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The Capital Theory Approach to Sustainability: A Critical Appraisal

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The Brundtland Report [WCED 1987] proposed that sustainable development is "development that meets the needs of the present generation while letting future generations meet their own needs." Economists initially had some difficulty with this concept; some dismissed it,[1] and others proliferated a vast number of alternative definitions and policy prescriptions [see surveys by Pezzey 1989; Pearce et al. 1989; Rees 1990; Lélé 1991].

In recent years, economists have made progress in articulating their conception of sustainability. The large number of definitions of sustainability proposed in the 1980s has been synthesized into a smaller number of positions in the 1990s.[2] There is agreement that sustainability implies that certain indicators of welfare or development are non-declining over the very long term; that is, development is sustained [Pezzey 1989]. Sustainable development is a process of change in an economy that does not violate such a sustainability criterion. Beyond this, the dominant views are based on the idea of maintaining a capital stock as a prerequisite for sustainable development. Within this school of thought there are, however, opposing camps that disagree on the empirical question of the degree to which various capital stocks can be substituted for each other, though there has been little actual empirical research on this question.

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There is a consensus among a large number of economists that the capital theory approach (CTA) is a useful means of addressing sustainability issues.[3] Capital theory concepts are beginning to inform policy, as in the case of the U.N. recommendations on environmental accounting and the U.S. response to them [Carson et al. 1994; Steer and Lutz 1993]. There are also a growing number of critics who question whether this is a useful way to address sustainability [e.g., Norgaard 1991; Amir 1992; Common and Perrings 1992; Karshenas 1994; Pezzey 1994; Common and Norton 1994; Faucheux et al. 1994; Common 1995].

The aim of this paper is to present a critique of the capital theory approach to sustainability. This critique outlines both the difficulties in using and applying the CTA from a viewpoint internal to neoclassical economics and the problems with this approach from a viewpoint external to neoclassical economics. The critique includes an analysis of the compatibility of sustainability, as originally conceived in the Brundtland Report and elsewhere, with the institutionalist approach of instrumental valuation. I also suggest some alternative approaches to sustainability-relevant analysis and policy.[4]

The Shifting Debate: Emergence of the Capital Theory Approach

The concept of sustainable development first appeared in the World Conservation Strategy put forward by the International Union for the Conservation of Nature in 1980 [IUCN 1980; O'Riordan 1988]. The most important aspect of this formulation was the argument that not only the affluent, developed countries were capable of degrading the environment. Poverty, especially when combined with population growth, was seen as a potential cause of environmental degradation, but degradation would also undermine development and lead to the perpetuation of poverty.[5] This marked a break with mainstream environmentalist thought, which viewed economic growth as the enemy of environmental quality. The World Commission on Environment and Development, chaired by Gro Harlem Brundtland, expanded the scope of sustainable development to the global scale: "Sustainable development becomes a goal not just for developing nations but for industrial ones as well" [WCED 1987, 4]. In *Our Common Future,* the WCED advanced the definition: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [WCED 1987, 43].

This statement implies that there are both basic needs and limits or constraints on economic activity that stem from both the human (i.e., how resources are used over time) and physical dimensions of the economy-environment system. Immediately following this definition, it is stated that sustainability is a universal or global goal and that even the "narrow notion of physical sustainability implies a concern for social equity between generations, a concern that must logically be extended to equity within each generation" [WCED 1987, 43]. Obviously, the views of the commission are not compatible with the normative theory of neoclassical economics. Not only do neoclassical economists conventionally dismiss the notion of basic needs [Hodgson 1988], but they have been historically very resistant to the idea that there may be necessary limits to economic growth. The remainder of the report itself fudges many of these issues, arguing, on the basis of little or no evidence, that growth did not need to stop, but rather could be accelerated and change direction and that such growth could be sustainable. In Judith Rees's [1990] and Sharachchandra Lélé's [1991] words, "It allows us to have our cake and eat it too" [Rees 1990, 435]. Though "a brilliant political document" [Common 1995, 3] that was constructed to raise the largest constituency possible for the goal of sustainable development, *Our Common Future* is a mass of contradictory statements and unfounded assertions.

It is not, therefore, very surprising that neoclassical economists initially had some difficulty with the concept of sustainability, with some dismissing it [Pearce 1994] and others proliferating a vast number of alternative definitions and policy prescriptions [see surveys by Pezzey 1989; Pearce et al. 1989; Rees 1990; Lélé 1991]. Additionally, the contradictory nature of *Our Common Future* and similar documents did not help to produce clarity among other schools of thought. As a result, much of the literature on sustainable development published in the late 1980s was vague about the definition of sustainability and the policies needed to achieve it [see Lélé 1991; Rees 1990; Simonis 1990; Stern 1994; Tisdell 1988].

In the 1990s, many people have put forward more precisely articulated definitions of sustainable development, conditions and policies required to achieve sustainability, and criteria to assess whether development is sustainable. With this has come a clearer understanding of what kinds of policies would be required to move toward alternative sustainability goals and of what are the limits to our knowledge. There is a general consensus, especially among neoclassical economists, about the principal definition of sustainable development used by David Pearce et al. [1989; 1991]: non-declining average human welfare over time [Mäler 1991; Pezzey 1992; Toman et al. 1994].[6] This definition of sustainability implies a departure from the strict principle of maximizing net present value in traditional cost benefit analysis [Pezzey 1989], but otherwise it does not imply a large departure from conventional economics. John Pezzey [1989; 1994] suggests a rule of maximizing net present value subject to the sustainability constraint of non-declining mean welfare.

The definition enunciated above encompasses many but not all definitions of sustainability. Quite clearly there is no concern here with intragenerational distribution, and therefore this definition goes against the letter and spirit of the Brundtland Report. Both the WCED and other analysts [e.g., Common 1995; Haas et al. 1994; O'Connor 1993a] argue that without a greater degree of intragenerational equity sustainability is unachievable. The developing countries and the low-income voters of the developed economies who constitute the majority of the world population will not agree to necessary sacrifices for the goal of sustainability unless the distribution of sacrifice is considered fair [see Arnoux et al. 1993], or they receive compensation for their losses from those more able to pay. Neither does it include a definition of sustainability based on maintaining a set of ecosystem functions, which seems to be implied by the Holling-sustainability criterion [Common and Perrings 1992; Holling 1973; 1986], or on maintaining given stocks of natural assets irrespective of any contribution to human welfare. Narrowly defined, a sustainable ecosystem could be too strict a criterion for the goal of maintaining human welfare [Karshenas 1994] and could in some circumstances lead to declining human welfare.[7] Not all ecosystem functions and certainly not all natural assets may be necessary for human welfare. Some natural phenomena, such as wildfires, and natural assets, such as smallpox bacteria, may be detrimental to people.

The advantage of formalizing the concept of sustainability is that this renders it amenable to analysis by neoclassical economic theory [e.g., Barbier and Markandya 1991; Victor 1991; Common and Perrings 1992; Pezzey 1989, 1994; Asheim 1994] and to quantitative investigations [e.g., Repetto et al. 1989; Pearce and Atkinson 1993; Proops and Atkinson 1993; Stern 1995]. Given the above formal definition of sustainability, many economists have examined what the necessary or sufficient conditions for the achievement of this limited definition of sustainability might be. Out of this activity has come the CTA described in the next section. The great attractiveness of this new approach is that it suggests relatively simple rules to ensure sustainability and relatively simple indicators of sustainability. This situation has seemingly cleared away the vagueness that previously attended discussions of sustainability and prompted relatively fast action by governments and international organizations to embrace specific goals and programs aimed at achieving this notion of the necessary conditions for sustainability.

The Essence of the Capital Theory Approach

The origins of the CTA are in the literature on economic growth and exhaustible resources that flourished in the 1970s, exemplified by the special issue of the *Review of Economic Studies* published in 1974 [Heal 1974]. Robert Solow [1986] built on this earlier literature and the work of John Hartwick [1977; 1978a 1978b] to formalize the constant capital rule. In these early models, there was a single, nonrenewable resource and a stock of manufactured capital goods. A production function produced a single output using these two inputs. This output could be used for either consumption or investment. The elasticity of substitution between the two inputs was unity, which implied that natural resources were essential but that the average product of resources could rise without bound given sufficient manufactured capital. In other words, all the models assume that sustainability is technologically feasible and examine under what institutional conditions sustainable development actually will be achieved.

The models express the notion of sustainability as non-declining welfare through the assumption that welfare is a monotonically increasing function of consumption [e.g., Mäler 1991]. The path of consumption over time (and therefore of the capital stock) in these model economies depends on the intertemporal optimization rule, which represents the institutional structure. Under the Rawlsian maxi-min condition, consumption must be constant. No net saving is permissible as this is regarded as an unjust burden on the present generation. Under the Ramsey utilitarian approach with zero discounting, consumption can increase without bound [Solow 1974]. Here the present generation may be forced to accept a subsistence standard of living if this can benefit future generations, though the latter may be much richer. Paths that maximize net present value with positive discount rates typically peak and then decline so that they are not sustainable [Pezzey 1994]. This is the best that a pure competitive market economy with no externalities can achieve. Pezzey [1989] and Geir Asheim [1991] suggest a hybrid version that maximizes net present value subject to an intertemporal constraint that utility be non-declining. In this case, utility will first increase until it reaches a maximum sustainable level. This has attracted consensus among neoclassical sustainability analysts as the general optimizing criterion that best characterizes sustainable development.

Under the assumption that the elasticity of substitution is one, non-declining consumption depends on the maintenance of the aggregate capital stock, i.e., conventional capital[8] plus natural resources, used to produce consumption and investment goods [Solow 1986]. Aggregate capital, W_t, and the change in aggregate capital are defined by:

$$W_t = p_{Kt}K_t + p_{Rt}S_t \tag{1}$$

$$\Delta W_t = p_{Kt}\Delta K_t - p_{Rt}R_t \tag{2}$$

where S is the stock of nonrenewable resources and R the use per period. K is the manufactured capital stock, and the p_i are the relevant prices. In the absence of depreciation of manufactured capital, maintenance of the capital stock implies investment of the rents from the depletion of the natural resource in manufactured capital–the Hartwick rule [Hartwick 1977; 1978a; 1978b]. Following John Hicks [1946], sustainable income is defined as the maximum consumption in a period consistent with the maintenance of aggregate capital intact [Weitzman 1976; Mäler 1991], and for a flow of income to be sustainable, the stock of capital needs to be constant or increasing over time [Solow 1986]. Technical change and population growth introduce complications but can be accommodated [see Solow 1986].

The definition of capital that satisfies these conditions must include all the productive assets available to the economy. The major subcategories of this "capital" are natural, manufactured, human, and moral, ethical [Hirsch 1976], cultural [Berkes and Folke 1992], or institutional capital. Natural capital is a term used by many authors (it seems Smith [1977] was the first) for the aggregate of natural resource stocks that produce inputs of services or commodities for the economy. Some of the components of natural capital may be renewable resources. Manufactured capital includes machinery, structures, etc., or what is more commonly referred to as just capital. Human capital follows the standard definition. Institutional capital includes the institutions and knowledge necessary for the organization and reproduction of the economy. For convenience, I give the name "artificial capital" to the latter three categories jointly. None of these concepts is unproblematic, but I will concentrate on the problems with the concept of natural capital.

Empirical implementation of the CTA tends to focus on measurement of sustainable income [e.g., El Serafy 1989; Repetto et al. 1989] or net capital accumulation [e.g., Pearce and Atkinson 1993; Proops and Atkinson 1993] rather than on direct estimation of the capital stock.[9] Any sustainability indices that attempt to make even a first approximation to reality must take into account population growth and technical change as well as changes in human capital. None of the recent empirical studies does so.[10] For example, David Pearce and Giles Atkinson [1993] present data from 18 countries on savings and depreciation of natural and manufactured capital as a proportion of GNP. They demonstrate that only eight countries had non-declining stocks of total capital, measured at market prices, and thus passed a weak sustainability criterion of a constant aggregate capital stock, but their methodology ignores population growth, human capital, or technological change.

Internal Appraisal of the Capital Theory Approach

In this section, I take as given the basic assumptions and rationale of neoclassical economics and highlight some of the technical problems that are encountered in using the CTA as an operational guide to policy. In the following section, I take as given solutions to these technical difficulties and examine some of the problems inherent in the normative neoclassical approach to sustainability.

Limits to Substitution in Production and "Strong Sustainability"

Capital theorists are divided among proponents of weak sustainability and strong sustainability. This terminology is confusing as it suggests that the various writers have differing definitions of sustainability.[11] In fact, they agree on that issue but differ on what is the minimum set of necessary conditions for achieving sustainability. The criterion that distinguishes the categories is the degree of substitutability believed to be possible between natural and artificial capital.[12]

The weak sustainability viewpoint follows from the early literature and holds that the relevant capital stock is an aggregate stock of artificial and natural capital. Weak sustainability assumes that the elasticity of substitution between natural capital and artificial capital is unity and that therefore there are no natural resources that contribute to human welfare that cannot be asymptotically replaced by other forms of capital. Reductions in natural capital may be offset by increases in artificial capital. It is sometimes implied that this might be not only a necessary condition, but also a sufficient condition for achieving sustainability [e.g., Solow 1986; 1993].

Proponents of the strong sustainability viewpoint, such as Robert Costanza and Herman Daly [1992], argue that though this is a necessary condition for sustainability it cannot possibly be a sufficient condition. Instead, a minimum necessary condition is that separate stocks of aggregate natural capital and aggregate artificial capital must be maintained. Other analysts, such as members of the "London School," hold views between these two extremes [see Victor 1991]. They argue that, though it is possible to substitute between natural and artificial capital, there are certain stocks of "critical natural capital" for which no substitutes exist. A necessary condition for sustainability is that these individual stocks must be maintained in addition to the general aggregate capital stock.

The weak sustainability condition violates the Second Law of Thermodynamics, as a minimum quantity of energy is required to transform matter into economically useful products [Hall et al. 1986] and energy cannot be produced inside the economy.[13] It also violates the First Law on the grounds of mass balance [Pezzey 1994].[14] Also, ecological principles concerning the importance of diversity in system resilience [Common and Perrings 1992] imply that minimum quantities of a large number of different capital stocks [e.g., species] are required to maintain life-support services. The London School view and strong sustainability accommodate these facts by assuming that there are lower bounds on the stocks of natural capital required to support the economy, in terms of the supply of materials and energy and in terms of the assimilative capacity of the environment, and that certain categories of critical natural capital cannot be replaced by other forms of capital.

Beyond the necessary conditions imposed by thermodynamics, it is an empirical question as to how far artificial capital can substitute for natural capital. There has been little work on this at scales relevant to sustainability. However, the econometric evidence from studies of manufacturing industry suggest on the whole that energy and capital are complements [Berndt and Wood 1979].

In some ways, the concept of maintaining a constant stock of aggregate natural capital is even more bizarre than maintaining a non-declining stock of total capital. It seems more reasonable to suggest that artificial capital might replace some of the functions of natural capital than to suggest that, in general, various natural resources may be substitutes for each other. How can oil reserves substitute for clean air or iron deposits for topsoil? Recognizing this, some of the strong sustainability proponents have dropped the idea of maintaining an aggregate natural capital stock as proposed by Costanza and Daly [1992] and instead argue that minimum stocks of all natural resources should be maintained [Faucheux and O'Connor 1995]. However, this can no longer really be considered an example of the CTA. Instead it is an approach that depends on the concept of safe minimum standards or the precautionary principle. The essence of the CTA is that some aggregation of resources using monetary valuations is proposed as an indicator for sustainability.

Construction of aggregate indices or subindices of inputs depends on the production function being weakly separable in those subgroups [Berndt and Christensen 1973]. For example, it is only possible to construct an index of aggregate natural capital if the marginal rate of substitution between two forms of natural capital is independent of the quantities of labor or capital employed. This seems an unlikely proposition as the exploitation of many natural resources is impractical without large capital stocks. For example, in the production of caught fish, the marginal rate of substitution, and under perfect competition the price ratio, between stocks of freshwater fish and marine fish should be independent of the number of fishing boats available. This is clearly not the case. People are not likely to put a high value on the stock of deep-sea fish when they do not have the boats necessary to catch them.

If substitution is limited, technological progress might reduce the quantity of natural resource inputs required per unit of output. However, there are arguments that indicate that technical progress itself is bounded [see Pezzey 1994; Stern 1994]. One of these [Pezzey 1994] is that, just as in the case of substitution, ultimately the laws of thermodynamics limit the minimization of resource inputs per unit output. David Stern [1994] argues that unknown useful knowledge is itself a nonrenewable resource. Technological progress is the extraction of this knowledge from the environment, and the investment of resources in this activity will eventually be subject to diminishing returns.

Limits to substitution in production might be thought of in a much broader way to include nonlinearities and threshold effects. This view is sometimes described as the "ecological" viewpoint on sustainability [Common and Perrings 1992; Common 1995] or as the importance of maintaining the "resilience" of ecological systems rather than any specific stocks or species. This approach derives largely from the work of Buzz Holling [1973; 1986]. In this view, ecosystems are locally stable in the presence of small shocks or perturbations but may be irreversibly altered by large shocks. Structural changes in ecosystems, such as those that come about through human interference, particularly simplification, may make these systems more susceptible to losing resilience and being permanently degraded. There is clearly some substitutability between species or inorganic elements in the role of maintaining ecosystem productivity; however, beyond a certain point, this substitutability may suddenly fail to hold true. Following Holling [1986], Charles Perrings

[1994b] argues that as both ecosystems and economies accumulate biomass or capital they can become increasingly fragile and prone to the effects of external shocks. Also, as the economy increasingly dominates its environment, it has less capacity to use the environment to buffer such shocks. The system is said to become less resilient. Perrings and Pearce [1993] argue that a laissez-faire economy existing in an environment subject to threshold effects will tend to operate close to such thresholds, thus making itself more susceptible to shocks. A classic case is pastoral agricultural systems in Sub-Saharan Africa subject to cyclical variations in rainfall such as the rangelands of Botswana. During rainy periods, livestock numbers tend to increase toward the current carrying capacity of the system. The decrease in carrying capacity during dry periods causes overgrazing, die-offs of livestock, and possibly permanent degradation of the rangeland [Perrings and Stern 1995].

A quite different approach to sustainability policy emerges from these considerations. It is probable that substitution between natural and artificial capital is limited, as is ultimately technical change, and the joint economy-ecosystem system may be subject to nonlinear and discontinuous dynamics. This implies that the best that the economy can achieve is to approach a steady state where the maximum sustainable volume of physical economic activity is dependent on the profit- [or utility] maximizing use of renewable resources subject to the sustainability constraint. As suggested by Daly [1977], qualitative change in the nature of economic output is still possible. Sustainability policy would require not just maintaining some stocks of renewable resources, but also working to reduce "threats to sustainability" [Common 1995] that might cause the system to pass over a threshold and reduce long-term productivity.

The problems with the CTA also apply in the context of the firm from which the concept is originally derived [Faucheux and O'Connor 1995]. Here, also, it is not apparent that the myopic policy of maintaining capital intact from year to year is the best or only way to ensure the maintenance, i.e., sustainability, of profits into the future. If a competing firm makes an innovation that renders the firm's capital stock obsolete, the latter's income may drop to zero. For example, the introduction of audio CDs quickly rendered vinyl records obsolete. This occurs despite the firm previously following a policy of maintaining its capital intact. The firm's income measured up to this point is clearly seen to be unsustainable. In fact, its policy has been shown to be irrelevant to sustainability. In the real world, firms will carry out activities that may not contribute to the year-to-year maintenance of capital and will reduce short-term profits by diverting revenue to such activities as research and development and diversification and by attempting to gain market share at the expense of maximizing profit.[15] For example, a company that diversified to also produce cassette tapes would have fared better than one that just produced records. These activities make the firm more resilient to future shocks and hence enhance its sustainability. The economy as a whole is participating in "a game against nature."

Unexpected innovations on the part of nature may cause the myopic economy to suffer a rapid decline in income. For example, an economy locked into coal-fired technologies will find it hard to adapt in the face of rapid global warming. An economy that diverts income to the research and development of alternative energy technologies will find it far easier to adapt and maintain income.[16]

Prices for Aggregation

Supposing that the necessary separability conditions are met so that aggregation of a capital stock is possible, analysts still have to obtain an appropriate set of prices so that the value of the capital stock is a sustainability-relevant value. The CTA is more or less tautological if we use the "right" prices. However, these correct "sustainability prices" are unknown and unknowable. A number of related arguments have been made,[17] but seemingly the most general argument is made by Pezzey [1994].

Pezzey's detailed argument is presented in the context of the Dasgupta and Heal [1974] and Solow [1974] models of a closed economy with capital accumulation and nonrenewable resource depletion with no technical progress, but many of the propositions have more general validity. Though his wording is somewhat enigmatic, Solow [1986] appeared (and has been widely understood) to claim that in such models non-declining aggregate wealth measured at competitive market prices along an efficient path (i.e., net present value [NPV] maximizing) guarantees sustainability. This turns out to be incorrect. As the 1974 literature showed, only at zero discount rates is an efficient path a sustainable path in this type of economy; at positive discount rates, an NPV-maximizing consumption path will peak and then decline monotonically.[18] Pezzey shows that there will then be a finite time period during which the economy is unsustainable (i.e., the current level of consumption cannot be maintained indefinitely), but aggregate wealth is rising. Hence, the maximum level of consumption that can be maintained indefinitely may be less than current consumption despite non-declining aggregate wealth. Furthermore, adopting a policy during the above finite time period that maintains the aggregate capital stock does not guarantee sustainability, because consumption must drop at the instant that the policy is adopted. Intuitively, the sustainability-relevant shadow price of the resource exceeds its market rent. Related results have been derived by Asheim [1994]. Pearce [1994], a major proponent of the CTA, concedes that this point may have important and negative implications for "green" accounting.

The further we depart from simple neoclassical growth models, the more distant is the prospect of finding the "true" sustainability prices. It becomes impossible when we consider nonlinearities, such as discontinuous changes in environmental parameters, as critical thresholds that are passed and irreversibilities such as species extinctions occur. There is an inherent danger in using rigid rules in a nonlinear and evolving economy-environment system. Richard Norgaard [1994] and Charles Perrings [1987] have both examined this question and argue that institutions, such as fixed property rights in nature, are likely to exacerbate environmental problems rather than reduce them. Perrings [1987, 94] argues against placing prices on *in situ* environmental resources under any circumstances, stating "few other ideas in economic theory can be so obviously misplaced."

Many environmentalists, and some environmental economists, argue that any positive prices for natural resources are better than zero prices. Michael Common [1995] argues that unless the new prices are the "true" sustainability prices, the shift in relative prices between different resources after positive prices are imposed may lead to the overexploitation of resources that are now relatively cheaper than in the previous state. This is especially important if the price ratio shifts against resources that are relatively more crucial for sustainability. Non-market pricing methodologies, such as contingent valuation, are likely to lead to higher prices for more aesthetically attractive resources or species. These resources may not be the most crucial for life support. In this case, development pressure will be deflected to the more critical resource.[19]

Limits to Substitution in Consumption[20]

Limited substitution possibilities in consumption may also make it impossible to derive meaningful capital aggregates that are monotonically related to welfare. I examine two significant sources of this phenomenon: basic subsistence needs and the direct role of environmental assets in welfare.

Certain goods that fulfill basic needs must be consumed, e.g., food, shelter, etc. It is apparent that at least minimal natural resource inputs are necessary to produce these goods and services. The case of food is clear–people must be able to capture energy from the environment in a form suitable for metabolism. Also, minimal material and energy inputs will be required to buffer or separate people from the vagaries of the external environment. Therefore, at least in producing these products, the average product of resources is bounded, and as these goods must appear in total output the ratio of total output to resource input must be bounded. This argument has been made most strongly by Daly [1977]. However, it is still often claimed that what is valued may be purely the product of human psychology [e.g., Pezzey 1994] and that there is no way to know if the ratio of the value of output to resource input is limited.

With limited exceptions [e.g., Vousden 1973; Krautkraemer 1985], the literature on resource depletion and sustainability has paid little attention to the direct value people might attribute to natural resources apart from their use in production. On the other hand, a large literature in environmental economics has attempted to estimate "existence values" and other non-consumptive use values for environmental assets. However, both the methodology used to assess these prices and their use in national accounts depend on substitutability assumptions [Common et al. 1994; Spash and Hanley 1995]. Limits to substitution between manufactured goods and services, produced by both artificial and natural capital, and natural capital in consumption or household production may stem from both utilitarian and non-utilitarian reasons.

Neil Vousden [1973] represented utilitarian limits to substitution in consumption by modifying the standard Dasgupta-Heal economy described above to allow the resource stock to enter the utility function. This would be reasonable if, for example, resource extraction means converting an environment into a less desirable form such as in opencast quarrying. Then, unless natural resources and produced goods and services are close substitutes in consumption, substitution of artificial capital for natural resources cannot indefinitely guarantee the maintenance of non-declining utility. At some point, the added utility from produced commodities and services will be smaller than the lost utility from converted environments. For example, assume that the utility function is a CES function and that the elasticity of substitution in consumption between resources and consumption goods is less than one. Given that the resource is nonrenewable and essential, even a constant level of welfare will not be possible, and utility must eventually decline.

From a non-utilitarian perspective, intrinsic value in nature may also limit consumption substitution possibilities. Intrinsic value may either be expressed as a right of a species or individuals of a species to exist or not be harmed, or as a limit on human rights of action with respect to nature. The former might be characterized as a rights-based belief system [Spash and Hanley 1995], which extends the humanist ethic to other species and/or inanimate nature. The latter is more characteristic of a religious ethic that does not assign rights to other organisms but does not believe humans have any intrinsic right to alter nature.[21] When views on intrinsic value are strongly held, they will be expressed in the form of lexicographic preferences [Edwards 1986; 1992] that do not allow any substitution. Both Stevens et al. [1991] and Spash and Hanley [1995] provide empirical evidence of the existence of such lexicographic preferences for wildlife. Dan Vadnjal and Martin O'Connor [1994] suggest the same in regard to unique landscapes.

External Appraisal of the Capital Theory Approach

A General Critique

Any conditions or indicators for sustainability derived from the CTA are only true indicators that society is developing sustainably under limited and unlikely conditions that are specific to the particular model of the economy that is implicitly or explicitly assumed. Common expresses this view:

> There is no prospect of a unique measure of PNDP [proper net domestic product]. What this approach would measure is PNDP for a model, not PNDP for an actual economy. And, the nature of adjustments to conventionally assessed NDP . . . would also be model dependent . . . [Sustainability] is not a problem that can be reduced to the dimensions of a single number indicator [1993, 8-11]

CTA analysis, or "green accounting," is as dependent on a specific underlying model of the economy as macroeconomic forecasting. Nevertheless, measures of sustainable income or net capital accumulation are given more credibility than is given to macroeconomic forecasts over a very short time horizon of a couple of years or so. The accuracy of sustainable income figures is comparable to macroeconomic forecasts over time horizons of a century or more. The opaque nature of the indices of sustainable income or aggregate capital that result from capital theory analysis often hides the restrictive assumptions underlying these models. The macroeconomic models used in forecasting are usually less restrictive in nature, and the assumptions are clearly laid out in the form of the model equations. Many of the assumptions underlying capital theory analysis are usually implicit rather than openly expressed. Despite the more complex nature of macroeconomic models, they have frequently been criticized for "incredible restrictions" [Sims 1980], and the forecasting performance of many models over even short time horizons is notorious. It seems probable that if we used the actual models behind CTA analyses for forecasting, the results would be even worse than those for conventional macroeconomic models.

Not only is the CTA a "black box" in that it hides its underlying scientific assumptions and the uncertainty inherent in its predictions of sustainability, but it is also a black box with respect to its inherent underlying value judgments. Public economic debate focuses on a large number of variables that reflect different interests: GNP, unemployment, interest rates, house prices, inflation, income distribution, progressivity of taxation, etc. The political process decides what weight is given to each of these factors in economic policy. However, in the last decade or two, politicians have increasingly delegated decision making to economic technocrats and espoused conservative economic rhetoric themselves [Hildred 1991; Norgaard 1994]. "Economic reasoning has been used in a power struggle against other types of reasoning for the determination of policy rather than used in a cooperative search for a deeper collective synthesis" [Norgaard 1994, 152]. The sustainability debate has fallen prey to the same process. The technocratic economic approach of decision making is artificially reductionist and noninclusive of dissident interests. A sustainability policy consisting of maintaining mean income, informed solely by estimates of sustainable income or of the sustainability of the economy using the CTA, rides roughshod over all other considerations.

Aggregation must be carried out using a certain set of prices. Even if these are the "correct" sustainability prices, they will reflect opportunity costs and revealed preferences that result from the distribution of wealth endowments among individuals and organizations. Many people will in general reject the normative neoclassical principles of consumer sovereignty and the Hicks-Kaldor compensation principle as foundations of public policy. As already mentioned above, it may not even be possible to pay compensation for irreversible environmental changes. This type of policymaking cannot be considered democratic [Hildred 1991; Sagoff 1988] and in many cases violates laws that prohibit the use of cost-benefit analysis [CBA] in deciding on the adoption of health or other standards [Sagoff 1988].

The CTA literature is in many ways the ultimate reductionist economics. Sustainability is an inherently multidimensional and uncertain subject. The CTA focuses on a single indicator that embodies particular ethical norms and a particular stance for the valuation of the environment. This approach generates an opaque indicator of sustainability that is understood by a select few but not by the majority of the public. "Only transparent and tangible indicators that people can really understand, and visualize and relate to their own lives, will produce the desired political constituency for needed government policies" [Henderson, quoted in Proops and Atkinson 1993]. This question already arises with respect to GDP and GNP indicators. During the recovery from the recession of the early 1990s in both the United States and the United Kingdom, governments extolled the rise in GNP while the media and the general public bemoaned the continuing severe recession. This discrepancy was probably one of the major reasons why President Bush failed to be reelected in 1992. The public clearly does not believe in GDP as an indicator of welfare. Why, similarly, would the public believe in a green GDP figure as an indicator of sustainability? On the one hand, this is a positive sign that the public has not been duped by reductionist economics, while on the other hand it is a depressing sign of how the general public has been excluded from economic debate.

Guiseppe Munda et al. [1994] characterize environmental management and especially management aimed at securing or increasing sustainability as an exercise in conflict management. They express the opinion that we need to

> provide more insight into the nature of these conflicts by providing systematic information and ways to arrive at political compromises in cases of divergent preferences . . . by making trade-offs in a complex situation more transparent to decision-makers [Munda et al. 1994, 101].

They suggest that multicriteria analysis (see below) may be one way to achieve this goal. Echoing Gunnar Myrdal [1958], Silvio Funtowicz and Jerome Ravetz [1994] make a similar plea for multiple criteria of valuation, explicit value statements, and democratic process. Mohan Munasinghe and Walter Shearer [1995, xx] suggest that "the task of the scientist is to provide information to help people choose among conflicting objectives and the consequences of their application."

On the other hand, single, supposedly universal frameworks of analysis facilitate central control and power and exclude the views of those directly affected or interested third parties who disagree with the dominant ideology [Norgaard 1994].

The CTA and Instrumental Valuation

The Brundtland vision of sustainability closely accords with the institutionalists' concept of instrumental valuation and implies a number of extensions of that principle. On the other hand, the CTA and neoclassical sustainability theory more generally represent a hijacking of that vision. As discussed above, *Our Common Future* is partly to blame in this respect as the document can be read to support only minor changes to the status quo on economic and environmental policy. The CTA could be said to involve the ceremonial encapsulation [Bush 1986] of sustainability. Mick Common and Tony Norton [1994] argue that the most useful result of the efforts being spent on green accounting is the generation of information that could be used in alternative forms of sustainability analysis. This information is the fund of knowledge that could allow a second phase of institutional adjustment where "knowledge that was once encapsulated becomes embodied in instrumental patterns of behavior" [Tool 1993, 136].

Marc Tool defines the instrumental social value principle in the following way: "do or choose that which provides for the continuity of human life and the noninvidious recreation of community through the instrumental use of knowledge" [1993, 121]. Sustainability concerns nothing more than the continuity and continuation of human life. Swaney argued that "'continuity of human life' implies that a balanced diet for malnourished people should come before luxury automobiles, . . . and that the human community must live within its ecological means" [1987, 1740]. Sustainability implies meeting both the basic needs of the present generation and that of future generations, both intragenerational and intergenerational equity.

Recreation of community implies changing those parts of the institutional structure that threaten the continuity of life. The neoclassical literature, discussed above, shows that sustainability may be technically feasible but not achieved due to an inappropriate institutional structure. Yet the CTA makes no attempt to change that institutional structure. The best that green accounting can do is to warn people that, given the assumption that sustainability is technically feasible, institutions are failing to allow or cause a transition to sustainability. The new dimension implied by sustainability is that the community is both a global community–a global community has to be created and those institutions that represent undue state sovereignty have to be eliminated–and an intergenerational community. Institutions that impair serious consideration of the rights of future generations also need to be revised. These new dimensions of community are gradually and tentatively being created. However, there currently appears to be a backlash or the supplanting of instrumentally warranted behavior by ceremonially warranted behavior–economic nationalism, the "property rights movement," etc.

Noninvidious change implies that the institutional change that takes place does not deny groups and individuals "options, entitlements, and the full development of their capabilities" [Tool 1993, 122]. The earlier zero economic growth and environmental preservationist movements failed because they sought to deny development to people in the developing countries. Sustainable development is predicated on promoting development in the developing countries. But sustainable development also implies a lack of invidious distinctions on the basis of the period within which people live, i.e., between those currently alive and the unborn. "Deep ecology" views on sustainability may also imply reducing invidious distinctions between the human and nonhuman. Thus, sustainability implies an extension of instrumental valuation to new dimensions. The CTA, however, implies making invidious distinctions on the basis of ability to pay, as asset prices reflect the current distribution of wealth endowments.

While superficially addressing the economic problem of sustainability, the CTA does not represent the instrumental use of knowledge. CTA analysts recognize that the current economy may or may not be sustainable and suggest a means of monitoring sustainability. However, the process of inquiry is uniquely narrow. First the sustainability issue is recognized, then it is reduced to a single dimension–"maintaining average per capita welfare"–and finally a theoretically necessary condition for achieving that goal is put forward–"maintain capital." No effort is made to investigate the root causes of nonsustainability in the institutional sphere despite the neoclassical literature mentioned above on exactly that issue. Neither is any effort made to investigate ways of bridging the gap between what is and what ought to be. Obviously a number of neoclassical economists are looking at such issues, but this is a largely piecemeal effort to correct various "externalities" connected with particular activities and not a comprehensive review of macroeconomic institutions and their consequences for the goal of sustainability.

Institutionalist economists can play a role in investigating the issues raised above which have been largely sidestepped by the mainstream. James Swaney [1987], Gregory Hayden [1993], and Peter Söderbaum [1992] are institutional economists who have made a start in this direction, but much remains to be done.

Alternative Approaches to Sustainability

An alternative approach to sustainability must address both methods of analysis and policymaking. There is a definite relationship between these two activities. Neoclassical normative analysis is particularly suited to a mode of technocratic policymaking that respects the status quo and demands strong justification of deviations from it. Alternative methods of analysis must provide information that can be useful in alternative modes of policymaking.

Analysis

For all of the reasons discussed above, it seems impossible to make precise statements about the sustainability of any course of economic development. Carl Folke and Tomas Kåberger [1991, 289] suggest that:

> It is not meaningful to measure the absolute sustainability of a society at any point in time. The best that is likely to be possible is to articulate general principles to assess the relative sustainability of the society or the economic activity compared to earlier states or economic activities.

while Norgaard [1994, 22] states that "it is impossible to define sustainable development in an operational manner in the detail and with the level of control presumed in the logic of modernity."

Finding ways to deal with sustainability empirically are still important–they are necessary to aid policies that might guide the economy in a more sustainable direction. This suggests a number of possible approaches to articulate sustainability concerns.[22] In the following, I examine three of many possible options:

1. Disaggregated sustainability indicators.
2. Economy-environment simulation models.
3. Historical assessment of sustainability performance.

Various sustainability indicators can be developed to determine whether individual activities are likely to add or detract from the goal of sustainability. These indicators cannot be used to determine whether an economy is sustainable in an absolute sense, though they may help determine whether we are likely to be moving away from or toward sustainability. There are a number of forms these indicators might take. They may be purely biophysical measurements of the quantity or quality of particular natural resource stocks. For example, the concentration of carbon dioxide in the atmosphere, the depth of agricultural soil, or the area and fragmentation of the range of an endangered species. They may also include economic indicators that are likely to take the form of productivity indices [Cleveland and Stern 1993]. An indicator of the difficulty of producing a resource commodity monitors the changing ability of a combination of the environment and technology to support economic activity.[23] In the terminology of John Commons [1934], these are indicators of efficiency that measure the ability of the environment to produce use value. Such indicators allow for the substitution of manufactured capital, labor, and knowledge for natural resources but do not make the far-reaching claims of sustainable income calculations. Production of a particular resource commodity may not be essential to a sustainable future, but an increase in economic value per unit of resources employed to appropriate natural resources must be beneficial to the economy. Declining productivity may warn us of an impending threat to sustainability. In terms of accountability, a statement such as "it is getting more and more costly to produce food" is more transparent than "this is the sustainable level of income."[24]

It is important to develop models of the economy-environment system that take into account the processes affecting sustainability. These models could be used to assess the impacts of policies or activities on the level of income and other variables in the future. As mentioned above, these are macro-forecasts for very long time horizons. Presenting the results as an inaccurate projection (with forecast error intervals or a sensitivity analysis) is more transparent than calculating the supposed level of sustainable income or net capital accumulation. This approach is already present in the case of global warming and assessments of the impact of global warming. We might be a bit surprised if climatologists instead only presented us with figures for sustainable levels of greenhouse gas emissions. Though these are useful, they do not help evaluate the magnitude of the future consequences of our present actions if we choose to increase the radiative forcing of the atmosphere.

A similar approach was taken by the Limits of Growth [Meadows et al. 1972], Carrying Capacity [Gever et al. 1986] and Beyond the Limits [Meadows et al. 1992] studies, though I am not advocating use of the specific assumptions or modeling techniques found in those studies. Studies of this type have been limited by empirical knowledge of the interaction of the economy and environment. Better policy models will depend on the gathering of empirical data and the development of theory regarding the actual interaction of the macroeconomy and the environment.

The recent literature on the environmental Kuznets curve (EKC) [e.g., Grossman and Krueger 1991; Shafik 1994; Panayotou 1993; Cropper and Griffiths 1994; Selden and Song 1994] has examined long-term economy-environment interactions. This literature has many shortcomings [Stern et al. 1996], but I think it shows more potential than the green accounting/CTA approach to foster more sophisticated forms of analysis that could be useful in assessing sustainability options. Unfortunately, this literature is currently being used by some to support either a laissez-faire approach to the environment or simply the extension of neoclassical environmental policy [e.g., Grossman and Krueger 1991; Shafik 1994; IBRD 1992]. Stern et al. [1996] use published estimates of the EKC together with World Bank growth forecasts to show that the World Bank's [IBRD 1992] conclusions from such studies are unwarranted. Whereas this kind of critique can be applied to the EKC, it cannot be applied to the CTA.

A historical approach would assess what effects activities have had in the past on the sustainability of development until the present. This can be measured as the impact of particular changes in the economy on income per capita and other components of welfare in the long run. This type of analysis is, however, limited by the length of time series available for the particular economy under consideration. Stern [1995] uses econometric analysis to examine the impact of changes in mining income in 19 developing countries with large mining sectors on GNP per capita over a 25-year time horizon. The strength of the results is affected by the relatively small number of observations and the large number of variables in the model, but qualitative conclusions can be drawn. The sample mean showed no improvement in long-term GNP per capita due to liquidating the mineral resource stock. This is despite the fact that most of these economies met the Hartwick rule condition for reinvesting the resource rents in alternative forms of capital as evaluated at market prices. A number of principally oil-producing economies did generate an increase in income that was permanent over this medium-term horizon. This should be a first step in the investigation. Further stages would examine why the latter group of economies has been more successful and then apply the conclusions to improving the performance of the other mineral economies.

Policymaking

In this section, I suggest some implications for policy implied by the definition of sustainable development: "development that meets the needs of the present generation while letting future generations meet their own needs" discussed in this paper. I see three basic dimensions to such a policy environment that stem directly from the definition and my elaboration outlined above:

1. A new intra- and intergenerational democracy.
2. Building of resilience.
3. Development of appropriate information, research, and decision frameworks.

These planks of the policy reflect respectively "the noninvidious recreation of community," "the continuity of human life," and "the instrumental use of knowledge."

As outlined in *Our Common Future*, sustainability implies intra- and intergenerational equity on an international basis. Though equality of opportunity is not essential, as only "needs" must be met, it is desirable. At the least, we should ensure equal rights for all including equal rights in decision making.[25] Essentially, any sustainability policy must respect the rights of future generations, but no single policy change will be adequate to ensure respect for the rights of future generations. Rather, Solow [1974] argues that a "social contract" is necessary that "binds the next Congress, and the next" [Solow 1974, 36]. In his 1986 paper, Solow writes "The image that comes to mind is Ulysses lashing himself to the mast because he knows he will be tempted by the Sirens" [1986; 148]. Change is required at a constitutional level.

In the present generation, at the global level, organizations such as the United Nations exist that allow some degree of global democracy. An increasing number of international agreements on human rights, the environment, etc., provide the constitutional backdrop. Clearly, this level of democracy is insufficient by the standards of the Brundtland Report or there would have been no need to argue for greater equality of opportunity and outcome among the members of the present generation. Not only will greater international democracy be required to meet the requirements of the present generation, but an equal degree of intertemporal democracy will be required to meet the needs of the future generations. The implication is that constitutional change alone is insufficient and members of future generations will need to be represented. At present, the members of future generations (beyond the next one or two generations who have potential parents and grandparents to care for them) are in a worse situation than the present day inhabitants of the developing countries.

One approach might be to set up an organization(s) as the representative(s) or guardian of future generations that would act in a similar way to that of independent central banks in their zealous fights against inflation. This organization would enter the political process to counterbalance the effects of the representatives of the current generation. Otherwise, sustainability will depend solely on the altruistic notions of the individuals taking part in the debate. To the degree that such a change seems unrealistic, long-term sustainability may also be unrealistic.

There appears at first glance to be a paradox or contradiction here. On the one hand, I argue that sustainability requires greater democracy in the present generation, and, on the other hand, I argue that rules or even organizations are needed to limit the effect of that democracy on economic and environmental decision making. Sustainability implies intergenerational democracy and does conflict with democracy as normally understood. However, if the question is properly framed, the present generation might agree to extend their democracy to include the unborn. As Mark Sagoff [1988] argues, people are likely to agree to more extensive environmental provisions as "citizens" rather than as "consumers." Environmental protection agencies of today are too often seen as representing the interests of "elitist environmentalists" or government bureaucracy.

Before such institutional changes are undertaken, the most useful action governments of today can carry out is to enhance the resilience of the economy to help maximize its survival in a form productive enough to meet the needs of future generations. A first step in resilience enhancement is the adoption of the precautionary principle with regard to actions that may "threaten" sustainability [Common 1995]. We would aim to limit or curtail such activities. Not that we know for certain that they will lower the level of welfare in the future, but we might have good reason to suppose so, and there may often be other benefits to adopting the policy. For example, the accumulation of greenhouse gases in the atmosphere appears to threaten sustainability. A policy to reduce greenhouse gases by shifting taxes from labor to fossil fuels might also increase employment and thereby address distributional interests–the so called double dividend [Fitzroy 1993]. A second step is to pursue the research and development of a number of alternative future technologies particularly in the energy sphere. A third step is to adopt resource use policies that enhance resilience. In the rangeland example discussed above, an organization that monitored the state of the rangeland, the weather, and the economy could act to adaptively regulate the quantity of livestock so as to reduce the occurrence of permanent degradation events. This might be accomplished through adjusting offtake prices [Perrings 1994a]. This contrasts with the neoclassical property rights approach.

Multicriteria analysis might be used to synthesize the output of alternative modeling techniques for policy purposes.[26] It is not entirely clear that multicriteria analysis represents a major advance on CBA. This is clearly the case when it is assumed that the decision maker's preferences are explicit. However, there do seem to be more possibilities to change the given preferences or examine the choices of competing groups with varying preferences in order to find a compromise.

Norgaard [1994] advocates a complete shift away from technocracy in order to incorporate new ways of knowing in the development of a sustainability strategy.[27] I would advocate a more partial strategy where technical expertise is available to all parties and modes of analysis are designed to be inclusive of alternative values and interests. Perhaps technical expertise might be made available in the way that legal aid is made available to less wealthy litigants in many countries. In the meantime environmental organizations and other NGOs are increasingly employing their own scientists and policy analysts. Sustainability problems have an inherently technical dimension–there is no way of getting away from this fact. On the other hand, we cannot simply set sustainability as a goal and then leave technicians to design policies without reference to the public arena as there may be many alternative sustainable scenarios and many alternative goals that may need to be sacrificed. There can be no complete separation of ends from means. Economic models of the type discussed in the previous subsection can be used to evaluate the impacts of changes of this sort in terms of whatever variables are deemed of interest. This approach would be a massive improvement on the present where normative neoclassical economics is not just designing means of implementing given goals, as was envisioned by Auguste Comte, but rather setting the policy agenda itself [Norgaard 1994].

Conclusions

The CTA has become established as the dominant theoretical basis for sustainability policy. Despite this, the two main schools of thought within this approach suggest different policy objectives. Those that emphasize substitutability between natural capital and artificial capital suggest that policymakers attempt to maintain an aggregate stock of capitals. Those that emphasize complementarity between the two classes of capital propose that policymakers focus on maintaining specific aggregates of capital or capital stocks.

Nevertheless, both these approaches depend on particular conceptions of economy-environment interactions and of the working of the economy and environment individually. Only under certain technical conditions is it possible to consistently aggregate a stock of natural capital. Only under certain conditions regarding substitution possibilities in production and consumption is maintenance of an aggregate capital stock sufficient to maintain welfare in the face of declining natural resource stocks. In either case, the true sustainability prices that should be used in this aggregation are unknown and unknowable. Further, only for an economy actually moving along a sustainable development path are the maximum sustainable consumption and environmentally adjusted national income identical when measured at market prices. From a normative perspective, focussing policy on single indicators of aggregate welfare obscures the underlying modeling assumptions, embodies the normative values of the status quo, and frustrates informed public debate on sustainability policy. Whereas an institutionalist approach is compatible with the Brundtland Report's definitions of sustainability, the CTA is not.

I suggest a number of directions for both theoretical and empirical research that could inform the debate over sustainability. Some of these approaches are also model dependent. However, the output of these techniques is more disaggregated information on the sustainability prospects of society, and the assumptions behind the techniques are always outlined. Techniques that involve forecasts can be subjected to sensitivity analysis or the construction of confidence intervals. More disaggregated and transparent information is more suitable for inclusion in a democratic debate on society's future options. Such an approach not only will provide better information for decision making, but will also help to make explicit the distributional and technological assumptions underlying the idea of sustainability. The policy implications of taking sustainability seriously are far more radical than is commonly supposed or *Our Common Future* suggested. The resources invested in green accounting do little to move us in that direction.

Notes

1. See Pearce [1994] for references. Most later changed their mind and joined the proliferators. Beckerman [1992; 1994] is one who still dismisses sustainability.
2. The literature on sustainable development and sustainability is vast and continually expanding. For surveys see Tisdell [1988], Pearce et al. [1989], Rees [1990], Simonis [1990], Lélé [1991], Costanza and Daly [1992], Pezzey [1992], and Toman et al. [1994].
3. This consensus goes beyond the narrow neoclassical school of environmental economists. For example, the topic of the International Society for Ecological Economics conference in Stockholm in 1992 was "Investing in Natural Capital: A Prerequisite for Sustainability"

[Jansson et al. 1994]. Also Swaney argues that "obviously, [green accounting] is important, and should be a high neoinstitutionalist research priority" [1987, 1769].

4. One of the most important dimensions of sustainability is that it is an international problem. The neoclassical sustainability literature generally ignores the international dimensions of the sustainability problem. I also generally ignore this dimension in this paper. A thorough review of alternatives to CTA will have to address this aspect.
5. This approach to sustainable development also recognized that the creation of closed reserves for nature preservation along the lines of the Western model would exclude people from the natural ecosystems on which their livelihoods depended. Apart from being socially unjust, such an approach would set up conservation schemes for failure as people resisted the expropriation of what was formerly common property. In addition, the geographical heterogeneity of tropical biodiversity could not necessarily be protected by such reserves. What was needed was management of natural ecosystems for multiple use together with development to raise living standards and reduce people's dependence on directly exploiting such systems.
6. Pearce et al. [1989, 37] also use this definition: "natural capital assets . . . should not decline through time." This is an example of the vagueness of the literature. Not everyone agrees that sustainability is a meaningful concept. Shmuel Amir [1992] is one writer who argues that sustainability and sustainable development are impossible to achieve.
7. Obviously, some level of ecosystem function would need to be maintained. However, that does not necessarily mean that all ecosystem functions need to be maintained at their current level of service. For example, clearing land for agriculture will probably be necessary to meet the basic needs of increasing population in some parts of the world. However, this activity will inevitably reduce the level of activity of ecosystem functions. Therefore, meeting basic needs or maintaining welfare can conflict with this definition of sustainability.
8. See comments below on the meaning of this concept.
9. One exception is the World Bank study *Monitoring Economic Progress* [IBRD 1995].
10. *Monitoring Economic Progress* [IBRD 1995] accounts for human capital.
11. This misunderstanding is still occurring. For example, Wilfred Beckerman [1994] asserts that strong sustainability has been superseded by weak sustainability as the goal of environmentalists.
12. Weak sustainability is sometimes called Solow sustainability [Common and Perrings 1992; Turner et al. 1992]. Demarcation between these categories varies among authors, with Turner et al. [1992] differentiating among four different views on the necessary conditions for sustainability.
13. Extraction of energy vectors such as coal or oil is not the production of energy.
14. Institutionalists strongly reject the idea that there are "eternal verities" or first principles from which economic principles can be deduced [Bush 1993]. However, any ecological economics rests on some first principles such as the Laws of Thermodynamics. One school of ecological economics took this further and constructed an "energy theory of value" [Costanza 1980; Cleveland 1987; Christensen 1989]. This approach has even more shortcomings than the neoclassical theory of value [Hayden 1991; Common 1995]. Current mainstream ecological economics thought argues that thermodynamics are relevant to understanding economic activity but are only one of the relevant factors that also include other aspects of the natural environment, as well as institutions, psychology, etc.
15. Once an innovation is made, the value of the innovation may be added to the value of the firm's "capital." But as long as the R&D process does not produce results, it will drain capital.
16. For analyses of the joint economy-environment system as an unpredictable dynamical system undergoing evolutionary change, see Perrings [1987] and O'Connor [1993b].

17. Richard Norgaard [1991] makes a point related to the Cambridge-Cambridge "capital controversy." Faucheux and O'Connor [1995] note that Hicks's [1946] definition of income referred to a price-taking firm and that conclusions that one may draw at this micro level do not necessarily apply at the macro level.
18. However, in an economy with unlimited technical progress, efficient paths may be sustainable at positive discount rates.
19. For example, if farmers or developers were taxed in aesthetically attractive regions for their use of environmental quality, this might promote development in less attractive but perhaps more crucial areas in terms of life support, e.g., wetlands.
20. See Stern [1996] for a more extensive discussion of substitutability in both consumption and production. In that paper, I argue that one of the defining characteristics of ecological economics is its insistence that substitution is difficult.
21. If people are stewards of nature for God, as in the Jewish, Christian, and Islamic traditions, then there are limits placed on human action. Animals, etc., do not have intrinsic rights, but they are to be respected as elements in the Divine creation.
22. Again, Norgaard argues that "even though I dismiss the possibility of defining sustainable development operationally, a more sophisticated exploration of the difficulties of organizing sustainable development is in order" [1994, 20].
23. Resource commodities are "produced" goods, extracted from the natural environment. Resource stocks are natural resources located *in situ* that may serve to produce resource commodities or may provide resource services.
24. See Peter Victor [1991] for a more extensive discussion of alternative sustainability indicators. See Gregory Hayden [1991] for a review of indicators compatible with instrumental valuation.
25. As discussed above, equality of opportunity does not necessarily follow from equal rights as this means that no saving can take place even if the current generation wishes to improve the opportunities of their children.
26. See the survey by Munda et al. [1994] for more details
27. In other places, Norgaard seems to advocate the type of policymaking environment I describe in the following.

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