroen C. J. M. van den Bergh and Marjan W. Hofkes, eds., *Theory and Implementation of Economic Models for Sustainable Development* (Dordrecht: Kluwer, 1998).

² E. O. Wilson, *Consilience* (New York: Alfred Knopf, 1998).

³ Kjell Arne Brekke, *Economic Growth and the Environment: On the Measurement of Income and Welfare* (Cheltenham: Edward Elgar, 1997) (emphasis added).

In accordance with the above definition, economic growth theory translates weak sustainability into intergenerational equity.⁴ Sustainability is usually interpreted as a constraint on economic growth, namely non-decreasing welfare. This interpretation is quite a strict criterion, as any temporary decrease in welfare implies unsustainable development. Pezzey⁵ has referred to "sustainedness" in this respect, since such a pattern can be assessed only after the fact. As a weaker alternative criterion Pezzey⁶ proposes "survivability," according to which a reduction of welfare is allowed as long as the level of consumption exceeds some subsistence level.

In the general economic case, social welfare is a function of utility, which is difficult to operationalize. In practice, simple models often equate utility with aggregate consumption, defined as gross output less investment ("Hicksian sustainability"). Maximizing happiness is equated with maximizing consumption. In principle, consumption would have to be interpreted in the general sense, to include environmental goods and services. However, consumption in such models is likely to be interpreted, in practice, in terms of *produced* goods and services, leaving out goods and services provided directly by the environment. The same problem applies also to the more general concept of utility. We return to this issue subsequently.

Another interpretation of sustainable economic "development," underlying Brekke's definition above, refers to continuing growth of Net National Product (NNP), defined as Gross National Product (GNP) minus capital consumption, or capital allowance, (to replace depreciation). GNP is commonly seen as total output of goods and services by the economy. It is often interpreted as the sum of returns to the factors of production, namely natural resources, labor and capital stock. Thus, sustainability is basically seen by neoclassical economists as a problem of managing a nation's portfolio of capital to maintain it at a constant level, either *in toto* or *per capita*. It includes natural capital, in principle, but it also allows for virtually unlimited substitution between human-made and natural capital.⁷ Common and Perrings have termed this "Hartwick-Solow sustainability."⁸ Note that "Hicksian sustainability," which requires non-decreasing

⁴ Michael A. Toman, John Pezzey and Jeffrey Krautkraemer, "Neoclassical Economic Growth Theory and 'Sustainability,'" in Daniel W. Bromley, ed., *Handbook of Environmental Economics* (Oxford: Blackwell, 1994).

⁵ John Pezzey, "Economic Analysis of Sustainable Growth and Sustainable Development," Environmental Department Working Paper, no. 15, Environmental Department, The World Bank (1989). Reprinted as J. Pezzey, "Sustainable Development Concepts: An Economic Analysis," World Bank Environment Paper 2 (1992).

⁶ John Pezzey, "Sustainability: An Interdisciplinary Guide," *Environmental Values* 1 (1993): 321-62.

⁷ See David Pearce, Edward Barbier, and Anil Markandya, *Sustainable Development: Economics and Environment in the Third World* (Cheltenham: Edward Elgar, 1990).

⁸ Mick Common, and Charles Perrings, "Towards an Ecological Economics of Sustainability," *Ecological Economics* 6 (1992): 7-34. See John M. Hartwick, "Intergenerational Equity and the Investing of Rents from Exhaustible Resources," *American Economic Review* 67 (1977): 972-74;

consumption—including consumption of environmental goods and services—is virtually equivalent to “Hartwick-Solow sustainability” defined in terms of maintaining the total capital stock of society.

An operationalized version of Hicks-Hartwick-Solow weak sustainability has been suggested by Pearce and Atkinson.⁹ It reduces to the following formula for countries:

$$Z = S/Y - d_M/Y - d_N/Y$$

where Z is an index of sustainability, Y is GNP, S is (national) savings, d_M is the rate of depreciation of man-made capital and d_N is the rate of depreciation of natural capital. An economy is weakly sustainable if $Z > 0$.

The economic perspective on weak sustainability, then, is that of an individual-acting-at-a-point-in-time, nationwide or even planet-wide, “portfolio manager.” The practical expression of this has been to focus attention on providing equal opportunities for present and future generations. Neoclassical models fit this perspective quite well, by using the standard methodology of dynamic optimization to generate optimal utility¹⁰ patterns over time. Although having different starting points, “intergenerational equity” and “weak sustainability” can lead to similar conclusions, as long as gross economic output or gross consumption are accepted as proxies for welfare.

Weak sustainability implicitly assumes that savings are invested in manufactured capital or human capital and that the latter are perfectly substitutable for natural capital. Furthermore, levels are irrelevant; only changes matter. Countries with a history of resource depletion and ecosystem damage may look sustainable. Indeed, numerical results in Pearce and Atkinson show that the Netherlands and Japan are examples, both of which have hardly any forest land. Such examples hint at the problem of the sustainability of open regions or countries, which evidently can surpass local sustainability limits by engaging in international trade. Indeed, one may ask whether trade can substitute for nature at the local level? The issue of regional or national sustainability, and

John M. Hartwick, “Investing Returns from Depleting Renewable Resource Stocks and Intergenerational Equity,” *Economic Letters* 1 (1978): 85–88; John M. Hartwick, “Substitution among Exhaustible Resources and Intergenerational Equity,” *Review of Economic Studies* 45 (1978): 347–54; Robert M. Solow, “Intergenerational Equity and Exhaustible Resources,” *Review of Economic Studies* 41 (1974): 29–45; and Robert M. Solow, “On the Intergenerational Allocation of Natural Resources,” *Scandinavian Journal of Economics* 88 (1986): 141–49.

⁹ David Pearce, and Giles Atkinson, “Measuring Sustainable Development,” in Bromley, *Handbook of Environmental Economics*.

¹⁰ In practice “utility” is almost always reduced to the consumption of economic goods. See John M. Gowdy, “Terms and Concepts in Ecological Economics,” *Wildlife Society Bulletin* 28 (2000): 26–33. The steps between maximizing utility to maximizing market output are explicit in Robert Dorfman, “Some Concepts from Welfare Economics,” in Robert Dorfman and Nancy Dorfman, eds., *Readings in Environmental Economics*, 2d ed. (New York: W. W. Norton, 1977).

sustainable trade, have hardly been touched upon. The "ecological footprint" has become a popular indicator of regional unsustainability and national unsustainable trade. However, recently one of us has argued that, like other one-dimensional measures of value, it suffers from severe methodological and theoretical shortcomings.¹¹

An instructive example of the extreme implications of weak sustainability in practice is the small Pacific island nation of Nauru.¹² In 1900 one of the world's richest phosphate deposits was discovered on Nauru and today, as a result of just over ninety years of phosphate mining, about eighty percent of the island is totally devastated. At the same time, the people of Nauru have had, over the past several decades, a high per capita income. Income from phosphate mining enabled the Nauruans to establish a trust fund estimated to be as large as \$1 billion. Interest from this trust fund should have insured a substantial and steady income and thus the economic sustainability of the island. Unfortunately, the Asian financial crisis, among other factors, has wiped out most of the trust fund. The people of Nauru now face a bleak future. Their island is biologically impoverished and the money Nauruans traded for their island home has vanished. The "development" of Nauru followed the logic of weak sustainability, and shows clearly that it may be consistent with a situation of near complete environmental devastation. More importantly, weak sustainability can cause extreme sensitivity to either natural disturbances (e.g., diseases in the case of agriculture focusing on only a few crops) or economic disturbances (international financial markets as in the case of Nauru). Such extreme sensitivity of regional systems to external factors illustrates a telling argument against weak sustainability. A substitution of natural for manufactured capital may be one-way: once irreplaceable natural resources are transformed into manufactured capital, there is no way to return to the original situation.¹³

III. STRONG SUSTAINABILITY

The alternative to weak sustainability is strong sustainability. In Brekke's words: "The second interpretation, known as '*strong* sustainability,' sees sustainability as non-diminishing life opportunities. . . . This should be achieved by conserv-

¹¹ See Jeroen C. J. M. van den Bergh and Harmen Verbruggen, "Spatial Sustainability, Trade and Indicators: An Evaluation of the 'Ecological Footprint,'" *Ecological Economics* 29 (1999): 63–74, and the comments by Wackernagel and Ferguson with reply by van den Bergh and Verbruggen in *Ecological Economics* 31 (1999): 317–21. A special issue of *Ecological Economics* 32, no. 3 (2000) was devoted to "The Ecological Footprint." For more on weak sustainability, see Maite Cabeza-Gutés, "The Concept of Weak Sustainability," *Ecological Economics* 17 (1996): 147–56.

¹² John M. Gowdy and Carl McDaniel, "The Physical Destruction of Nauru: An Example of Weak Sustainability," *Land Economics* 75 (1999): 333–38; Carl N. McDaniel and John M. Gowdy, *Paradise for Sale: A Parable of Nature* (Berkeley: University of California Press, 2000).

¹³ Many examples exist of the adverse consequences of substituting human-made for natural capital. For a discussion of the Easter Island case, see Jon Erickson and John M. Gowdy, "Resource

ing the stock of human capital, technological capability, natural resources and environmental quality.”¹⁴

Under the strong sustainability criteria, minimum amounts of different types of capital (economic, ecological, social) should be independently maintained, in real physical/biological terms. The major motivation for this insistence is derived from the recognition that natural resources are essential inputs in economic production, consumption, or welfare that cannot be substituted for by manufactured or human capital. A second possible motivation is quasi-moral, namely, acknowledgment of environmental integrity and “rights of nature.” A third is simply risk mitigation. In all three cases, it is understood that some environmental components are unique and that some environmental processes may be irreversible (over relevant time horizons).

“Very strong” sustainability—as supported by the deep ecology movement and those who believe in the “right-to-life” of other species—would then imply that every component or subsystem of the natural environment, every species, and every physical stock must be preserved.¹⁵ This criterion seems impossible, for three reasons. The first is probably sufficient: the dependence of our current industrial economy on primary resources. The second reason is that species and ecosystems are subject to continuous processes of natural change, and while human activity accelerates some of these processes and inhibits others, humans are—at the end of the day—a part of nature. A third reason is legal and philosophical: if other species have absolute rights, as argued for by some, those rights must contradict other rights, especially property rights, already enshrined in law and custom.

A compromise version of strong sustainability focuses on ecosystems and environmental assets that are critical in the sense of providing unique and essential services (such as life-support) or unique and irreplaceable services. The ozone layer is an example of the first; songbirds or coral reefs might be an example of the second. Another way of formulating such a compromise is that a minimum amount of certain environmental assets should be maintained, based on the idea that these assets are partly complementary to economic assets and partly substitutable by the latter.

Actually, both “weak” and “strong” criteria, as formulated above, involve an implicit assumption that may be challenged. They both imply a centralized decision-making process and a decision maker who decides on behalf of “society” among alternative programs and plans. But the real world is not at all like that. In reality, virtually all economic decisions are decentralized among many much narrower interests, namely individuals, family groups,

Use, Institutions and Sustainability: A Tale of Two Pacific Island Cultures,” *Land Economics* 76 (2000): 345–54.

¹⁴ Brekke, *Economic Growth and the Environment*, p. 91 (emphasis added).

¹⁵ Pearce and Atkinson, “Measuring Sustainable Development.”

communities of people with common interests, or firms. Even with the best intentions as regards future generations and planetary welfare, most decision makers will optimize within a much narrower context. On the other hand, if firms were to sell "services," rather than "products," and all material goods were regarded by producers as "capital" rather than "throughput," the incentives facing decentralized managers would be much more consistent with planetary sustainability. Decentralized decision makers at the family or firm level would not, and need not, choose between weak or strong.

IV. UTILITY AND SUBSTITUTION

The opposition between weak and strong sustainability has been reduced to the distinction between substitution and complementarity of natural and manufactured capital. This distinction has often been discussed in the context of production processes.¹⁶ However, the distinction also applies to consumption and individual welfare.

Economic theory begins with the notion of "economic man" or *Homo economicus*. Economic man enters an exchange market with an ordered set of conscious preferences for goods and services, which is assumed to be fixed and stable over time.¹⁷ How preferences are formed or whether they correspond to biology or physical reality is considered to be outside the scope of economics. There is no explicit notion in standard utility theory of humans as biological beings whose survival depends on harvesting biological products for food and other purposes. For example, our direct dependence on agriculture, in turn, results in an indirect dependence on the hydrological cycle, several nutrient cycles (C, N, S, P), the ozone layer for protection against UV radiation and a stable climate and biophysical environment. It is climatic stability over long time periods that allows humans and other long-lived plants and animals to develop and maintain effective defenses against biological attack by more rapidly evolving microorganisms.

This neglect of larger context is consistent with, and perhaps accounts for, the general hostility of the economic profession to the lexicographic preference ordering which denies universal substitutability. Yet, there is much evidence that lexicographic preference ordering is a better characterization than con-

¹⁶ See the special issue of *Ecological Economics* 22 (1997) on the contributions of Nicholas Georgescu-Roegen to ecological economics. See also D. Stern, "Limits to Substitution and Irreversibility in Production and Consumption: A Neoclassical Interpretation of Ecological Economics," *Ecological Economics* 22 (1997): 197-215; and Jeroen C. J. M. van den Bergh, "Materials, Capital, Direct/Indirect Substitution and Mass Balance Production Functions," *Land Economics* 75 (1999): 547-61.

¹⁷ Jeroen C. J. M. van den Bergh, Ada Ferrer-i-Carbonell, and Giuseppe Munda, "Alternative Models of Individual Behavior and Implications for Environmental Policy," *Ecological Economics* 32 (2000): 43-61.

tinuous and differentiable preference functions.¹⁸ The existence of lexicographic preferences casts doubt on the numerous attempts to measure preferences for characteristics of nature such as biodiversity.¹⁹ Stevens et al. concluded that when it came to "valuing" wildlife a majority of respondents used decision-making processes inconsistent with the neoclassical assumptions of universal substitution and trade-offs. Another common assumption is that preferences are fixed. However, there is evidence that preferences are changing and influenced in a coevolutionary way by culture and nature.²¹

Actually, it does matter what we believe. Our preferences, and our actions based on those preferences, have real consequences in the physical universe of which we are a part. Humans may "prefer" to use fossil fuels rather than solar energy, they may "prefer" to trade the Earth's biological diversity for consumer goods, but acting on these preferences will change the physical world we live in, probably for the worse. Such an outcome would presumably not be preferred.

In fact, preferences in the real world can be inconsistent, as several well-known paradoxes demonstrate. Transitivity is mathematically convenient but it is not necessarily a property of the real world. In reality, most people do not know what they prefer in many situations, because they do not know the whole range of possible choices, still less the consequences of the possible choices. In fact, the consequences may well be unknowable or incalculable. This is certainly the case for many long-term environmental policies.

V. VALUATION OF "NATURAL CAPITAL"

The relationship between valuation and sustainability has not received much attention. Valuation theory suggests that under weak sustainability the value of an environmental service can, under certain conditions, be approximated by the price of a market good that is a (close) substitute in production or consumption.²² Possibly, additional information on functional relationships in

¹⁸ Clive Spash and Nick Hanley, "Preferences, Information and Biodiversity Preservation," *Ecological Economics* 12 (1995): 191–208.

¹⁹ John M. Gowdy, "The Value of Biodiversity: Markets, Society and Ecosystems," *Land Economics* 73 (1997): 25–41.

²⁰ Thomas H. Stevens, Jaime Echeverria, Ronald J. Glass, Tim Hager, and Thomas M. Moore, "Measuring the Existence Value of Wildlife: What Do CVM Estimates Really Show?" *Land Economics* 67 (1991): 390–400.

²¹ Bryan Norton, Robert Costanza, and Richard Bishop, "The Evolution of Preferences: Why 'Sovereign' Preferences May Not Lead to Sustainable Policies and What to Do about It," *Ecological Economics* 24 (1998): 193–211.

²² A. Myrick Freeman III, *The Measurement of Environmental and Resource Values: Theory and Methods* (Baltimore: Resources for the Future, 1993); Richard C. Bishop and Richard T. Woodward, "Valuation of Environmental Quality Under Certainty," in Bromley, *Handbook of Environmental Economics*.

production or consumption is needed. Strong sustainability implies a complementary relationship between an environmental service and a market good in production or consumption, from which a shadow price can be derived (as long as nonuse values are zero).

Another approach to link sustainability and values is to look at the costs of unsustainability. In practice, the depreciation of natural capital is quantified only for market-priced extractive resources such as forest products, fish or minerals. Repetto and colleagues at the World Resources Institute have performed detailed studies for a number of countries, including Costa Rica, Indonesia and the Philippines.²³ This approach to estimating depreciation can be extended, in principle, to certain other environmental assets—such as topsoil or recreational land—which provide services with the potential for indirect market valuation, e.g., by correlating land prices with climatic and other variables.

However, this method breaks down completely when applied to other types of natural capital that do not yield a market product.²⁴ Examples include climatic stability, the hydrological cycle, the carbon, oxygen and nitrogen cycles, and biodiversity. Since there is no credible basis for assuming that human-made or human capital can substitute for essential ecosystem services such as these, the notion of weak sustainability can only be used as a negative indicator. That is, if the weak sustainability criterion is violated, our current socioeconomic system will not survive anyway. Linking to the earlier points on utility, the system inputs are lexicographically ordered.

Attempts to quantify the economic value of these ecosystem services in monetary terms have been undertaken recently.²⁵ In particular, the study by Costanza et al. concluded that the annual global value of ecosystem services is between \$17 trillion and \$54 trillion, with a “most likely” value of \$33 trillion. Most of the value measures were based on the product of marginal prices based

²³ Robert Repetto and Malcolm Gillis, eds., *Public Policies and the Misuse of Forest Resources* (Cambridge: Cambridge University Press, 1988); Robert Repetto et al., *Wasting Assets: Natural Resources in the National Income Accounts* (Washington, D.C.: World Resource Institute, 1989).

²⁴ There is, of course, a vast literature containing valiant attempts to put market prices on non-market goods. For an accessible discussion of the most commonly used current method, contingent valuation, see Bengt Kriström “Contingent Valuation,” in Jeroen van den Bergh, ed., *Handbook of Environmental and Resource Economics* (Cheltenham: Edward Elgar, 1999). Critiques of contingent valuation abound including Stevens et al., “Measuring the Existence Value of Wildlife: What do CVM Estimates Really Show?” and Arild Vatn and Daniel Bromley, “Choices without Prices without Apology,” *Journal of Environmental Economics and Management* 26 (1993): 129–48.

²⁵ Ismail Serageldin, *Sustainability and the Wealth of Nations: First Steps in an Ongoing Journey* (Washington, D.C.: World Bank, 1995); Robert Costanza, Ralph d’Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert O’Neill, José Paruelo, Robert Raskin, Paul Sutton, and Marjin van den Belt, “The Value of the World’s Ecosystem Services and Natural Capital,” *Nature* 387 (1997): 253–60.

on willingness to pay (WTP) times quantity—the price quantity product (PQP)—whereas the theoretically correct measure would have been consumer surplus (area under the demand curve and above the supply curve). It was therefore argued that the published numbers were in fact underestimates. One of the objections against this calculation is that it uses marginal valuation figures to support a valuation of the most extreme (non-marginal is an understatement) environmental change imaginable, namely the loss of all the world's ecosystems. Neither weak nor strong sustainability apply to such a change.

At any rate, the PQP for ecosystem services is certainly nonzero. On the basis of cost of protection and amelioration alone, it must be at least a few percent of GWP. Nevertheless, the consumer surplus value for some of these services can probably be regarded as *infinite*, for the simple reason that without some of the services in question the biosphere (and human life with it) could not survive. In conventional graphical terms, the demand curve for some ecosystems services becomes vertical before reaching the origin.

Clearly we cannot meaningfully quantify the depreciation of an infinite quantity by using fractional rates. However, the real depreciation loss is still finite near the margin, at least as long as the biosphere does not collapse. The main point of the exercise would be to estimate the rate of increase of depreciation as the system is perturbed further and further away from its historical coevolutionary equilibrium state.

Thus, even if the demand curves for essential ecosystem functions could be quantified only in this near-equilibrium region, the current and projected near-term depreciation loss could be estimated quantitatively. This estimate could contribute to making the Pearce-Atkinson criterion far more realistic.

The various sustainability measures—weak, strong, and Holling (see next section)—may require specific valuation approaches. This possibility needs to be examined before economic valuation of environment and nature can support the development of monetary indicators in the context of sustainability, such as a green or sustainable GDP. The outcome is very likely that each sustainability criterion gives rise to a unique valuation approach.

VI. NATURAL SCIENCE PERSPECTIVES AND SUSTAINABILITY

The practical expression of the strong sustainability concept is likely to be in terms of preservation of certain species (or genera), safe minimum standards for impacts on environmental quality, and sustainable use of renewable natural resources. Preservation of the physical magnitude of nonrenewable mineral resources would mean leaving them unused. One can interpret this criterion as derived from physical and ecological constraints (carrying capacity) receiving priority over everything else.

Many ecologists would support the idea that environmental sustainability is mainly a matter of stability, resilience, and biotic diversity. According to

Common and Perrings,²⁶ *stability* is defined at the level of biological populations. In other words, variables return to equilibrium values after perturbation. *Resilience* (resistance to change, or robustness) is defined at the system level and refers to maintenance of organization or structure and functions of an system in the face of stress. Perrings²⁷ mentions two variants: one is concerned with the time taken for a disturbed system to return to its initial state.²⁸ The other refers to the magnitude of disturbance that a system can absorb before it changes to another state.²⁹

Resilience can be considered as a global, structural stability concept, based on the idea that multiple locally stable ecosystem equilibria can exist. In other words, the stability of a local equilibrium of a system implies resilience of the respective system, but resilience does not necessarily go along with the stability of a (each) local equilibrium. Sustainability can thus be directly related to resilience, in the face of ecosystem stress relating to human influences.

Common and Perrings refer to this approach as ecological "Holling-sustainability."³⁰ Traditional economic models do not adequately address fluctuations and cycles. Business cycle theories might be useful in this respect.³¹ Indeed, one may wonder why other types of dynamic macroeconomics—apart from growth theory—have seen so little application in environmental economics, for example, to address questions related to the interaction between sustainability and unemployment. Neoclassical models do not incorporate any information about actual ecosystem structure. In order to be able to deal with stability and uncertainty in a way consistent with ecological theory, integration of economic and ecological models is necessary. Unless externalities cover dynamic impacts—including evolutionary effects of activities and decisions made now—"internalization" or "optimization" of such externalities is inadequate to realize environmental sustainability in the sense of Holling. This perspective can be linked to the one of strong sustainability, by recognizing that maintenance of natural capital does require a precautionary approach which takes safety margins into account, as stability is not guaranteed by operating at the margin of optimal levels of capital.

²⁶ Common and Perrings, "Towards an Ecological Economics of Sustainability."

²⁷ Charles Perrings, "Resilience in the Dynamics of Economy-Environment Systems," *Environmental and Resource Economics* 11 (1998): 503–20.

²⁸ Crawford S. Holling, "The Resilience of Terrestrial Ecosystems: Local Surprise and Global Change," in William C. Clark and R. C. Munn, eds., *Sustainable Development of the Biosphere* (Cambridge: Cambridge University Press, 1986).

²⁹ Crawford S. Holling, "Resilience and Stability of Ecological Systems," *Annual Review of Ecological Systems* 4 (1973): 1–24.

³⁰ Common and Perrings, "Towards an Ecological Economics of Sustainability," based on Holling, "Resilience and Stability of Ecological Systems."

³¹ See Carlos E.F. Young, "Effective Demand and 'Weak' Sustainability: A Macroeconomic Model," in Jeroen C. J. M. van den Bergh and Jan van der Straaten, eds., *Economy and Ecosystems in Change: Analytical and Historical Approaches* (Cheltenham: Edward Elgar, 1996).

As noted earlier, the operational principles of the Hartwick-Solow sustainability approach were formulated in terms of investment rules. By contrast, in the case of Holling sustainability the operational implications can be formulated along two dimensions. First, "creative destruction" should be allowed. In other words, control for purposes of preservation should not be too tight. An example is excessively vigorous fire suppression in forest ecosystems that leads to accumulation of biomass and subsequently to fires with extreme temperatures that destroy many of the seeds needed for recovery.³² Second, human influences on remaining natural ecosystems should be reduced to an absolute minimum, without any lower bound. Another difference relates to the sort of (un)sustainability indicators to be used. The Hartwick-Solow approach implies value based indicators; the Holling approach implies physical and biological indicators. In terms of concrete implications the "weak sustainability" approach of Hartwick-Solow is further away from Holling sustainability than the "strong sustainability" approach. Nevertheless, the motivations for the latter two approaches are quite different.

VII. CONSISTENCY BETWEEN SCIENCES

The above mentioned perspectives on sustainability are not necessarily in disagreement with each other. It is possible that they give rise to similar or identical conclusions in some specific cases. The important point, however, is that they may also lead to different and possibly conflicting conclusions, in some situations. When conflicts occur, one has to make a choice. In view of the fundamental differences of perspectives/starting points, such choices may seem to some to be largely a subjective issue, while to others they may appear to be amenable to scientific analysis.

E. O. Wilson lists several qualities of good theory in general and mathematical models in particular. Among these is "consilience," that is, "Units and processes of a discipline that conform with solidly verified knowledge in other disciplines have proven consistently superior in theory and practice to units and processes that do not conform."³³ The economic notion of weak sustainability does not pass the test of consilience with the established laws of biological and physical science. Weak sustainability cannot be reconciled with accepted knowledge from other sciences or even subdisciplines within economics, with respect to the following points:

(1) The economic characterization of preferences emphasizing substitution between consumed goods and services is inconsistent with accepted findings and principles from psychology, biology, and is at odds with empirical results from environmental economics, in particular in economic valuation studies.³⁴

³² Holling, "Resilience of Terrestrial Ecosystems."

³³ Wilson, *Consilience*, p. 198.

³⁴ Spash and Hanley, "Preferences, Information and Biodiversity Preservation."

The assumption that preferences are lexicographic is realistic, notably in the context of trading-off economic and environmental services. However, they receive no serious attention, in spite of the fact that they imply a shift in emphasis from weak to strong sustainability.

(2) The foundation of weak sustainability developed in economic growth theory (by Hartwick and Solow) was formulated explicitly for nonrenewable resources, not for complex biological systems. In ecological systems sustainability is related to resilience to perturbations. Moreover, the tools of growth theory—deterministic dynamic optimization models with one dynamic equation describing the environment—are too rough to incorporate scientific findings describing living evolutionary systems. Therefore, growth theory cannot offer a complete, and perhaps not even relevant, perspective on sustainability (although it can of course be useful for studying economic growth in other contexts and related to other questions).

(3) Production functions in the standard analysis of economic growth and environmental sustainability assume unlimited substitution options in physical terms. In many cases the results cannot really be interpreted, due to the fact that there is no clear relationship between physical and value units—for process inputs and outputs. A recent discussion on this issue was presented in a special issue of the journal *Ecological Economics*.³⁵

(4) Whereas global sustainability and sustainable development have received an enormous amount of attention, their implications for open systems like regions and countries have not been dealt with systematically. The large and growing literature on international trade and environment adopts essentially a static perspective, focusing mainly on policies to deal with “externalities.” Regional and national sustainability should be consistent with global sustainability. Their analysis requires an integration of insights in growth theory, international trade theory, resource economics, and ecology. No one has yet succeeded to doing so, and it seems likely that analytical approaches will fall short in this respect. Moreover, possibly the various sustainability criteria differ in terms of spatial implications.

For the present, we pass on the most interesting question, which might be recast as “under what specific conditions/circumstances could the Hartwick-Solow criteria be accepted—if any?” In more familiar language, for what questions is a weak sustainability test adequate, and conversely, for what questions must we adopt a stricter test?

VIII. CONCLUSIONS

Much of the confusion in the discussion of strong sustainability arises from

³⁵ *Ecological Economics* 22 (1997). For an evaluation of the literature and a proposal for production functions consistent with mass balance, see van den Bergh, “Materials, Capital, Direct/Indirect Substitution and Mass Balance Production Functions.”

a failure to distinguish between the two assumptions dividing weak and strong sustainability. The first is the assumption of substitutability between natural, human and manufactured capital. The second is that economic well-being "covers" all other concerns. If the second assumption is accepted (as it sometimes is by advocates of strong sustainability), then the argument about substitutability boils down to a purely economic debate about elasticities of substitution, technological advances and so on. If, on the other hand, substituting manufacturing (or its incarnation as financial capital) for natural resources is incompatible with maintaining a suitable physical environment for the human species, then strong sustainability implies that we must step outside the conventional market framework in order to establish the conditions for maintaining human happiness. Related is the conclusion that the various sustainability criteria—weak, strong, and Holling—imply specific valuation approaches to support monetary indicators in the context of sustainability, such as a green or sustainable GDP. Markets work only in carefully defined and constrained contexts. Policies for sustainability should consider not only the limits to market solutions, but also maintaining the context in which markets operate. Natural sciences—in particular, ecology—and economics have different interpretations of sustainability. The differences seem to derive from the distinct focal points of each. The economic approach focuses on long-term allocation of capital on the basis of dynamic macro-level optimization models. Uncertainty is reduced to risk. The ecological approach emphasizes pure uncertainty and surprises with micro-level descriptions of ecosystem dynamics. In terms of its implications, the Hartwick-Solow "weak sustainability," which is directly linked to the growth theory approach, is further away from the ecological Holling sustainability than the "strong sustainability" approach. Nevertheless, the latter two focus on different aspects, namely, ecosystem resilience and complementarity of economic and ecological systems, respectively.

Bromley suggests that we move away from "sustainability" to "social bequests": "This approach liberates us from a zero-sum game in which our gain is an automatic loss for future generations. Regard for the future through social bequests shifts the analytical problem to a discussion about deciding what, rather than how much, to leave for those who will follow."³⁶ If we cast the problem as "how much," the question and the answer will always imply that some amount of a resource should be used and some amount left. We use twenty-five percent of a rainforest and leave the rest, for example. But then the next time we make a decision, we start all over again and use twenty-five percent of what's left, and so on, until it is all gone. By focusing on bequests of specific rights and opportunities for future generations, we can get away from the straightjacket of substitution and marginal trade-offs.

³⁶ Daniel W. Bromley, "Searching for Sustainability: The Poverty of Spontaneous Order," *Ecological Economics* 24 (1998): 231–40.