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INTERPRETING ECOLOGICAL ECONOMICS IN THE NEOCLASSICAL PARADIGM: LIMITS TO SUBSTITUTION AND IRREVERSIBILITY IN PRODUCTION AND CONSUMPTION

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Abstract

There are many methodological approaches within ecological economics. Modifications to the neoclassical paradigm represents one of the principal modes of analysis. This paper examines the parallels between the ideas of some ecological economists concerning production and consumption, when viewed from a neoclassical perspective. It is well known that ecological economics is characterized by various arguments concerning limits to substitution between various inputs (energy, natural capital etc. vs. manufactured capital, labor etc.) in production and the implications these have for sustainability. However, various authors have also expressed concerns regarding limits to substitution in consumption. Ideas about irreversibility in production and economic development are also prominent in ecological economics. Likewise, many authors have argued for similar irreversibilities in consumption behavior. In analogy to the term technological change, I coin the term "preferential change". This paper illuminates the parallels between these four mostly independent research programs.

Keywords: Methodology; Neoclassical paradigm; Substitution; Irreversibility; Consumption; Production

1. Introduction

Work within a modified neoclassical paradigm represents one of a plurality of approaches in ecological economics (Norgaard, 1989; Christensen, 1989). This paper looks at a number of important ideas in ecological economics through a neoclassical lens. It is seen that what might seem disparate ideas could form part of a general and systematic modification of the "standard model" of neoclassical economics. The standard model is understood to be the set of assumptions and methods of analysis typically used in advanced textbooks or applied economics.

Specifically, ecological economists propose that the economy is characterized by limits to substitution and important irreversibilities. These affect both production processes and consumption behavior. Limits to substitution and irreversibility have been emphasized by ecological economists looking at production and economic development. However, workers in areas of consumption behavior have documented similar phenomena but have not compared these phenomena with their counterparts on the production side of the economy. The reason for this in part is that some of these researchers are working entirely within the conventional neoclassical environmental economics paradigm, and perhaps have not internalized that literature, while some others are philosophers. The inherent symmetry in neoclassical economics between models of production and consumption facilitates such a comparison, which I attempt to make in this paper.

Pearce (1994) suggests that one of the fundamental differences between ecological economics and environmental economics is the maintained hypothesis regarding the elasticity of substitution between natural resources and manufactured capital. Much of the environmental and resource economics literature assumes that substitution between resources and capital in production is fairly easy and that there is no limit to the extent to which this substitution can be continued (eg. Dasgupta and Heal, 1974; Solow, 1974). In general, ecological economists assume that substitution is more difficult and that there are limits to substitution. There are a number of reasons for this that all concern the physical nature of the inputs and the physical laws governing the production process which are generally ignored in neoclassical economics (Martinez-Alier, 1987). These claims also have well known implications for the sustainability of economic production or development (eg. Toman *et al.*, 1994).

There is also an extensive tradition of writers concerned with ethical and equity concerns in association with environmental issues. Two recent contributions focus on ethical limits to trade-offs between environmental assets and other goods and services (Spash and Hanley, 1995; Vadnjal and O'Connor, 1994). Sagoff (1988) focuses on the ethical underpinnings of differences between individuals' and society's decision-making concerning environmental or other social goals and concerning consumption goods and services. There are also utilitarian reasons why substitutability between environmental and non-environmental goods and services may be limited (eg. Hanemann, 1991). In both cases a neoclassical analysis can follow similar lines to the analysis of the limits to substitution in production within some necessary modifications.

As exemplified by Samuelson's (1947) synthesis, the theories of consumption and production are symmetrical in the neoclassical paradigm. Indifference curves in consumption theory are matched by output isoquants in production theory, marginal utilities by marginal products and so forth. It might appear that ecological economics poses a challenge to this neat mathematical formulation. Production processes are governed by physical laws, most crucially the laws of thermodynamics, whereas utility is a subjective variable representing people's whims and desires. Some authors argue that there need not be any direct correspondence between physical inputs and welfare due to the subjective nature of the latter. "A growth in the **value** of output, ... does not necessarily require a growth in materials and energy use" (Pezzey, 1992, 324, my emphasis). This is true to a degree, but there are differences between the various inputs to the utility production process. Some of these reflect physical properties of the commodities or services and others properties of the preference structure. In this paper I attempt to show how there are parallels between the limits to substitution in production proposed by ecological economists and limits to substitution in consumption.

Other ecological economists emphasize irreversibilities in production and economic development rather than, or in addition to, limits to substitution. One of the most fundamental of these is the tendency for entropy to increase as a result of any energy transformation process. This has been linked to limits to growth of the economy and the increasing impact of economies on the environment due to the mass-balance principle as their level of activity increases (Georgescu-Roegen, 1971; Ayres and Kneese, 1969; Perrings, 1987). Another, is the irreversibility of much economic development that transforms or degrades natural environments (eg. Krutilla, 1967; Pearce, 1976). Irreversibility of environmental impacts and evolutionary development and brought together in the literature on nonlinear economic-ecological systems, especially that relating to concepts of resilience and the existence of thresholds (eg. Perrings, 1994; Perrings and Walker, 1995). These metaphors can and have been extended to the ongoing joint development of the economy-environment system. "Ecological economics is concerned with the evolution of non-linear ecological economic systems in which system history means that system history is relevant to current and future opportunities" (Perrings *et al*., 1995, 9).

Another literature examines aspects of consumption behavior which do not seem to be well explained by the standard neoclassical approach. Within this literature there is a strong focus on connections between environmental quality, environmental degradation, economic growth, and welfare. Questions that are raised include: Why do people demand more environmentally damaging goods while expressing a preference for a better environment? Why do we find that people in economically more developed countries do not seem to be happier than those in poorer countries? These are related to the process of the formation of preferences and the concept of relative versus absolute poverty. Some important recent contributions are by Sagoff (1988), Daly and Cobb (1989), and Schmookler (1993). Norgaard (1994) goes beyond many earlier works in integrating some of these aspects together with the production side concerns, discussed above, in a vision of coevolutionary development.

I look at these two issues in terms of irreversible change. Such irreversible change in preferences may be likened to technological change in production. I coin the term preferential change to express the ongoing nature of this change. Traditionally such changes have been seen as occasionally exogenous shocks (eg. Chalfant and Alston, 1988). Following from the symmetry between production and consumption in neoclassical economics, similar tools could be applied to test hypotheses about changes in people's behavior over time. A further insight linking the two issues can be found in the material on limits to substitution in consumption as. I will show that irreversible changes combined with limited substitution possibilities can explain the pervasiveness of the two phenomena.

The first two sections of the paper review the literature on limits to substitution in production and in consumption. I do not further review the material discussed above on environmental irreversibilities as this material has been extensively discussed in this journal and elsewhere and it is not essential to developing my arguments in the remainder of the paper.[1] Therefore, I go on in the following section to examine the concept of irreversible change in consumption, and then to link irreversible change with limits to substitution. Finally, I present some conclusions.

2. Limits to Substitution in Production

Substitution of one commodity by a similar alternative is one of the key mechanisms through which neoclassical economists have proposed that an economy could circumvent the rising scarcity of a particular commodity in either consumption or production (eg. Solow, 1974). Many ecological

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[1] For example see O'Connor (1991), Ruth (1995a), and the references above.

economists have proposed that there are limits to such substitution. There are a number of reasons for this.

Most fundamentally, the second law of thermodynamics (the efficiency law) implies that a minimum quantity of energy is required to carry out the transformation of matter. Therefore there must be limits to the substitution of other factors of production for energy. The first law of thermodynamics (the conservation law) implies the mass-balance principle (Ayres and Kneese, 1969). In order to obtain a given material output greater or equal quantities of matter must enter the production process as inputs with the residual as a pollutant or waste product. Therefore, there are minimal material input requirements for any production process producing material outputs. All economic processes require energy, though some may not require the direct processing of materials. However, this is only true at the micro-level and at the macro-level all economic processes require the indirect use of materials, in either the maintenance of labor or the production of capital.

Ecological economists have also argued that at the macro-level some forms of "natural capital" are not replaceable by produced capital at least beyond certain minimum stock sizes (Costanza and Daly, 1992; Pearce *et al*., 1989). These stocks may provide life-support services to the economy or represent pools of irreplaceable genetic information or "biodiversity". The limited substitutability argument has also been extended to incorporate non-linear dynamics and irreversible changes as described above in relation to resilience. The fear is that excessive substitution of human-made capitals for this stock of natural capital will lead to the approach of a threshold beyond which natural systems will lose resilience and suffer catastrophic collapse (Common and Perrings, 1992; Pearce and Perrings, 1994; Perrings, 1994). These propositions are not as fundamental as those based on thermodynamics and are largely an empirical question. Though we cannot demonstrate these forms of non-substitutability from basic physical laws they may be just as important as thermodynamics in constraining actual production and utility or welfare functions.

At the micro-level Ruth (1993, 1995b) and Islam (1985) modified conventional production functions to take thermodynamic constraints into account. Ruth (1993, 1995b) discusses the case of simple transformation processes where minimum essential requirements of energy and matter to produce a given quantity of output can be calculated using thermodynamics. If the input combinations to produce a given quantity of output are represented by a single isoquant relating inputs of energy and matter to output, then the essential minimum quantities can be represented by two asymptotes parallel to the axes (see Figure 1). Ruth (1993, 1995b) used this approach to modify a Cobb-Douglas production function in an analysis of the iron and steel industry. Generalizing for a variable output level:

$$\gamma_1 (J - YJ^*)^{\gamma_2} (E - YE^*)^{\gamma_3} + \gamma_4 YJ^* + \gamma_5 YE^* - Y = 0 \qquad (1)$$

where J is the input of materials, E is the input of energy, Y is output, all of which are measured in physical units so that J* and E* can be calculated from the thermodynamically determined minimum inputs per unit output of materials and energy respectively. It is only practical to calculate such limits for specific simple transformation processes. However, when we can calculate such limits it seems that we should take advantage of such a priori knowledge in estimating production relations, and examining scenarios involving input substitution. Econometricians regularly take advantage of a priori economic theory to a similar end in estimating production relationships.[2] One limitation of this production function is the assumption that the elasticity of substitution adjusted for the minimum input requirements is unitary.

Islam (1985) takes a somewhat similar approach. He uses Houthakker's (1955) method of deriving the Cobb-Douglas production function. Instead of calculating isoquants from a Pareto density unrestricted over the input space he uses a truncated density over the input space to reflect minimum input requirements. This results in isoquants with a tight curvature and zones where the marginal rate of transformation is positive ie. an uneconomic region (Borts and Mishan, 1962). The derivation of the functional form is perhaps more rigorous than that used by Ruth (1993) but as a result it is more complex involving integrals. Though both these approaches are well suited for specific applications they are extremely difficult, if not impossible to generalize to the more complex situations that researchers interested in sustainability issues will want to investigate. In these situations inputs may already have undergone many transformations, the number of which could be increased or reduced with implications for substitution possibilities within the process under consideration, and outputs will not be easy to measure in purely physical terms.[3] The

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[2] It is highly unusual for econometricans to simply estimate a production function when they wish to estimate such parameters as the elasticity of substitution. Instead they typically will estimate a production function jointly with behavioral equations implied by economic theory, or exploiting the theory of duality estimate behavioral equations derived from a dual representation of the technology such as a profit function. This enables them to exploit more of the available data and, given that the a priori theory is correct, should increase the efficiency of estimation.

[3] See O'Connor's (1991) critique of the Faber *et al*. (1987) approach.

process of greatest interest to sustainability analysts is the "production" of GNP or some adjusted version in the macroeconomy.

In the extreme, the Leontief production functions used in input-output analysis assume no substitutability between inputs. Though these functions are much used by ecological economists in both energy analysis (Bullard and Herendeen, 1975a, 1975b; Bullard *et al.*, 1978; Hannon, 1974; Hannon *et al.*, 1984) and environmental accounting (Ayres and Kneese, 1969; Daly, 1968; Leontief, 1970; Victor, 1972) it would seem that this is more as a matter of convenience and the empirical usefulness of the input-output methodology than for theoretical reasons. After all, Leontief's work (1936) is a fundamental building block in mainstream applied economics and national accounting. Perrings (1987) and O'Connor (1993a, 1993b) use closely related neo-Ricardian von-Neumann (von-Neumann, 1945-6; Sraffa, 1960) models to model the evolution of a joint ecologic-economic system. Here non-substitutability seems to be a more fundamental feature rather than an undesirable byproduct. The neo-Ricardians sought to develop a rigorous economics that did not depend on the marginal productivity distribution theory of neoclassical economics. In the Perrings-O'Connor models pollution cannot be eliminated by internalization, undesirable stocks in the environment cannot be excluded from the production process simply because managers decide not to employ them.

All the studies cited in the previous paragraph refer, of course, to the macro level. Substitution fundamentally more constrained at this level of analysis. Capital and labor require energy and materials for their construction and maintenance. Therefore substitution between the former two factors and natural resources is more limited on an economy-wide basis than within an individual firm or industry as implied by micro-level production functions (Cleveland *et al.*, 1984; Hall *et al.*, 1986). There is an indirect energy cost to capital (and labor), and therefore if we substitute capital for energy the total energy savings will be less than the saving in direct energy use. As there are eventually diminishing returns to increases in the use of any factor of production, even if the energy cost of producing the marginal unit of capital does not increase, there will eventually be decreasing returns to capital and therefore a limit beyond which capital / energy substitution would be irrational. This phenomenon is recognized by Smith (1978) who differentiates between "gross" and "net" substitution (p154). Stern (1994) presents a graphical interpretation of this theory. In Figure 2 the curve E = f(K) is a neoclassical isoquant for a constant level of output. The indirect energy costs are represented by g(K).[4] Addition of direct and indirect energy costs results in the "net" isoquant E = h(K).

A more general approach at both the micro- and macro-levels, in either analytical or empirical applications, is to employ either CES functions or flexible functional forms, in particular the translog function. Toman *et al*. (1994) point out that a CES function with an elasticity of substitution less than one has a bounded average product and therefore reflects minimum input requirements. These requirements can be estimated econometrically. However, the CES function cannot be effectively generalized to more than two inputs (Uzawa, 1962; McFadden, 1963). Flexible functional forms allow variable and arbitrary elasticities of substitution and different substitution possibilities between different pairs of inputs. The translog function has the important global property that it shares with the Cobb-Douglas function (a special case of the translog) that output approaches zero as any input approaches zero. This is not the case for the Generalized Leontief function which is another widely used flexible functional form. The translog production function can effectively model minimum input requirements, any elasticity of substitution, and uneconomic regions, for any number of inputs and outputs (Stern, 1994). The translog function is also fairly simple to implement econometrically.

3. Limits to Substitution in Consumption

3.1. Introduction

There is a fundamental sense in ecological economics in which the allocation of property rights is seen to be more critical than is commonly the view in mainstream environmental economics (eg. Spash, 1994; Woodward and Bishop, 1995; Bromley, 1995; Jaeger, 1995). Normative environmental economics primarily focuses on efficiency rather than equity. Given the basic conditions that underpin the first fundamental theorem of welfare economics, the second fundamental theorem of welfare economics asserts that any efficient allocation can be achieved with the appropriate set of lump sum taxes and transfers between individuals. Therefore efficiency is separable from equity. The Coase theorem (Coase, 1960) is a special case. In cost-benefit analysis the Hicks-Kaldor (Hicks, 1939; Kaldor, 1939) potential compensation principle is invoked to justify moves between Pareto efficient allocations. However, when substitutability in consumption

[4] These would be calculated in terms of a flow of energy costs over the lifetimes of the relevant capital goods (Cleveland and Stern, 1993).

is limited it becomes increasingly difficult for the gainers from an environmental change to compensate the losers.

Several writers and researchers have proposed that there are or should be limits to substitution in consumption either at the level of the individual or at the level of social choice. In this section, I describe three specific approaches. First, I look at Sagoff's (1988) views on the citizen vs. the consumer. Then I look at the concept of lexicographic preferences for environmental quality or stocks and its relation to the ideas of intrinsic value in nature or rights of wildlife or other elements in nature. Finally, I look at two cases of continuous neoclassical utility functions with limited substitutability. The first case concerns limited substitution between environmental quality and other commodities and its implications for contingent valuation (CVM) and sustainability. The second concerns limited substitutability between basic needs commodities and other commodities and the implications for sustainability.

3.2. Citizens and Consumers

Sagoff (1988) suggests that a more useful model of human preferences than the neoclassical approach is a dichotomous distinction between consumer and citizen. He argues that people will agree to more altruistic proposals when they act in a citizen mode, for example in a referendum, than when in the consumer mode, for example when making purchasing decisions.

> "As a *citizen*, I am concerned with the public interest, rather than my own interest; with the good of the community rather than simply the well-being of my family... as a *consumer*, ..., I concern myself with personal or self-regarding wants and interests; I pursue the goals I have as an individual. I put aside the community-regarding values I take seriously as a citizen, and I look out for Number One instead." (Sagoff, 1988, 8).

Sagoff's approach applies to both decision making by an individual and to social decision making. If we adopt the neoclassical approach to social decision making and base decisions on the preferences of individual consumers then Sagoff's proposition about individual decision-making implies that we should treat social decision-making concerning the environment on the basis of what individuals would vote for in the citizen mode. He further argues that it is a "category mistake" to treat decisions about public policy as if they were consumer decisions. If this were the case then we might make a decision as citizens to leave some things to the market while deciding to regulate other activities on the basis of other criteria such as safety, environmental quality etc.

Common *et al*. (1994) argue that if individuals act in this way then a general utility function with arguments in both environmental quality and consumer goods is undefined. Though not all decision-making can be explained by utility maximization, the utility function is very well defined for all consumer expenditure decisions. Substitutability is limited in that for the purposes of consumer decision making, the individuals decisions as "citizen" are taken as given. The social welfare maximizing decision-maker can no longer trade off the supply of "citizen commodities" such as environmental quality with "consumer commodities" so that conventional cost-benefit analysis is ruled out. As pointed out by Berrens and Polasky (1995) in their article in this journal concerning the Paretian Liberal Paradox first raised by Sen (1970), there may no longer be a coherent and consistent optimal policy.[5] Kohn (1993) suggests that a Bergson-Tintner-Samuelson ethical function that nests a personal utility function and a "vitality function" for nature could bring the ideas of Sagoff (1988) within the neoclassical paradigm. However, Stevens *et al*. (1993) point out that this is just one within a number of alternative formulations.

Obviously, not everyone operates in the bimodal way suggested by Sagoff. Many people would "vote their pocket book" and make citizen decisions on the same basis as consumer decisions. Many other people make many altruistic decisions as consumers, voluntarily participating in such activities and behaviors as recycling, energy conservation, vegetarianism etc. The following section examines an extreme case of the latter decision-making approach.

3.3. Lexicographic Preferences

Sagoff characterizes the decision making of an individual in the citizen mode as being concerned with the "public interest". However, individuals may also make decisions in the "natural interest" or the "divine interest". 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, 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. In the Jewish, Christian, and Islamic traditions people are seen to be "stewards" of nature on behalf of God. Animals and other organisms do not have intrinsic rights but they are to be respected as elements in the Divine creation. In a quite real way the property rights in nature are assigned to God.

[5] For further discussion and a survey see Sen (1995).

Such intrinsic value may be expressed within a utilitarian preference system as existence value. Edwards (1986) proposed that when such beliefs are more strongly held they will be expressed as a limit to substitution in the form of lexicographic preferences. He also noted that a lexicographic ordering "could be bounded by a constraint on personal welfare" (Edwards, 1986, 147). Stevens *et al*. (1991) also suggest that below a minimum level of income, income might always be preferred to wildlife. Above this level, wildlife is always preferred to income. Implicitly in the Stevens *et al*. (1991) formulation, utilitarian preferences may be held for ordinary consumption goods and services in that more income is always better than less given a certain level of wildlife. Similarly more wildlife is always better than less given a certain level of income. This situation means that the indifference is undefined. The following paragraphs illustrate this behavior geometrically following Spash and Hanley (1995) very closely.

Figure 3 presents the standard model of lexicographic preferences for two goods W and X which both provide utility. W is the environmental good, and X a marketed good. Assume that an individual has an endowment of W_1, X_1 (A). No increase in X can compensate the individual for a reduction in W, but increasing X with non-declining W does increase utility. Therefore, the only point on the line CAB which gives equal utility to A is A itself, while any reduction in W below W_1 will give less utility, irrespective of any associated increase in X. The shaded area, including the line AB, shows the bundles of goods W and X which are preferred to that at A. All points are either better than A or worse than A but none are of equal utility. Thus the individual's preferences are described by point A rather than an indifference curve and no indifference curves exist.

Figure 4 introduces a subsistence level of income, X_{min}, to the analysis. Stevens *et al*. (1991) argue that an individual situated at A would be willing to pay X_1-X_{min} to prevent any reduction in the environmental good W. As before, increases in income with no change to wildlife increase welfare. However, an individual located at D with the endowment W_1, X_0 always prefers more income to more wildlife. Any point to the right of D at the level of income X_0 is preferred to D. However, any point between X_0 and X_{min} is preferred to D whether the level of the environmental good is higher or lower. Any point with income lower than X_0 is worse than D irrespective of its level of W. Therefore, indifference for this individual is also defined by a single point and the utility function is undefined.

Spash and Hanley (1995) suggest, following Sen (1987), that the level of X_{min} is susceptible to being culturally determined and is consistent with a variety of material levels of well-being. Individuals who regard themselves as on the minimum standard of living may be willing to pay nothing for an increase in W, but will give an infinite valuation of a decrease in W. This is one possible explanation of the large difference between WTP and WTA measures frequently encountered in empirical applications of CVM. Other explanations of this phenomenon are discussed below.

Lexicographic preferences embody a degree of irreversibility (Spash and Hanley, 1995). In Figure 5 the individual is again assumed to have the endowment A. Clearly the individual is willing to give up some X to increase W from W_1 to W_2 as long as X does not fall below X_{min}. Bundle E (X_2,W_2) would give greater utility than bundle A (X_1,W_1). However, once the move to E has been made there is no way to return to A without reducing utility. The reduction in W from W_2 to W_1 would be given an infinite valuation. Therefore, W_2 now becomes the new reference point at or above which W must be maintained. Section 4 will take this aspect of irreversibility and extend it to more general cases.

Spash and Hanley (1995), Vadnjal and O'Connor (1994), and Stevens *et al*. (1991) all provide evidence of the existence of lexicographic preferences revealed in CVM surveys. Often a large percentage of respondents make a zero bid for the preservation of the resource or asset in question yet state that they believe it should be preserved or protected from development. Vadnjal and O'Connor's (1994) study is particularly interesting as participants in Auckland were questioned about the preservation of Rangitoto Island in Auckland's Waitemata Harbor a site with which they were all familiar. Also the results of the survey were analyzed by textual analysis in addition to the more conventional techniques. Three quarters of the respondents who were willing to pay towards the preservation of the island, nevertheless stated that they did not think of this as giving a monetary valuation of the worth of Rangitoto to them. The remainder willing to pay positive amounts split fairly equally among those who thought that their WTP was an expression of the value of Rangitoto and those who said that they found the questions difficult to answer for one reason or another eg. unfamiliarity with paying for Rangitoto. This survey suggests that lexicographic preferences may be even more prevalent than the other studies have shown.

Boyce *et al*. (1992) attempted to test whether intrinsic value was a reason for the large empirical disparities between WTP and WTA, though they do not directly discuss lexicographic preferences. The commodity under consideration was small Norfolk Island Pine Trees. In the WTA experiments participants could sell the trees back to the experimenters, while in the WTP experiments they could buy the trees from the experimenters. In half of each sample the participants were told that if they did not buy the tree (WTP) or if they sold it back (WTA) it would be killed. The needless destruction of a living thing was supposed to capture a dimension of intrinsic value. The bids for the WTA/kill experiment were skewed towards much higher values than the other three (some people refused to sell). The implication is that some participants saw that they had a moral obligation to protect the trees in their endowment from needless destruction. In the WTP/kill experiment participants had an endowment of \$40 and no trees. Nobody bid more than \$40 to stop the destruction of the trees. All this is consistent with the lexicographic preferences model though it may also be consistent with some other models described below.

3.4. Continuous Neoclassical Utility Functions

Lexicographic preferences imply that a continuous utility function does not exist. Substitutability may still be limited if a neoclassical function does exist. Krutilla (1967) was the first to discuss nonsubstitutability in the neoclassical case. In this subsection I examine two cases of potential limited substitutability. The first is a generalization of no substitution between environmental quality and other commodities to limited substitution in continuous functions. This has implications for both CVM and sustainability. The second concerns limited substitutability between basic needs commodities and other commodities. This mainly has implications for sustainability analysis.

3.4.1. Environmental Quality, Contingent Valuation, and Sustainability

One of the conditions that lead to the preferences described above being lexicographic is that for a given level of wildlife, more income is always better, while for a given level of income, more wildlife is always better. That is, preferences have the property of non-satiation. Alternatively, an individual may be indifferent to increased income given a certain level of wildlife and vice versa, as long as income is above a subsistence level and wildlife is greater than a minimal value respectively. A function that satisfies such conditions is the familiar Leontief function (Figure 6). Wildlife and other goods are perfect complements. An individual at A is at the subsistence level of income X_0. They have a WTP of zero for increases in wildlife from W_0 to any higher level. However, they have an infinite WTA for a reduction in W below W_0.

Now assume that utility increases to U1 through a simultaneous increase in both X and W. An individual at B again has a zero WTP for any increase in wildlife but an infinite WTA for any decreases. Leontief preferences thus generate irreversibility and large differences between WTP and WTA in the same manner as lexicographic preferences. The model can also generate finite non-zero WTPs. An individual at C will be willing to pay $X' - X_1$ to see an increase in W from W_0 to W_1. but will still be WTA an infinite amount for any decrease. Any individuals on the lower right branch of the indifference curve, for example at D will be indifferent to the level of wildlife and will be WTP and WTA zero.

This is obviously an extreme case where the elasticity of substitution is zero. For a continuous and smooth function the elasticity of substitution will be non-zero. Hanemann (1991) argues that observed differences between WTP and WTA in CVM studies are a function of the income elasticity of demand for environmental commodities and the elasticity of substitution between those goods and all other goods. Three other explanations have been suggested for observed disparities. Brown (1994) lists intrinsic value and the loss aversion / endowment effect (first introduced by Kahnemann and Tversky, 1979). A lack of realism of some elicitation procedures may also be a cause of disparities between WTP and WTA (Brookshire and Coursey, 1987).

I have already discussed the role of intrinsic value above. Intrinsic values may be expressed by individuals who have somewhat ambiguous moral principles through utility functions with limited trade offs. We might imagine that close to subsistence income some trade off between income and the moral principle would be entertained. However, at higher incomes no such trade offs would be necessary. It seems reasonable that the minimum subsistence level will be correlated with the level of welfare attained. That is, more wealthy people in a Western society for example may consider owning a car a necessity while it is not considered a necessity by the urban poor. Also the minimum moral standard may vary. The indifference map would be similar to Figure 6 but the curves would be "rounded off" at the corners. Such a utility function might be represented by a CES function with an elasticity of substitution less than one and would exactly parallel the micro level production function discussed in section 2 above.

Loss aversion could be modeled within the standard utility framework in two ways. First, a higher WTA than WTP might be due to low substitutability between the environmental asset and other goods and services as discussed above. Then if the current endowment is located at a point where the indifference curve is sharply curved different values will be given for any non-infinitesimal changes in the endowment of the environmental asset. Why would the current endowment be located at this point? If individuals are similar they will place low value on losses of the environmental asset until its level reaches the zone of sharp curvature, where compensation demanded rises sharply. Thus the economy will tend to move towards this point where the shadow price of the resource begins to rise steeply. The main argument against this theory is that if there are no effective markets for the environmental good there is no reason why this trend should stop at this point. Presumably protest against further environmental destruction and ad hoc conservation efforts would rise to slow or block the trend, once the loss of utility was great enough. An alternative argument is discussed below in the section on irreversibility.

The second explanation does not involve non-substitutability. Instead losses and gains might be seen as goods (and bads) in themselves. Contingent valuations might be placed on the experience of gaining an asset or losing it, rather than on the consumption of services from the assets. The former would have two different prices.

Adamowicz *et al*. (1993) tested Hanemann's (1991) proposal using a live sports event vs. the substitute of televized coverage of the event and a movie in a theater vs. a video cassette of the movie and access to a VCR.[6] Some participants were told that the substitute did not exist. Little if any effect of the substitute was found though the results are not inconsistent with Hanemann (1991). The researchers found that WTA was larger than WTP whether a substitute existed or not. The existence of a substitute caused both measures to fall though WTA fell slightly more decreasing the disparity. The appropriateness of this test though clever is, however, somewhat questionable. A sports event is neither a public good nor a unique phenomenon on the same scale as Hells Canyon or other examples of the "grand geomorphological wonders" in the words of Krutilla (1967).

With limited exceptions (eg. Vousden, 1972; 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. The basic Dasgupta and Heal (1974) and Solow (1974) models assume a closed economy with capital accumulation and non-renewable resource depletion. The production function is a Cobb-Douglas function with two inputs - capital and the resource and no technical progress. Under appropriate conditions concerning intertemporal decision rules sustainability is feasible (Dasgupta and Heal, 1974; Solow, 1974; Pezzey, 1994). Vousden (1973) considered a standard Dasgupta-Heal (1974) economy with the addition that the resource stock also enters the utility function. This would be reasonable if for example resource extraction means converting an environment into a less desirable form as for example 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

[6] See Adamowicz *et al*. (1994) and Brown (1994) for clarification of the results.

consumption between resources and consumption goods is less than one. Given that the resource is non-renewable and essential even a constant level of welfare will not be possible and utility must eventually decline.

3.4.1. Basic Needs and Sustainability

Up to this point in this section, I have considered substitution between environmental assets or commodities and other goods and services. Another substitution question which combines both production and consumption has been very significant in ecological economics though rarely stated in this formal manner. The concept of basic needs (ILO, 1976) implies that some commodities or types of commodities have no substitutes in consumption. What exactly constitutes a basic need is much disputed and such needs are inevitably partly cultural constructed. For the purpose of sustainability analysis we have to imagine what commodities are absolutely necessary for survival under any imaginable technology ie. given the laws of physics and human biology as we currently understand them. These would include basic foodstuffs whether naturally grown or artificially synthesized and methods of buffering people from harsh external environments which are currently carried out by buildings, clothes etc. There is no way that either category could be supplied without inputs of energy and matter.

Thus basic needs imply that there are limits to substitution in consumption and our scientific knowledge indicates that producing these commodities requires minimum inputs of some natural resources in production. The opposing view is that resource inputs could become infinitesimally small for finite outputs implied by the Cobb-Douglas production function while maintaining utility indefinitely. In this view output would become what Daly (1977, 118) called "angelized GNP".

4. Irreversible Change in Consumption: "Preferential Change"

Neoclassical economists are very reticent to discuss the origin of preferences. Preferences are often assumed to be exogenously given and not a product of the economic system. Typically it is also assumed that preferences are unchanging over time. When changes in preferences are admitted they are described as originating "outside" the economic system (Hirschleifer, 1984). In the past economists held similar views regarding technology. However, this view has been fundamentally changed and today it is accepted that technological change is an endogenous process within the economic system (Romer, 1994).

In the opinion of Stigler and Becker (1977) it is most reasonable to assume that the preferences of individuals are fixed and unchanging. Any changes in preferences that are observed are likely to be the result of ignoring changes in other variables such as the prices of other goods and services, the result of compositional change in the population under consideration, or, most interestingly, due to changes in the technology of household production of "commodity objects of choice" from market goods and time. These latter changes in technology may be pure technical change as for example in the case of "labor-saving" appliances or due to the accumulation of various "capitals". Some examples that they give are "music appreciation capital" and "euphoric capital" associated with the consumption of heroin. Stigler and Becker (1977) admit that their proposition is axiomatic, rather than a falsifiable hypothesis. However, they argue that the assumption that preferences are constant is more illuminating than to explain away various behaviors in terms of exogenous shifts in tastes.

Empirical work on the stability of preferences appears to have concentrated on the first two reasons for apparent changes in preferences. For example, Chalfant and Alston (1988) suggest that previous econometric work on the stability of preferences has found instability due to incorrect functional forms or omitted variables. We will return to Stigler and Becker's (1977) more fundamental point after examining some evidence for changing preferences on a more macro scale.

In "The Illusion of Choice" Schmookler (1993) describes the evolutionary development of preferences in response to the forces present in a market economy. Schmookler's main point is that the economy is an evolutionary system. People's preferences are moulded by the opportunities to consume that are available. They can only choose to consume from a menu of choices that is available to them. Future opportunities are moulded by the exercising of these preferences. In the absence of markets for many environmental resources, people cannot easily influence their availability through the exercising of their preferences in the market place. In the absence of political action and the presence of transactions costs to Coase bargaining, a nonoptimal provision of environmental resources will tend to worsen over time from the perspective of earlier generations. From the perspective of those people the menu of choices which initially was only slightly wrong gets increasingly wrong. However, the majority of people in each generation may not perceive this worsening. Schmookler asks whether they are truly exercising free choice.

Easterlin (1974) surveyed the level of happiness reported by people living in various countries at a broad range of levels of economic development. Easterlin found that within each country the rich reported a higher level of happiness than the poor. However, there was no correlation between the average happiness in a country and its level of income relative to other countries. Later evidence (Freedman, 1978) showed that there was some correlation between the wealth of a country and the happiness of its people but this correlation was due entirely to the lowest income countries. Among middle and high income countries no such relationship existed. Attainment of a basic subsistence level is important for increasing welfare but subsequent income increases have little or no effect. This is the justification for the UNDP's human development indicator which counts PPP dollars up to the poverty line of $4829 on a proportional basis, but counts dollars above this poverty line on a steeply declining basis (UNDP, 1992).

Many ecological economists have argued that economic growth does not increase welfare as welfare is primarily (Common, 1995) or partly (Howarth, 1996) dependent on people's relative socio-economic position in society rather than their absolute level of welfare. A significant portion of the consumption of wealthier individuals may be so-called positional goods whose utility declines as their consumption spreads among the population (Hirsch, 1977; Common, 1995; Jaeger, 1995). Also it is often argued that advertising forms many of people's desires raising the utility of goods that were formerly not so desirable (Galbraith, 1967; Common, 1995, Jaeger, 1995).

Let us put some of these varied observations in the context of neoclassical theory. Assume that all consumers in a given region or country at a particular point in time, 0, have the same monotonic utility function, f( ), and consume one homogeneous good "income", I. Then quite obviously people's relative income will explain their relative happiness by the constraint it imposes on their maximum utility. If in period 1 incomes all rise by a given percentage over incomes in period 0 then the absolute gaps between individuals in terms of income will increase, though proportionally relative incomes will stay the same. If this change leaves everyone feeling just as well off as they were before the increase then the utility (U) of individual i:

$$U_{1i} = f(A_1 I_{1i}) = f(A_0 I_{0i}) = U_{0i}$$

$$A_0 = 1 \qquad A_1 = I_{0i} / I_{1i} \qquad (2)$$

where A is the augmentation factor of income.[7] This is of course tautological. AI is termed the effective units of income. The insight here is that we can produce the same result of utility depending on interpersonal rankings without specifically invoking interpersonal comparisons. This allows us to consider other possibilities for the result. In this example, increases in income are offset by changes in an augmentation factor that makes the increased income less useful per unit than previously. Why might this happen? One approach is to link the augmentation factor to

[7] To emphasize that I am not proposing an exogenous theory of preferential change the augmentation factor is not an explicit function of time.

general expectations within a society. In a Western society the abstract concept of success will be a function of a different standard of living depending on the historical period. If success is a major input to welfare ie. through self-esteem, then the income aspect of success is measured against the mean income in any period which under economic growth is continuously increasing.[8] In this example utility is not so much a function of what other people's income is ie. through envy, than of the general expectations of society. If this is the case then even if growth succeeds in reducing income inequality there would still be a desire for growth because at least some people would want to exceed the expectations of society. In the Stigler and Becker (1977) terminology, A_t, is a form of capital "success capital" - the more of it present the higher the level of utility.

Pezzey (1992) notes that there is a wealth of psychological evidence that "the maintenance of a state [is] associated with a decreasing response to that state [because] any beneficial effects of improved circumstances may be cancelled by adaptation" (Kahneman and Varey, 1991, 136-143). He argues that "if such total adaptation does happen, then life is a 'hedonic treadmill': as long as basic survival needs are provided for, any quality of life will give the same utility" (Pezzey, 1992, 351).

This so far is only one simple example. We can apply the same approach to positional goods and the effects of advertising. Just as in production, in addition to neutral preferential change, biased preferential change may also occur. In the above example, the usefulness of a positional good in producing utility might be declining faster than that of other products. The augmentation index will be an inverse function of the number of people consuming the commodity. Advertising might make the advertised good more productive in producing utility than previously. Generalizing from (2), I propose a utility function where each of n commodities is premultiplied by an augmentation index:

$$U = f(A_1X_1, \ldots, A_nX_n, \Pi) \qquad (3)$$

where Π is a fixed parameter vector.

It should now be apparent that this factor augmentation model is close to Stigler and Becker's (1977) approach. The utility function is parametrically fixed, but the augmentation factors change over time. Changes in these factors may in some cases be due to changes in the various capitals that Stigler and Becker write of. In other cases they may be due to pure technical changes in household production such as labor-saving appliances and as Stigler and Becker suggest, methadone. This approach however appears to be even more general than Stigler and Becker's.

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[8] See Schmookler (1993) particularly pp145-147 for a discussion of the rise of success as a primary objective of individuals in the USA and other Western societies.

Also, the way I have presented it gives it a rather left-wing spin compared to the rather right-wing tone of Stigler and Becker's work. To some degree the question of whether preferences are stable but the augmentation factors or capitals are changing or whether preferences themselves change is semantic. Stigler and Becker say that advertising is not insidious, it does not change preferences, instead it helps consumers accumulate information and appreciation capital. But this latter capital is just a change in preferences by a different name. If we accept that technological change in production is due to economic forces we should be able to accept that preferential change in consumption is also due to economic forces.

In production theory there is the same duality between a capital representation and a technological change representation. For example, the skill levels of workers can be termed the "human capital" associated with those workers, or skill levels can be measured indirectly in terms of the effective units of labor associated with each worker or hour of labor. The former is a useful approach when direct measurement is possible. Similarly, I have proposed that there is a duality between natural capital and effective units of natural resources (Stern, 1994; Perrings and Stern, 1995; Stern, Perrings, and Patnaik, 1995). For example, we can attempt to measure directly the quality of agricultural land, or we can estimate indirectly (econometrically) the number of effective units of land associated with each unit of land area. The latter is much less expensive.

I believe that it should be possible to derive empirical estimates of preferential change. Econometric estimates would be carried out on systems of demand equations. Estimating augmentation trends requires for identification purposes as many equations as there are trends. Given that the various commodity demands are functionally dependent, we can only estimate n-1 demand or expenditure share equations. The nth equation is logically the objective function. In production analysis we can estimate the production function or profit function. However, we cannot estimate directly either a utility function, an indirect utility function, or an expenditure function. In the former two cases the dependent variable is unobserved. In the latter one of the arguments is unobserved (see Varian (1992) for more details). This means that we can only estimate n-1 trends. One approach is to use Harvey and Marshall's (1991) method of estimating relative factor augmenting technical change. Augmentation trends are estimated relative to a general neutral technical change trend. The sum of the individual augmentation factors is zero in each time period. An alternative is to use one of the commodities as a numeraire and estimate augmentation factors for the other commodities relative to that of the numeraire commodity. A natural choice for some of the issues raised here is to choose a basic needs commodity as the numeraire. Alternatively, and depending on the application, we can drop the augmentation assumption and estimate preferential change using the standard biased technical change framework (eg. Christensen *et al*., 1973).

If we can assume that the effective units per crude unit of some basic needs commodity is constant then we could calculate an index of preferential change using the standard index numbers approach and expenditure shares weights. An estimate of this index could be used to assess whether the hedonic treadmill (Pezzey, 1992) is in fact a reality. Estimates of individual augmentation trends might tell us something about whether commodities are perceived as positional, or may be augmented perhaps through advertising over time.

There are other reasons why increases in income may not add to utility which are more concerned with changes in the product and consumption mix than with changes in preferences. Schor (quoted in Wallich, 1994) claims that:

> "the U.S. market for goods has become skewed by the assumption of full-time, two career households. Automobile makers no longer manufacture cheap models, and developers do not build the tiny bungalows that served the first postwar generation of home buyers ... U.S. goods are appropriate only for high incomes"

So if somebody wants to choose a low income lifestyle their utility will be reduced because they will not have access to the goods that previous generations could enjoy on the same real income. Imagine an individual who built a hut out of mud bricks and corrugated iron on their own land in a city in a developed country. The authorities would be likely to not grant a permit or destroy the structure because it violated building codes, health codes, etc. The option to consume this package of housing services would not be available. The individual might end up sleeping on the street or be forced to pay a large amount of money for conventional housing. Alternatively, Smith (1776) argued that shoes had become a necessity of life in England not for protective purposes but because people would be ashamed to be seen without them.[9]

An alternative explanation of the failure of economic growth to increase people's perceived happiness is the substitution argument. In this view economic growth comes at the expense of the environment and social institutions such as "community" (Pezzey, 1992). Damage to the environment occurs through the use of the environment as a source of raw materials, as a depository for waste, and as a location for economic activity (eg. roads). Damage to community can occur due to the increasing division of labor, and improved transportation and communication systems that facilitate the dispersal of population and economic activities. Daly and Cobb (1989)

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[9] See Pezzey (1992) for further examples.

and Schmookler (1993) are some of the recent authors who argue that both effects substantially negate the benefits of economic growth.

It is an empirical question as to what extent these two effects, substitution and technological change in preferences, contribute to the perception that growth does not increase welfare beyond the subsistence level. Schmookler's (1993) conception of the process through which environmental quality is lost fits in with Pezzey's (1992) idea of a hedonic treadmill but instead of preferential change, the treadmill is one of continuous substitution of marketed goods and services in place of environmental quality, community and other non-marketed inputs to welfare. As there are no markets in the latter inputs, individuals cannot choose how much of them they wish to consume. Therefore an increase in welfare can only come about by an increase in the consumption of goods and services - individuals are permanently at a corner solution to the utility maximization problem due to the constraint of given non-marketed inputs. If production of the marketed inputs comes at the expense of the non-marketed inputs, then the given quantity of non-marketed inputs will decline and individuals will be forced to reduce their level of welfare. To regain the higher level of welfare further increases in the consumption of marketed inputs will be necessary and so on *ad infinitum*.

5. Conclusions

This paper has demonstrated how various ideas in ecological economics relate to the "standard model" of neoclassical economics. Ecological economics have important things to say about the possibilities of substitution of commodities in, and irreversible changes in the "technologies" of, production and consumption. I believe that the connections and parallels between research in these areas has not always been as clear as it might be. I further believe that my attempt to relate these ideas to the corresponding concepts in the much more elaborated neoclassical paradigm helps to illuminate these links. Some of these ideas have emerged among environmental economists working primarily within the neoclassical framework. In these cases the necessary modifications to that paradigm are quite clear. Some of the other ideas have originated from within other schools of thought, though there may be related to work within the neoclassical school. The paper attempts to point out these connections or to suggest new approaches to modify the neoclassical "standard model" to accommodate these ideas.

My hope is to bridge by a small increment the gap between ecological economists working within the neoclassical school and those working within other paradigms. The former group might gain new ways of looking at ideas emerging in other schools of thought, while the latter might gain some insight into connections between the different ideas provided by the neoclassical formalization.

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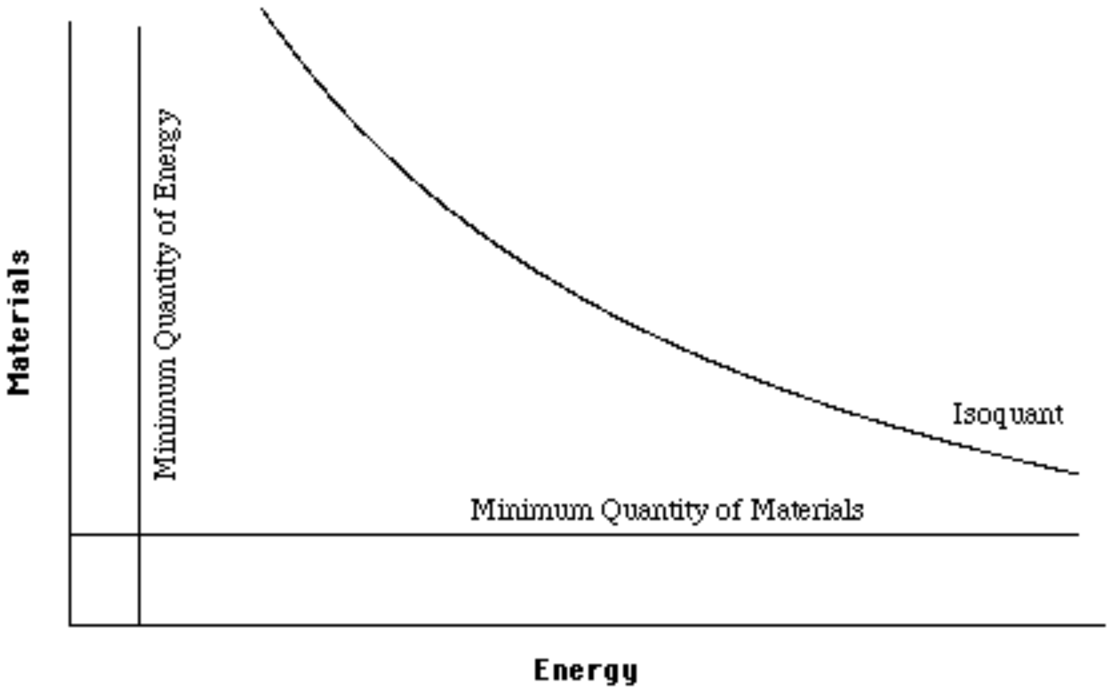
Figure Captions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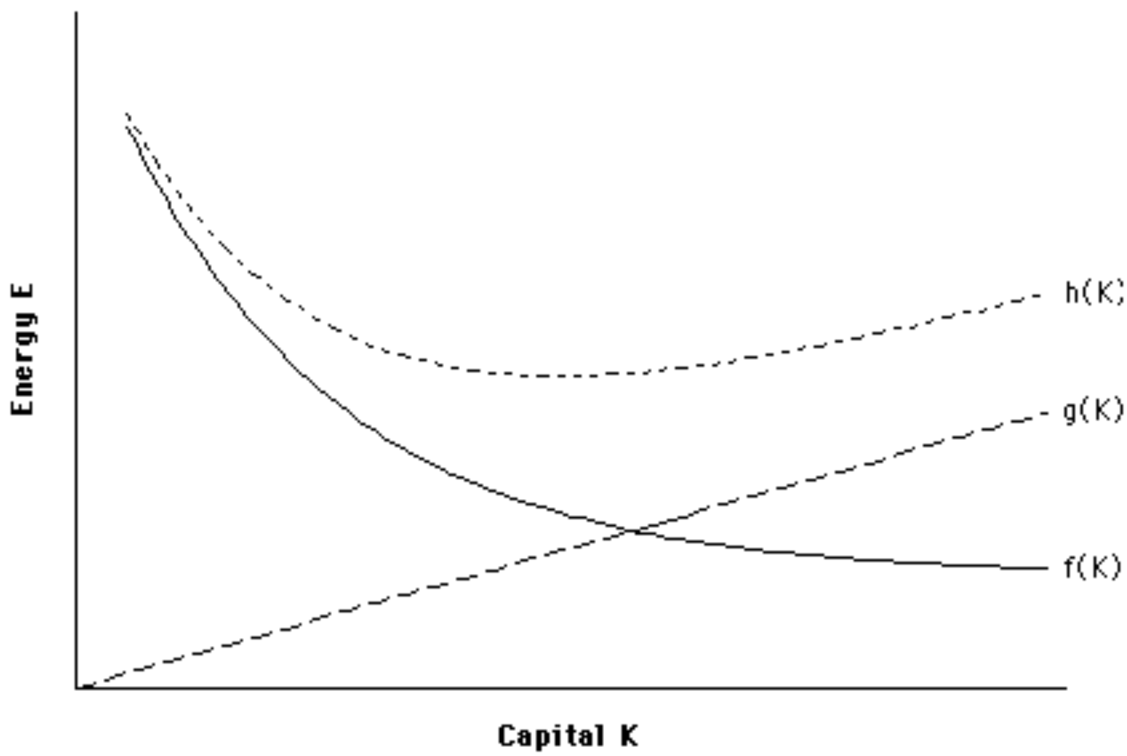
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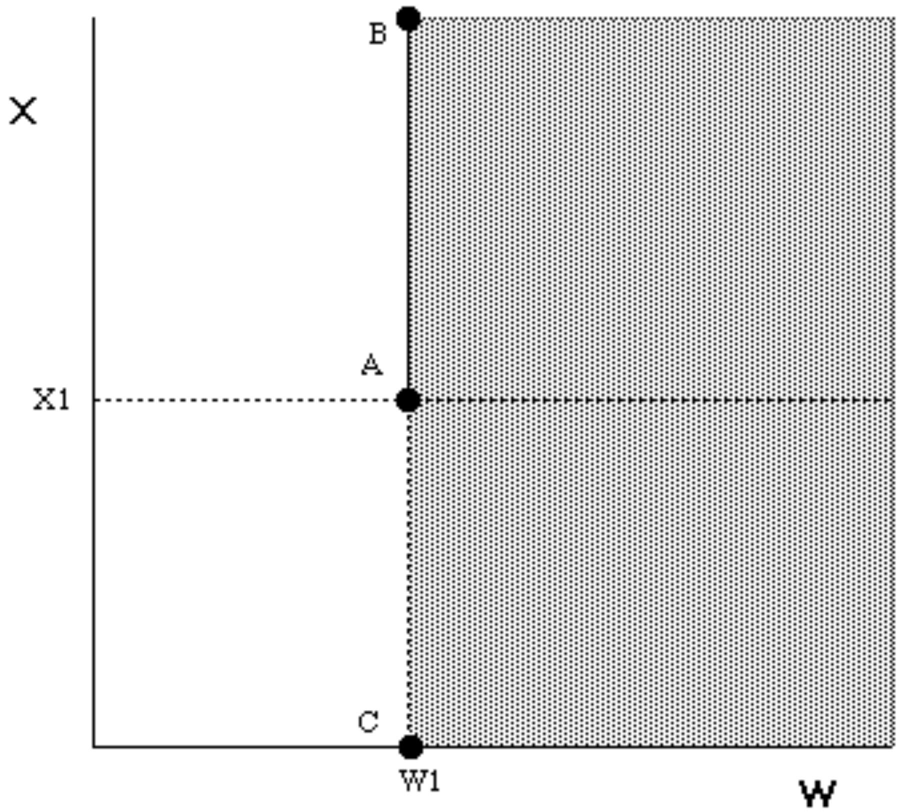
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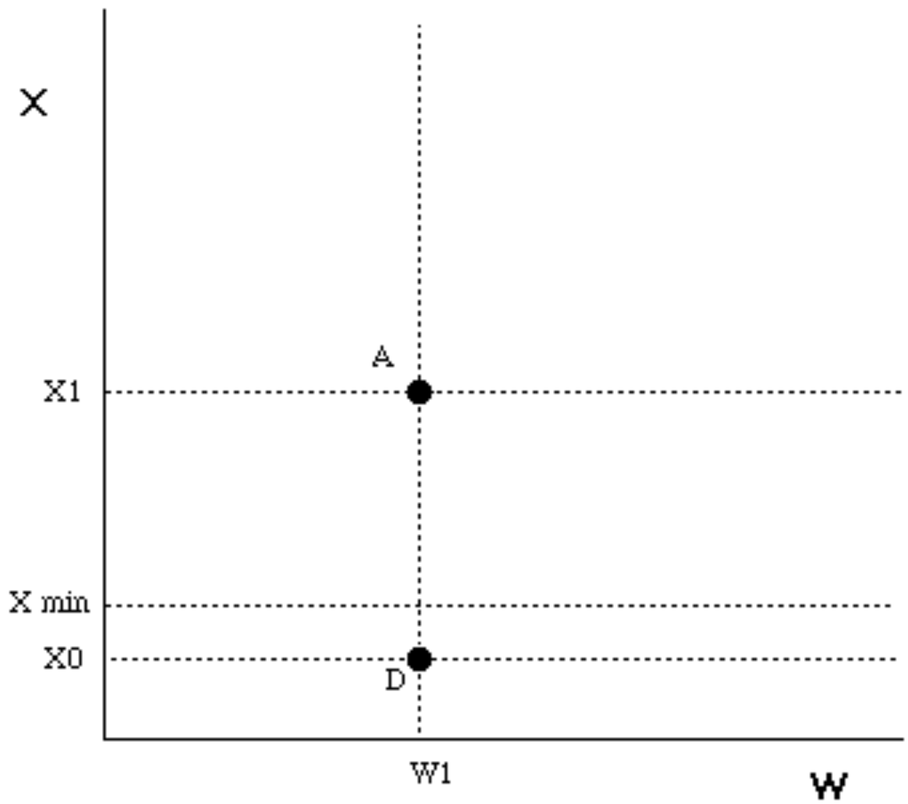
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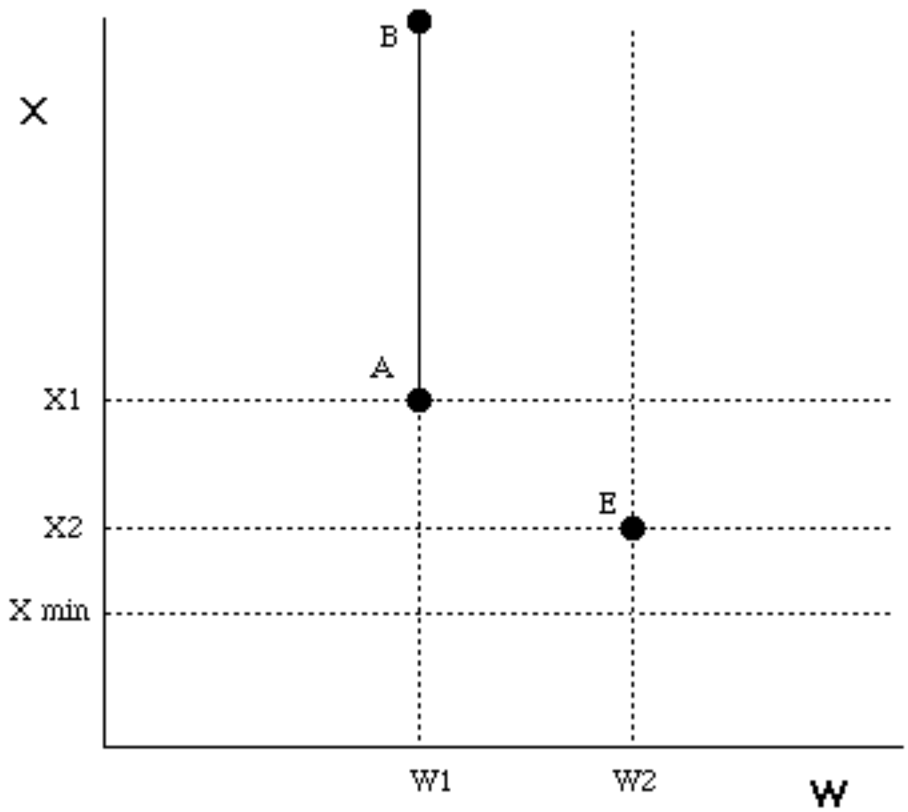
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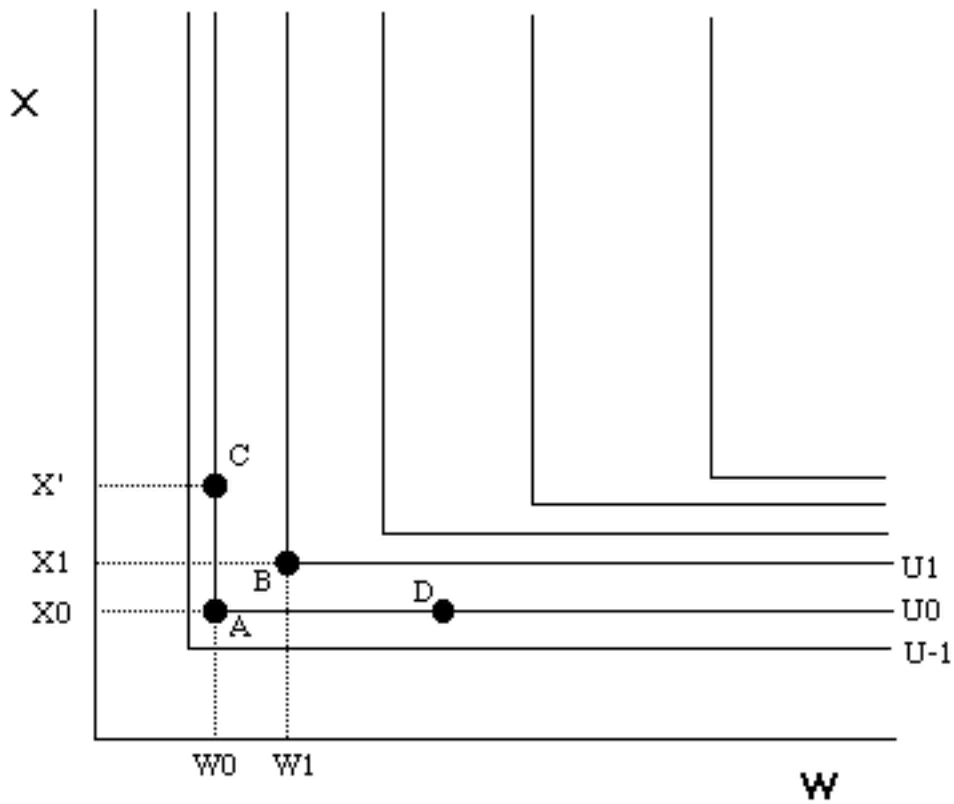
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