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THE CAPITAL THEORY APPROACH TO SUSTAINABILITY: A CRITICAL APPRAISAL

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Summary

This paper examines critically some recent developments in the sustainability debate. The large number of definitions of sustainability proposed in the 1980's have been refined into a smaller number of positions on the relevant questions in the 1990's. The most prominent of these are based on the idea of maintaining a capital stock. Though these concepts are beginning to inform policies there are a number of weaknesses in these positions. Therefore it is important to carry out a stock-taking of both the theoretical and normative issues before inaccurate conceptions become too enshrined in policy. I examine the many internal difficulties with the capital theory approach and also ethical difficulties with the adoption of such a reductionist approach to sustainability. The latter involve the fossilization of the status quo distribution of income and wealth through the choice of aggregation prices, and the lack of inclusion of alternative views on valuation through the same choice. Finally, I examine alternative approaches to sustainability analysis and policy making. These approaches accept the open-ended and multi-dimensional nature of sustainability and explicitly open up to political debate the questions that are at risk of being hidden behind a mask of technocratic apparent objectiveness.

I. INTRODUCTION

Sustainability is a property of economies that are sustainable, that is they satisfy a sustainability criterion. Any sustainability criterion must imply 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. The literature on sustainable development and sustainability is vast and continually expanding. There are also a large number of surveys of that literature (eg. Tisdell, 1988; Pearce *et al.*, 1989; Rees, 1990; Simonis, 1990; Lélé, 1991; Costanza and Daly, 1992; Pezzey, 1992; Toman *et al.*, 1994). In this paper, I critique some recent developments in the debate over the definition and meaning of sustainability, and the implications of these developments for policy.

In recent years, economists have made some progress in articulating what they mean by sustainability. The large number of definitions of sustainability proposed in the 1980's have been refined into a smaller number of positions on the relevant questions in the 1990's. 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 opposing camps 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.

Capital theory concepts are beginning to inform policy, as in the case of the UN recommendations on environmental accounting and the US response to them (Beardsley, 1994; Carson *et al.*, 1994; Steer and Lutz, 1993). There are also a growing number of critics who question this approach as a basis for formulating policy (eg. Norgaard, 1991; Amir, 1992; Common and Perrings, 1992; Karshenas, 1992; Pezzey, 1994; Common and Norton, 1994; Faucheux *et al.*, 1994; Common, in press). It is therefore important to carry out a stock-taking of both the theoretical and normative issues before possibly inaccurate conceptions become too enshrined in policy.

The paper is structured as follows. In the second section, I discuss the background to the emergence of the capital theory approach (CTA henceforth) and briefly outline the basic features of the approach including the debate between proponents of "weak sustainability" and "strong sustainability". The third section examines the limitations of the CTA from within the viewpoint of neoclassical economics. The following sections examine the drawbacks of this paradigm from a viewpoint external to neoclassical economics and discuss alternative methods of analysis and decision-making for sustainability. The concluding section summarizes the principal points.

II. THE CAPITAL THEORY APPROACH

a. Context of the Emergence of the Capital Theory Approach

Much of the literature on sustainable development published in the 1980's was vague (see Lélé, 1991; Rees, 1990; Simonis, 1990). There was a general lack of precision and agreement in defining sustainability, and outlining appropriate sustainability policies. This confusion stemmed in part from an imprecise demarcation between ends and means. By "ends" I mean the definition of sustainability ie. what is to be sustained, while "means" are the methods to achieve sustainability or necessary and/or sufficient conditions that must be met in order to do the same. As the goal of policy must be a subjective choice, considerable debate surrounded and continues to surround the definition of sustainability (eg. Tisdell, 1988). This paper focuses, however, on the debate concerning the means of achieving given sustainability goals.

Sharachchandra Lélé (1991) stated that "sustainable development is in real danger of becoming a cliché like appropriate technology - a fashionable phrase that everyone pays homage to but nobody cares to define" (607). Lélé pointed out that different authors and speakers meant very different things by sustainability, and that even UNEP's and WCED's definitions of sustainable development were vague, and confused ends with means. Neither provided any scientific examination of whether their proposed policies would lead to increased sustainability. "Where the sustainable development movement has faltered is in its inability to develop a set of concepts, criteria and policies that are coherent or consistent - both externally (with physical and social reality) and internally (with each other)." (613). Judith Rees (1990) expressed extreme skepticism concerning both sustainable development and its proponents. "It is easy to see why the notion of sustainable development has become so popular ... No longer does environmental protection mean sacrifice and confrontation with dominant materialist values" (435). She also argued that sustainable development was just so much political rhetoric. A UNEP report stated: "The ratio of words to action is weighted too heavily towards the former" (quoted in Simonis, 1990, 35). Common (in press) argues that in the early days of the sustainability debate, vagueness about the meaning of sustainability was advantageous in attracting the largest constituency possible, but in the longer run, it was not a sustainable policy in itself!

In the 1990's many people have put forward much more precisely articulated definitions of sustainable development, conditions and policies required to achieve sustainability, and criteria to assess whether development is sustainable. This has coincided with a shift from a largely politically-driven dialogue to a more theory-driven dialogue. With this has come a clearer understanding of what kinds of policies would be required to move towards alternative sustainability goals, and what the limits of our knowledge are. There is a stronger awareness of the distinction between ends and means. Most, but not all (eg. Amir, 1992), analysts agree that sustainable development is a meaningful concept but that the claims of the Brundtland Report (WCED, 1987) that growth just had to change direction were far too simplistic.

There is a general consensus, especially among economists, on 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).[1] This definition of sustainability implies an optimizing principle of intertemporal equality rather than of maximizing net present value as in traditional cost benefit analysis (Pezzey, 1989). Otherwise it does not imply a large departure from conventional economics. It encompasses many but not all definitions of sustainability. For example, it excludes 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. A sustainable ecosystem might not be an undesirable goal but it could be too strict a criterion for the goal of maintaining human welfare (Karshenas, 1992) and could in some circumstances lead to declining human welfare. Not all ecosystem functions and certainly not all natural assets may be necessary for human welfare. Some aspects of the natural world such as smallpox bacteria may be absolutely detrimental to people. In the context of the primary Pearce *et al.* definition, the Holling-sustainability criterion is a means not an end.

The advantage of formalizing the concept of sustainability is that this renders it amenable to analysis by economic theory (eg. Barbier and Markandya, 1991; Victor, 1991; Common and Perrings, 1992; Pezzey, 1989, 1994; Asheim, 1994) and to quantitative investigations (eg. Repetto *et al.*, 1989; Pearce and Atkinson, 1993; Proops and Atkinson, 1993; Stern, in press).

b. The Capital Theory Approach

Given the above definition of sustainability, many economists have examined what the necessary or sufficient conditions for the achievement of sustainability might be. Typically they assume that welfare is a monotonically increasing function of income or consumption (eg. Mäler, 1991) and then argue that for a flow of income to be sustainable, the stock of capital needs to be constant or increasing over time (Solow, 1986). The definition of capital that satisfies these conditions must be very broad, composed of a number of categories of "capital": natural, manufactured, human, and institutional. 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. Manufactured capital refers to the standard neoclassical definition of "a factor of production produced by the economic system" (Pearce, 1992). Human capital also follows the standard definition. Institutional capital includes the institutions and knowledge necessary for the organization and reproduction of the economic system. It includes the ethical or moral capital referred to by Fred Hirsch (1976) and the cultural capital referred to by Fikret Berkes and Carl Folke (1992). The latter three categories are jointly termed artificial capital. None of these concepts is unproblematic and natural capital is perhaps the most problematic.

Sustainable income is, therefore, the maximum consumption in a period consistent with the maintenance of aggregate capital intact (Weitzman, 1976; Mäler, 1991). This is an extension of John Hicks' (1946) definition of income as the maximum consumption in a period consistent with the maintenance of wealth. Empirical implementation of the CTA tends to focus on measurement of sustainable income (eg. El Serafy, 1989; Repetto, 1989) or net capital accumulation (eg. Pearce and Atkinson, 1993; Proops and Atkinson, 1993) rather than on direct estimation of the capital stock.

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 ideas of what sustainability is.[2] 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.[3]

The weak sustainability viewpoint holds that the relevant capital stock is an aggregate stock of artificial and natural 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. Weak sustainability assumes that there are no natural resources that contribute to human welfare that cannot be fully replaced by other forms of capital. There is perfect substitutability between natural and artificial capital. Growth could continue indefinitely as long as the economy obeys the sustainability criterion that it invests the rents from the exploitation of exhaustible natural resources in artificial capital that can yield a stream of income of the same size in the future. This principle is known as the Hartwick Rule (Hartwick 1977, 1978a, 1978b).

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. Costanza and Daly (1992) state: "It is important for operational purposes to define sustainable development in terms of constant or nondeclining total natural capital, rather than in terms of nondeclining utility" (39).[4] 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 economic system.[5] 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 (eg. 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 this recognition it is an empirical question as to how far artificial capital can substitute for natural capital. Costanza and Daly (1992) point out that the mere existence of manufactured capital demonstrates that natural capital is not a perfect substitute for manufactured capital and *vice versa*. This is also supported by econometric studies that find energy-manufactured capital complementarity in the manufacturing sector (Berndt and Wood, 1979).

In some ways the concept of maintaining a constant stock of aggregate natural is even more bizarre than Solow's (1986) idea of 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?

It seems to me that artificial capital cannot totally replace natural capital in the production of natural resource services or commodities but it can substitute for it to a relatively large degree in the production of final goods and services. Technological progress might reduce the quantity of natural resource inputs required per unit of output, but in most cases technical progress cannot be separated from the installation of new manufactured capital (Sen, 1970) or the use of more energy and natural resources (Cleveland *et al.*, 1984; Jorgenson, 1984; Hall *et al.*, 1986). Further, there are arguments that indicate that technical progress itself is bounded (see Stern, 1994).[6]

The theoretical models that underpin the CTA typically assume a Cobb-Douglas production function with constant returns to scale, no population growth, and no technological change. Any indices of net capital accumulation which attempt to make even a first approximation to reality must take these variables into account. None of the recent empirical studies does so. For example David Pearce and Giles Atkinson (1993) present data from eighteen 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 and thus passed a weak sustainability criterion of a constant aggregate capital stock, but their methodology ignores population growth, returns to scale or technological change. Under these conditions, the test is only valid if the rate of growth of total factor productivity is equal to the rate of population growth.[7]

III. INTERNAL APPRAISAL OF THE CAPITAL THEORY APPROACH

There is a consensus among a large number of economists that the CTA is a useful means of addressing sustainability issues.[8] The attractiveness of this approach is that it suggests relatively simple rules to ensure sustainability and relatively simple indicators of sustainability. There are, however, many dissenters from the view that this is a useful way to address sustainability (eg. Norgaard, 1991; Amir, 1992; Common and Perrings, 1992; Karshenas, 1992; Pezzey, 1994; Common and Norton, 1994; Faucheux *et al.*, 1994; Common, in press) and it is important to assess the advantages and shortcomings of this approach.

a. Model Dependence

Any conditions or indicators for sustainability derived from the CTA are only true indicators that society is developing sustainably under limited and unlikely conditions which are specific to the particular model of the economy that is implicitly or explicitly assumed. Mick Common (1993) 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." (8-11)

The first problem that needs to be solved in order to implement the CTA is to find an adequate model of the economy for the purpose of sustainability policy.[9] The current state of empirical economics renders this a difficult but not altogether worthless task. Macroeconomic forecasters routinely make economic forecasts without knowing the true structure of the economy. Indeed, long-term forecasting might be one of the alternatives to the CTA. 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 a hundred year or greater time horizon. The opaque nature of the aggregated 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 far 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 simulated the actual models behind CTA analyses the results would be even worse than for conventional macroeconomic models.

b. Capital Aggregation, Sustainability Prices, and Sustainable Income

The types of models which admit an index of aggregate capital, whether aggregate natural capital or aggregate total capital, is very limited. Within a partial equilibrium framework, it is always possible to construct an index of aggregate input given that there exists an explicit production function which is separable in inputs and outputs. However, construction of subindices of aggregate input depend 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 fresh water 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 boats to catch them with. The complementarity argument put forward by Daly and

Costanza (1992) would imply, therefore, that there is no unique index of aggregate natural capital and we do need to look at individual stocks of individual resources.

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. There are two basic problems: the "capital controversy" and the general difficulty of obtaining prices relevant for sustainability. Also there are dangers in applying incorrect prices to environmental resources when none existed before.

Richard Norgaard (1991) points out that the CTA relies on the assumption that there is a monotonic relationship between capital and the rate of interest. It is, however, quite possible that using the market or intragenerationally socially efficient prices in year A total assets passed on to the next generation are less than that enjoyed by the present, while in year B the total passed on is greater than that enjoyed by the present, but the value of the capital stock in year A is greater than in year B. This is because the relative prices of the individual components of the capital stock are different in the two periods as assessed by the individuals alive in those periods. The price vector will change over time with changing scarcities and changing technologies. Thus society may pass on assets to the next generation worth more in their valuation than those they received from the previous generation but yet the course of development might still not be sustainable. This is essentially the question raised by the "capital controversy".[10]

The CTA is tautological if we use the "right" prices.[11] However, these correct "sustainability prices" are unknown and unknowable. There is no reason why a rising capital stock in the present, aggregated using efficient prices that internalize externalities imposed on the current generation, might not actually imply a declining capital stock at some time in the future. John Pezzey (1994) shows that it will, under quite reasonable conditions.

Assuming that the economy can be represented by simple models such as those used by Partha Dasgupta and Geoffrey Heal (1974) and Robert Solow (1974), with a single types of artificial and natural capital, Pezzey proves mathematically that Solow's (1986) claim that non-declining aggregate wealth guarantees sustainability is untrue. Imagine an economy setting out on the process of economic development. Assume that initially conditions allow this economy to follow a sustainable development path but instead the economy follows a (single peaked) present value optimal path. Pezzey demonstrates that there will be a finite time period during which the economy is unsustainable (ie. the current level of income cannot be maintained indefinitely) but aggregate wealth is rising. This implies that adopting a policy at a given point in time that maintains the aggregate capital stock does not necessarily guarantee sustainability. The maximum level of income that can be maintained indefinitely may be less than current net income despite non-declining aggregate wealth. Related results have been derived by Geir Asheim (1994). Pearce (1994), a major proponent of the CTA, concedes that this point may have implications for 'green' accounting.

Sylvie Faucheux *et al.* (1994) make a related point. Unless the economy is on a sustainable path, environmentally adjusted national income does not correspond to sustainable national income. Adjustments for natural capital depreciation reflect the cost of respecting sustainability norms or of the cost of moving towards sustainability. It is entirely possible that adjusted national income might be zero or negative. Yet this does not necessarily mean that the long-run maximum sustainable income is also zero or negative. It is also possible that the aggregate capital stock (measured at present relative prices) may need to decline so that the economy can move towards a sustainable path. For example, thermal powerstations, unsustainable sawmill capacity, excess oil refining capacity etc. might be scrapped.

Fundamentally, there are two different meanings of sustainable income in the literature. On the one hand sustainable income is used to mean the maximum level of consumption that could be maintained indefinitely. On the other hand sustainable income is used to mean the maximum consumption that could be made from current output while respecting some sustainability norms. Generally these two indicators are not identical.

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 non-linearities such as discontinuous changes in environmental parameters as critical thresholds are passed and irreversibilities such as species extinctions. 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.

Hicks' (1946) definition of income referred to a price taking firm (Faucheux *et al.*, 1994). With no control over relative price changes a sensible policy for a profit maximizing firm to maximize minimum income over a given period of time is the myopic policy of transferring capital intact from period to period. However, in the economy as a whole the relative prices of the various capital stocks are no longer exogenous but at least partly endogenous, and entirely endogenous in the World economy. Even leaving aside distributional issues, in this case formulation of a sustainability policy is no longer necessarily the same. Just as macroeconomic management of the government budget deficit cannot be compared to the management of a household budget, as Margaret Thatcher did, so macroeconomic management of wealth cannot be directly compared to the management of the wealth of an individual firm. "Very definitely, in the field of economics, it turns out that what seems to be true for individuals is not always true for society as a whole" (Samuelson, 1980, 11-12).

Even for the individual firm, extending the notion of Hicksian income to sustainable income may be problematic. Though a firm may be optimizing in an uncontrolled external environment its policy may not be sustainable. For example if a competing firm makes an invention that renders the firm's capital stock obsolete, the latter's income may drop to zero. This is despite it 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 long-run sustainability. In this case it does seem that we can transfer our analysis of the firm to that of the economy. However, the economy can be managed to minimize the effects of surprises of this kind.[12] Firms can and do also aim at increasing their resilience to external shocks by such measures as investing in research and development and maximizing market share at the possible expense of short term profits.

Many environmentalists, and some environmental economists such as David Pearce, argue that any positive prices for natural resources are better than zero prices. Common (in press) 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 which 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. The tendency to protect resources that are aesthetically attractive rather than those that are useful in life support makes this particularly likely.[13] Perrings (1987) argues against placing prices on *in situ* environmental resources under any circumstances, stating "Few other ideas in economic theory can be so obviously misplaced" (94).

Atmospheric carbon dioxide is an interesting example of the difficulties of aggregating a natural capital stock. Carbon dioxide is a crucial form of natural capital that helps maintain the atmosphere at a reasonable temperature for the operation of the economy and provides a raw material for photosynthesis.[14] As the concentration of carbon dioxide in the atmosphere increases away from current or recent values, the consensus view is that mean global temperatures will tend to increase with detrimental effects on agriculture, sea levels etc. However, the opposite situation is also problematic. A decrease in the concentration of carbon dioxide, lowering temperatures, would also have adverse economic effects. This implies that the marginal product schedule of carbon dioxide is declining in carbon dioxide and crosses the ordinate at approximately the current level of carbon dioxide. If carbon dioxide is a form of capital then its "correct" neoclassical price is zero. Yet, intuitively, assigning a zero value to the World's stock of carbon dioxide undervalues a resource crucial for life on Earth. What price should be assigned to the CO_2 stock in order to aggregate it with the other natural capital stocks? Neoclassical capital theory does not provide a satisfactory answer.

d. Limits to Substitution in Consumption

Typically economists assume that there is an absence of non-substitution effects in consumption. The existence of limits to substitution in consumption is an argument against aggregation of a natural capital stock for non-technological reasons. There may be both utilitarian and non-utilitarian reasons for limited substitutability between manufactured and natural capital in consumption or household production.

Preserved natural environments are a source of direct utility. The utility derived from these stocks of resources may result from use value eg. visits to a national park; option value - utility people experience from knowledge that they could visit the area in question; or through existence value - utility people experience due to their knowledge that a particular part of the natural environment has been preserved, even if they do not plan to visit it. 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.

Intrinsic value in nature is a further justification for the preservation of given natural resource stocks without reference to production possibilities. Intrinsic value may either be expressed as a right of a species or individuals of a species etc. 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, 1994) which extends the humanist ethic to other species and/or inanimate nature. The latter is more characteristic of a religious ethic that seeks to limit the extent of a humanist type rights system.[15] Intrinsic value may be expressed within utilitarian preferences as existence value. When such beliefs are more strongly held they will be expressed as a limit to substitution in the form of lexicographic preferences. In the model proposed by T. Stevens *et al.* (1991) utilitarian preferences may be held for ordinary consumption goods and services but a minimum level of wildlife will not be traded off against other goods. Both Stevens *et al.* (1991) and Clive Spash and Nick Hanley (1994) provide empirical evidence of the existence of lexicographic preferences for wildlife. Vadnjal and O'Connor (1994) suggest the same in regard to unique landscapes.

IV. EXTERNAL APPRAISAL OF THE CAPITAL THEORY APPROACH[16]

Is the process of estimating sustainable income or net aggregate capital depletion really worthwhile given the many problems discussed above? I argue that even if all the above theoretical and empirical problems with the CTA could be satisfactorily solved there are fundamental moral and ethical problems with this approach. First, aggregation must be carried out using a certain set of prices. Even if these are "correct" sustainability prices they will reflect opportunity costs and revealed preferences that result from the distribution of wealth endowments among individuals and organizations. Secondly, not everyone may accept the consumer sovereignty and trade-offs implicit in the CTA. As Mark Sagoff (1988) has written, the relevant mode of decision making for issues affecting future generations is as a citizen not as a consumer.

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. "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.

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. Hazel Henderson asserts that: "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." (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 Bush failed to be reelected to the US presidency 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?

G. Munda *et al.* (1994) characterize environmental management and especially management aimed at securing or increasing sustainability as an exercise in conflict management. They go on to 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. Silvio Funtowicz and Jerome Ravetz (1994) make a similar plea for multiple criteria of valuation, explicit value statements and democratic process. On the other hand complex, 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).

V. ALTERNATIVE APPROACHES TO SUSTAINABILITY

An alternative approach to sustainability that meets the requirements of the previous section must address both methods of analysis and policy making. There is a definite relationship between these two activities. Neoclassical normative analysis is particularly suited to a mode of technocratic policy-making 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 policy making.

a. 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 Richard Norgaard (1994) 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" (22).

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.[17] 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 sustainability goal. 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 towards 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 be economic indicators which 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.[18] It also neatly encapsulates the idea of substituting manufactured capital, labor, and knowledge for natural resources but does 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. On the accountability side, 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".[19]

It is important to develop models of the economy that take into account the processes which affect 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 a very 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. 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 macro-economy and the environment. The great effort being invested in green accounting is useful in so far as it is gathering information for this type of analysis (Common and Norton, 1994).

Recently environmental Kuznets curve (EKC) models have been used to examine long-run economy-environment interactions.[20] The EKC hypothesis proposes that there is an inverted U-shape relationship between environmental degradation and income per capita. A number of researchers (Grossman and Krueger, 1991; Shafik, in press; Panayotou, 1993; Cropper and Griffiths, 1994; Selden and Song, 1994) have estimated EKC's using cross-sectional and panel data for a variety of pollutants and deforestation variables. The apparent inference is that increasing income per person will eventually reduce environmental degradation caused by each individual.[21] There are a number of problems with this idea, the most relevant here being that, in the early stages of development, growth may damage the environment so severely that the economy does not succeed in developing to the stage where environmental degradation is supposed to decrease. All the same, more sophisticated forms of this analysis could be useful in assessing sustainability options.

An historical approach would assess what effects activities have had in the past on the sustainability of development up till 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 very long run. This type of analysis is, however, limited by the length of time series available for the particular economy under consideration. Stern (in press) uses econometric analysis to examine the impact of changes in mining income in nineteen developing countries with large mining sectors on GNP per capita over a twenty five 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. However, the indications are not encouraging. The sample mean showed no improvement in long-run GNP per capita due to liquidating the mineral resource stock. A number of principally oil producing economies did generate an increase in income.

b. Policy-Making

In the longer run, sustainability must be addressed by building new institutions. Such institutions would need to address the following concerns:

1. Improved decision-making processes and procedures.
2. Respecting the rights of future generations.
3. Resilience enhancement and the precautionary principle.

Multicriteria analysis might be used to synthesize the output of alternative modeling techniques for policy purposes.[22] It is not entirely clear that multicriteria analysis represents a major advance when analysis is carried out on a technocratic basis. This is certainly when it is assumed that the decision maker's preferences are explicit. However, there do seem to be more possibilities than under cost-benefit analysis 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.[23] 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. 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 setting the policy agenda let alone merely designing policies to implement given goals as in the positivist vision of Auguste Comte (Norgaard, 1994).

Essentially, any sustainability policy must respect the rights of future generations. "Valuation [(hat is pricing at opportunity cost) when there is too little caring for the future (ie. too little asset transfer) will not lead to sustainability" (Howarth and Norgaard, 1992, 476). Many authors argue that adoption of zero discount rates are essential to the respect of future generations. Howarth and Norgaard (1992, 1993) show that, in theory, adoption of an appropriate rights structure will result in "the" fair intergenerational discount rate. This is much easier said than done! One approach might be to set up an organization as the representative or guardian of future generations that would act in a similar way to Central Banks' 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. In an intermediate stage various other institutions would probably play a related role as discussed in the rest of this section.

When sustainable development is seen as a very uncertain trajectory into a future laden with unknown and unexpected shocks, a principle means to increase sustainability is to enhance the economy's resilience to such shocks. A first step in resilience enhancement is the adoption of the precautionary principle with regard to actions that may "threaten" sustainability (Common, in press). 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 adopt resource use policies that limit the impact that unplanned environmental variation is likely to have on the economy. Following Holling (1986), 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. In other words the system becomes 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. During rainy periods livestock numbers tend to increase towards 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). 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). It is important to note that in the general context there is no explicit optimal policy in the neoclassical sense (Clark, 1990).

VI. CONCLUSIONS

The CTA has become established as the dominant theoretical basis for economic 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 policy makers attempt to maintain an aggregate stock of capitals. Those that emphasize complementarity between the two classes of capital propose that policy makers 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, there are two meanings attributed to "sustainable income" in the literature: the maximum consumption out of current gross income possible while respecting some sustainability norms; the maximum consumption that can be maintained in the long-run. Only for an economy actually moving along a sustainable development path are these measures identical. From a normative perspective, focussing policy on single indicators of aggregate welfare embodies the normative values of the status quo and frustrates informed public debate on sustainability policy.

This paper is not intended to be unduly pessimistic but rather to caution analysts and policy makers against the pitfalls in the CTA. 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 much 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 also help to make explicit the distributional and technological assumptions underlying the idea of sustainability.

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Notes

[1] Pearce *et al.* (1989) also use the definition: "natural capital assets ... should not decline through time" (37).

[2] This misunderstanding is still occurring as evidenced by Wilfred Beckerman's (1994) paper, in which he asserts that strong sustainability has been superseded by weak sustainability as the goals of environmentalists.

[3] 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.

[4] It is not entirely clear how strongly Costanza and Daly (1992) question the possibility of some substitutability between resources and manufactured capital. For example they state: "There are clear economic limits to growth, but not development" (43) and go on to define development as growth that does not require an increase in resource throughput. Daly (1992) specifically argues that "No one denies the reality of technical progress; but to call such changes the substitution of capital for resources is a serious confusion". However, the standard weak sustainability capital theory approach appears to assume that the manufactured capital stock is adjusted for technological improvements.

[5] Extraction of energy vectors such as coal is not production of energy.

[6] The shift from primary and secondary industry towards services in the course of development can only mitigate natural resource scarcity to a limited degree. First, services do require resources, albeit fewer resources than manufactured goods, in their production. Second, the shift to services is partially accomplished by a global shift in the division of labor - not all countries can avoid manufacturing. Third, the absolute size of the manufacturing sector may not decline even though its size relative to services does decline.

[7] Total factor productivity growth is a function of technical change and returns to scale (Capalbo, 1988).

[8] 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).

[9] "Adequate" is understood as sufficient for the purpose at hand in some statistical sense eg. goodness of fit, predictive power, non-violation of normality conditions etc.

[10] Pezzey's (1994) argument discussed below is essentially a variant on this problem.

[11] These prices would be prices for which a constant capital stock would sustain income or at the least maximize minimum income over the sustainability horizon and maybe also meet distributional conditions. I use quotation marks to indicate that there may be an infinite number of sustainability scenarios, each associated with a given income distribution.

[12] Though, of course, surprises cannot be eliminated.

[13] 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. Note that many of the analytical models used by capital theorists assume that there is only one form of natural capital and therefore effects of this type cannot occur.

[14] Pollution is "uncontrolled capital accumulation" albeit capital of a detrimental variety for the economic system (O'Connor, 1993). In the following discussion I am not implying that the current concentration of carbon dioxide is "optimal". In neoclassical theory the optimal level of carbon dioxide would balance the marginal costs of investment in carbon dioxide with the marginal benefits of investment in carbon dioxide. Also the current concentration of CO_2 is not necessarily output maximizing - the argument is relevant to any period in which the stock is output maximizing.

[15] If people are stewards of nature for God, as in the Jewish, Christian, and Islamic tradition, 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.

[16] Many of the issues discussed in this section are dealt with a far more thorough manner by Norgaard (1994).

[17] Again Norgaard (1994) 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" (20).

[18] 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.

[19]See Peter Victor (1991) for a more extensive discussion of alternative sustainability indicators.

[20] See David Stern *et al.* (1994) for a survey of the literature and a critical examination.

[21] This inference is clearly made by Gene Grossman and Alan Krueger (1991), Nemat Shafik (in press) and in the World Bank Development Report 1992 (IBRD, 1992).

[22] see the survey by Munda *et al.* (1994) for more details

[23] In other places he seems to advocate the type of policy-making environment I describe in the following.

References

Ahmad, Y. J., Salah El Serafy, and Ernst Lutz (Editors), Environmental accounting for sustainable development. Washington DC, The World Bank, 1989.

Amir, Shmuel, The environmental cost of sustainable development. Discussion Paper QE92-17, Quality of the Environment Division, Resources for the Future, Washington DC, 1992.

Asheim, Geir B., Net national product as an indicator of sustainability. Scandinavian Journal of Economics 96, 1994, 257-265.

Barbier, Edward B. and Anil Markandya, The conditions for achieving environmentally sustainable development. European Economic Review 34, 1990, 659-669.

Beardsley, T., Green economics: the U.S. makes a foray into sustainable accounting. Scientific American 271(1), 1994, 86.

Beckerman, Wilfred, Sustainable development - Is it a useful concept?, Environmental Values 3, 1994, 191-209.

Berkes, Fikret and Carl Folke, A systems perspective on the interrelations between natural, human-made, and cultural capital. Ecological Economics 5, 1992, 1-8.

Berndt, Ernst R. and L. R. Christensen, The internal structure of functional relationships: Separability, substitution, and aggregation. Review of Economic Studies 40, 1973, 403-410.

Berndt, Ernst R. and David O. Wood, Engineering and econometric interpretations of energy-capital complementarity. American Economic Review 69, 1979, 342-354.

Capalbo, Susan M., Measuring the components of aggregate productivity growth in U.S. agriculture. Western Journal of Agricultural Economics 13, 1988, 53-62.

Carson, C. S. *et al.*, Integrated economic and environmental satellite accounts. Survey of Current Business 74(4), 1994, 33-49.

Clark, Colin W., Mathematical bioeconomics: the optimal management of renewable resources. New York, John Wiley, 1990.

Cleveland, Cutler J., Robert Costanza, Charles A. S. Hall, and Robert K. Kaufmann, Energy and the U.S. economy: A biophysical perspective. Science 225, 1984, 890-897.

Cleveland, Cutler J. and David I. Stern, Productive and exchange scarcity: an empirical analysis of the U.S. forest products industry. Canadian Journal of Forest Research 23, 1993, 1537-1549.

Common, Mick S., A cost effective environmentally adjusted performance indicator. Discussion Papers in Environmental Economics and Environmental Management 9307, Department of Environmental Economics and Environmental Management, University of York, York, 1993.

Common, Mick S., Sustainability and policy: limits to economics. Sydney, Cambridge University Press, in press.

Common, Mick S. and T. W. Norton, Biodiversity, natural resource accounting and ecological monitoring. Environmental and Resource Economics 4, 1994, 29-54.

Common, Mick S. and Charles A. Perrings, Towards an ecological economics of sustainability. Ecological Economics 6, 1992, 7-34.

Costanza, Robert and Herman E. Daly, Natural capital and sustainable development. Conservation Biology 6, 1992, 37-46.

Cropper, Maureen and C. Griffiths, The interaction of population growth and environmental quality. American Economic Review 84(2), 1994, 250-254.

Daly, Herman E., Steady state economics. San Francisco, W.H. Freeman, 1977.

Daly, Herman E., Natural capital and sustainable development. Paper presented at the 2nd Meeting of the International Society for Ecological Economics, Stockholm, Sweden, August 1992.

Dasgupta, Partha and Geoffrey Heal, The optimal depletion of exhaustible resources. Review of Economic Studies 41, 1974, 3-28.

El Serafy, Salah, The proper calculation of income from depletable natural resources. In: Y.J. Ahmad, S. El Serafy, and E. Lutz (Editors), Environmental Accounting for Sustainable Development. Washington DC, The World Bank, 1989.

Faucheux, Sylvie, Geraldine Froger, and Martin P. O'Connor, The costs of achieving sustainability, Discussion Papers in Environmental Economics and Environmental Management 9410, EEEM, University of York, York, 1994.

Fitzroy, Felix R., Taxation and welfare in economies with externalities and unemployment. Discussion Paper Series No. 9314, Department of Economics, University of St Andrews, St Andrews, 1993.

Folke, Carl and Tomas Kåberger, Recent trends in linking the natural environment and the economy. In: C. Folke and T. Kåberger (Editors), Linking the Natural Environment and the Economy: Essays from the Eco-Eco Group. Dordrecht, Kluwer, 1991.

Funtowicz, Silvio O. and Jerome R. Ravetz, The worth of a songbird: ecological economics as a post-normal science. Ecological Economics 10, 197-208, 1994.

Gever, J., Robert K. Kaufmann, D. Skole and C. Vörösmarty. Beyond Oil: The Threat to Food and Fuel in the Coming Decades. Cambridge MA, Ballinger, 1986.

Grossman, Gene M. and Alan B. Krueger, Environmental impacts of a North American Free Trade Agreement. NBER Working Paper 3914. Cambridge MA, National Bureau of Economic Research, 1991.

Hall, Charles A. S., Cutler J. Cleveland, and Robert K. Kaufmann. Energy and resource quality: the ecology of the economic process. New York, Wiley Interscience, 1986.

Hartwick, John M.. Intergenerational equity and the investing of rents from exhaustible resources. American Economic Review 66, 1977, 972-974.

Hartwick, John M., Investing returns from depleting renewable resource stocks and intergenerational equity. Economics Letters 1, 1978a, 85-88.

Hartwick, John M., Substitution among exhaustible resources and intergenerational equity. Review of Economic Studies 45, 1978b, 347-354.

Hicks, John R., Value and capital: An inquiry into some fundamental principles of economic theory. Oxford, Oxford University Press, 1946.

Hirsch, Fred, Social Limits to Growth. London, Routledge, 1976.

Holling, C. S., Resilience and stability of ecological systems. Annual Review of Ecological Systems 4, 1973, 1-24.

Holling, C. S., The resilience of terrestrial ecosystems: local surprise and global change. In: W. C. Clark and R. E. Munn (Editors), Sustainable Development of the Biosphere. Cambridge, Cambridge University Press, 1986.

Howarth, Richard B., and Richard B. Norgaard, Environmental valuation under sustainable development. American Economic Review: Papers and Proceedings 80, 1992, 473-477.

Howarth, Richard B., and Richard B. Norgaard, Intergenerational transfers and the social discount rate. Environmental and Resource Economics 3, 1993, 337-358.

IBRD, World Development Report 1992. Oxford University Press, New York, 1992.

International Union for the Conservation of Nature, World conservation strategy: living resource conservation for sustainable development. Gland, Switzerland, I.U.C.N.-U.N.E.P.-W.W.F., 1980.

Jansson, Ann-Marie, Monica Hammer, Carl Folke, and Robert Costanza, Investing in Natural Capital: The Ecological Economics Approach to Sustainability. Washington DC, Island Press, 1994.

Jorgenson, Dale W., The role of energy in productivity growth. Energy Journal 5(3), 1984, 11-26.

Karshenas, Massoud, Environment, Employment and Sustainable Development. Technology and Employment Programme Working Paper, International Labor Office, Geneva, 1992.

Lélé, Sharachchandra M., Sustainable development: A critical review. World Development 19, 1991, 607-621.

Mäler, Karl-Göran, National accounts and environmental resources, Environmental and Resource Economics 1, 1991, 1-15.

Meadows, Dennis H., Donella L. Meadows, J. Randers, and W. Behrens, The limits of growth. New York, Universe Books, 1972.

Meadows, Dennis H., Donella L. Meadows, J. Randers, Beyond the limits: global collapse or a sustainable future ? London, Earthscan, 1992.

Munda, Guiseppe, P. Nijkamp, and P. Rietveld, Qualitative multicriteria evaluation for environmental management. Ecological Economics 10, 1994, 97-112.

Norgaard, Richard. B., Sustainability as intergenerational equity: the challenge to economic thought and practice, Internal Discussion Paper: Asia Regional Series. Washington DC, The World Bank, 1991.

Norgaard, Richard. B. Development betrayed: the end of progress and a coevolutionary revisioning of the future, Routledge, London, 1994.

O'Connor, Martin P., Entropic irreversibility and uncontrolled technological change in the economy and environment. Journal of Evolutionary Economics 3, 1993.

Page, Talbot, Conservation and efficiency. Baltimore MD, Johns Hopkins University Press, 1977.

Panayotou, Theo, Empirical tests and policy analysis of environmental degradation at different stages of economic development. Working Paper WP238. Geneva, Technology and Employment Programme, International Labor Office, 1993.

Pearce, David W. (Editor), Macmillan dictionary of modern economics. 4th edition, London, Macmillan, 1992.

Pearce, David W., Reflections on sustainable development. Paper presented at the Fifth Annual Conference of the European Association of Environmental and Resource Economists, University College, Dublin, 22-24 June 1994.

Pearce, David W. and Giles D. Atkinson, Capital theory and the measurement of sustainable development: an indicator of weak sustainability. Ecological Economics 8, 1993, 103-108.

Pearce, David W., Anil Markandya, and Edward B. Barbier, Blueprint for a Green Economy. London, Earthscan, 1989.

Pearce, David W., Scott Barrett, Anil Markandya, Edward B. Barbier, R. Kerry Turner, and Tim Swanson, Blueprint II: Greening the World Economy. London, Earthscan, 1991.

Perrings, Charles A., Economy and environment: a theoretical essay on the interdependence of economic and environmental systems. Cambridge, Cambridge University Press, 1987.

Perrings, Charles A. and David W. Pearce, Biodiversity conservation and sustainable development, Discussion Papers in Environmental Economics and Environmental Management 9301, EEEM, University of York, York, 1993.

Perrings, Charles A., Stress, shock and the sustainability of resource use in semi-arid environments, The Annals of Regional Science 28, 1994a, 31-53.

Perrings, Charles A., Ecological resilience and the sustainability of economic development, Discussion Papers in Environmental Economics and Environmental Management 9405, EEEM, University of York, York, 1994b.

Perrings, Charles A. and David I. Stern, Econometric modeling of agroecosystems, unpublished manuscript, EEEM, University of York, 1995.

Pezzey, John C. V., Economic analysis of sustainable growth and sustainable development. Environment Department Working Paper No. 15, The World Bank, Washington DC, 1989.

Pezzey, John C. V., Sustainability: an interdisciplinary guide. Environmental Values 1, 1992, 321-362.

Pezzey, John C. V., The optimal sustainable depletion of non-renewable resources. Paper presented at the Fifth Annual Conference of the European Association of Environmental and Resource Economists, University College, Dublin, 22-24 June 1994.

Proops, John L. R. and Giles D. Atkinson, A practical sustainability criterion when there is international trade. Department of Economics, University of Keele, Working Paper Series No. 93/21, 1993.

Rees, Judith A., Natural resources: Allocation, economics and policy. 2nd edition. London, Methuen, 1990.

Repetto, Robert, The global possible, resources, development and the new century. New Haven CT, Yale University Press, 1985.

Repetto, Robert, W. Magrath, M. Wells, C. Beer, and F. Rossini, Wasting Assets: Natural Resources in National Income Accounts. Washington DC, World Resources Institute, 1989.

Sagoff, Mark, The economy of the Earth. Cambridge, Cambridge University Press, 1988.

Samuelson, Paul A., Economics, 11th Edition, McGraw-Hill, Tokyo, 1980.

Selden, Tom M. and Daquin Song, Environmental quality and development: Is there a Kuznets curve for air pollution. Journal of Environmental Economics and Environmental Management 27, 1994, 147-162.

Shafik, Nemat, Economic development and environmental quality: an econometric analysis. Oxford Economic Papers, in press.

Sen, Amartya., Introduction. In: A. Sen (Editor), Growth Economics: Selected Readings. Harmondsworth, Middlesex, Penguin, 1970.

Simonis, Udo E., Beyond growth: elements of sustainable development. Berlin, Sigma, 1990.

Sims, Christopher A., Macroeconomics and reality, Econometrica 48, 1980, 1-48

Smith, V. K., Control theory applied to natural and environmental resources. Journal of Environmental Economics and Management 4, 1977, 1-24.

Solow, Robert M., Intergenerational equity and exhaustible resources. Review of Economic Studies 41, 1974, 29-46.

Solow, Robert M., On the intertemporal allocation of natural resources. Scandinavian Journal of Economics 88, 1986, 141-149.

Spash, Clive L. and Nick D. Hanley, Preferences, information, and biodiversity preservation. Discussion Paper in Ecological Economics 94/1, Department of Economics, University of Stirling, Stirling, 1994.

Steer, A. and Ernst Lutz, Measuring environmentally sustainable development. Finance and Development, December 1993, 20-23.

Stevens, T., J. Echeverria, R. Glass, T. Hager, and T. More, Existence values of wildlife. Land Economics 67, 1991, 390-400.

Stern, David I., Natural resources as factors of production: three empirical studies. Ph.D. Dissertation, Boston University, Boston MA, 1994.

Stern, David I., The contribution of the mining sector to sustainability in developing countries, Ecological Economics, in press.

Stern, David I., Mick S. Common, and Edward B. Barbier, Economic growth and environmental degradation: A critique of the environmental Kuznets curve. Discussion Papers in Environmental Economics and Environmental Management 9409, EEEM, University of York, York, 1994.

Tisdell, Clem, Sustainable development: differing perspectives of ecologists and economists, and relevance to LDC's. World Development 16, 1988, 373-384.

Toman, Michael A., John C. V. Pezzey, and J. Krautkraemer, Neoclassical economic growth theory and "sustainability". In: D. Bromley (Editor), Handbook of environmental economics. Oxford, Blackwell, 1994.

Vadnjal, Dan and Martin P. O'Connor, What is the value of Rangitoto Island? Environmental Values 3, 1994.

Victor, Peter A., Indicators of sustainable development: Some lessons from capital theory. Ecological Economics 4, 1991, 191-213.

Weitzman, Martin L., On the welfare significance of national product in a dynamic economy, Quarterly Journal of Economics 90, 1976, 156-162.

World Commission on Environment and Development, Our common future. Oxford, Oxford University Press, 1987.

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