ENVIRONMENTAL DEGRADATION AND REMEDIATION: IS ECONOMICS PART OF THE PROBLEM?*

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Abstract. It is argued that standard environmental economic and 'ecological economics', have the same fundamentals of valuation in terms of money, based on a demand curve derived from utility maximization. But this approach leads to three different measures of value. An invariant measure of value exists only if the consumer has 'homothetic preferences'. In order to obtain a numerical estimate of value, specific functional forms are necessary, but typically these estimates do not converge. This is due to the fact that the underlying economic model is not structurally stable. According to neoclassical economics, any environmental remediation can be justified only in terms of increases in consumer satisfaction, balancing marginal gains against marginal costs. It is not surprising that the optimal policy obtained from this approach suggests only small reductions in greenhouse gases. We show that a unidimensional metric of consumer's utility measured in dollar terms can only trivialize the problem of global climate change.

Keywords: environmental remediation, global climate change, invariant measure of value, marginal analysis, neoclassical criterion of value, representative consumer, structural stability

1. Introduction

This paper is concerned with some theoretical issues in actions designed to remedy environmental degradation. These issues relate to the economic valuation of environmental damage and the attempted determination of remedial action based solely on monetary benefits and costs. Unfortunately this approach restricts the amount of information simply to consumer satisfaction (in terms of utility, measured in money) and reduces environmental policy to be determined by a single and imperfect metric, expressed in terms of some currency, say dollars. This metric is common to both conventional economics and ecological economics. The paper is organized as follows. Section 1 is a brief critique of the so-called 'ecological approach' to the environment. Section 2 considers the conventional economics approach to global climate change, which relies on specific functional forms when the basic economic model is not structurally stable. Section 3 relates the issue of structural stability to the question of an invariant measure of value in economics, as it

* An earlier version of this paper was presented at a workshop on Natural Capital, held at the University of Toronto, April 23 1999.

Environmental Monitoring and Assessment **86:** 47–61, 2003.

turns out that only special assumptions about human behavior guarantee both structural stability and an invariant measure of value. The requirements for an invariant measure of value are stated as the Chipman-Moore conditions. In Section 4, the problem of structural stability of the basic economic (general equilibrium) model is discussed in greater detail. The final section draws conclusions and lessons for environmental policy.

2. Value in Ecological Economics

The vast majority of the economics profession would argue that the well-being of the human agent is of primary importance; and that therefore economics, which maximizes the satisfaction of human wants, should play the central role in all decisions, including decisions affecting the environment. The ecosystem can be taken into account as a constraint in the maximizing process. In this way, all the requirements of the ecosystem can be systematically incorporated without sacrificing the fundamental goal of all human activity, which is maximizing human well-being, however defined. It could then be argued that the economics literature has successfully incorporated natural resource management and that even the notions of strong and weak sustainability (Pearce, 1989) can be integrated into conventional economics. Furthermore, a sub-branch of economics called 'ecological economics' is now well established as a 'science', with its own societies all over the world and with its own journals. It could be argued that the International Society of Ecological Economics has done much to integrate ecosystems into economics.

However, much of what is called ecological economics is indistinguishable from 'standard' neoclassical economics. A leading proponent of ecological economics and the founding editor of the journal called *Ecological Economics* is Robert Costanza. He has also edited a much used textbook called *Ecological Economics* (Costanza, 1991). Let us take as an example of ecological economics, the article published in *Nature* (1997, Vol. 387, pp. 253–260) by Costanza and his co-authors.

Costanza *et al*. (1997) attempt to put a monetary value on all the ecological services provided by the biosphere. For this they divide up the biosphere into 17 biomes, and value each. They then conclude that the value of the 17 biomes is equal to 1.8 times world GNP. Costanza *et al*. (1997) use the standard consumer surplus (CS) as a method of valuation. However, the numerical estimation of CS requires the use of a particular utility function to derive the demand curve for a 'representative consumer'. This technique has obvious difficulties for a global valuation. Unfortunately there is also a conceptual confusion in their work. While they claim to be using 'willingness-to-pay' (WTP) as the standard of value, they refer to the cost of the *loss of a particular biome* as the value of it. The loss value is conceptually distinct and is called 'willingness-to-accept' (WTA). Indeed in economics there are three distinct measures of value: CS, WTP, and WTA, which are equivalent only under very special circumstances (see below). For normal goods, it can be shown that WTP < CS < WTA. The estimation of any of the three measures of value requires the use of a specific functional form of a demand function. The choice of the functional form is usually arbitrary, and varying the functional form could change the results dramatically. But all this is very well known to economists.

For environmental amenities or ecological services, there are no markets and therefore no market *demand curves*. Economists therefore use survey methods or some other surrogate to estimate a demand curve and determine the change in CS, as the potential gain associated with any proposed public action, such as environmental remediation. For some ecological services which are clearly valuable to society, even the survey and surrogate methods may not be possible, as the ecological services are provided 'free' by the biomes. In such a case it is of interest to find some measure of what society would *lose* if the biome were destroyed. This approach requires WTA as the appropriate measure, as the authors imply towards the end of their article. But, like WTP, WTA estimates can only be done at a higher level of abstraction, where the numerical estimate is again highly dependent on the *choice* of the functional form of the demand curve- the estimate of WTA could vary by a factor of 2 or even 4. For each ecological service provided by a different biome, the abstraction must necessarily be at a different level. Each valuation may be a legitimate thought experiment, taken individually, but each remains nothing more than a mental exercise. But to add up each diverse mental exercise and to come up with a total value of 1.8 times world GNP is a gross error.

As a mental exercise, it is legitimate to estimate the *marginal social opportunity cost* (MSOC) of a particular ecological service of a particular biome. But as this value is 'at the margin', it requires the assumption that the *rest* of the price system is constant, or as economists say, in equilibrium. The theoretical justification is as follows: if the economy were perfectly competitive and in equilibrium, then the WTP measure and the MSOC measure should be identical, at least in theory. Nevertheless each MSOC value (or the WTA value) is still a thought experiment, a mental exercise subject to important *ceteris paribus* assumptions. Thus to regard the value of the biosphere as being 1.8 times world GNP is a fallacy.

We have no doubt that the authors were trying to draw the attention of decision-makers to the importance of the 17 biomes, and the extent to which human society is dependent on the proper functioning of the hydrological cycle, the carbon cycle, etc. and the interdependence of the ecosystems. Indeed one might ask why did they stop there? Why not put a monetary value on the moon, the loss of which would disrupt ocean tides? Why not put a money value on the sun too?

No economist in his or her right mind would try to put a monetary value on the moon or the sun. These celestial bodies are not *marginal* to the world economy. The 17 biomes determine the very existence of life itself on this planet. Therefore they are also not marginal. Putting a monetary value on them is simply absurd.

But the absurdity does another disservice. First, it makes a mockery of environmental protection. And second, it hides important intergenerational ethical issues. It seems to suggest that difficult ethical issues can be settled simply on the basis of a one-dimensional monetary metric. The protection of the biosphere for future generations is an ethical matter, not a monetary matter.

The above critique of Costanza *et al*. (1997), who is a leading ecological economist, shows that in essence ecological economics is no different from conventional economics, which also treats environmental remediation *at the margin*. But conventional economists are unlikely to add different thought experiments, as if each was a homogeneous quantity. The approach of conventional economics is much more subtle. The next section shows that.

3. Value in Conventional Economics

The fundamental approach of maximizing consumer satisfaction requires assuming a 'representative agent'. This approach is individualist, anthropocentric and completely unequal to challenges such as global climate change, ozone depletion and large-scale land and water pollution. The representative agent approach in turn dictates a *maximand* in which the only information that is allowed is the utility (or consumer satisfaction) of that representative agent (see, e.g. Sen, 1977a, b, 1979a, b). The representative agent is assumed to have an exogenously given set of preferences over goods, not only today but over *all* goods and also at *all* times. The latter gives rise to *time preference*, or a rate of discount. The entire economy is seen as an auction market in which 'true' prices for all goods and all environmental services emerge; where they do not emerge or where the actual prices deviate from the 'true' prices, the economist can 'correct' these by various techniques, or can 'invent' them by survey or other implicit methods. In all the calculations carried out within the above framework, the optimum is obtained by balancing the marginal benefits to the representative consumer compared with the marginal costs to the consumer. The logical consequence of the above is that the *optimal level of pollution is never zero*. As a result of the acceptance of the concept of time preference, all flows of money (as the only *numeraire* allowed in economics) are discounted. But discounting of necessity allows only short time horizons, not 500 or 1000 years.

The poverty of the conventional economic approach to the environment can be illustrated by considering the work of Nordhaus (1994), and Nordhaus and Popp (1997). But as Nordhaus has been heavily criticized by others, only a brief restatement of his method and his results is necessary. Nordhaus maximizes the discounted value of the consumption of a representative consumer, subject to output produced by a constant returns to scale Cobb-Douglas production function. The production of output generates greenhouse gases, which in turn lead to losses in output. This is a standard optimal growth exercise, which is also no more than a thought experiment. A thought experiment is subject to all sorts of caveats, and I am sure Nordhaus is aware of that. In spite of the limitations of thought experiments, we get, from Nordhaus, an 'optimal policy' recommendation to reduce GHGs by

11.1% in 2025 and by 13.4% in 2075. These reductions are relative to 'uncontrolled emissions' that would have occurred if no curbs on emissions had been placed.

As stated above, Nordhaus's work has been heavily criticized for some specifics of his model. For example, Ekins (1996) argues that Nordhaus ignores the benefits of reductions in other noxious substances that would accompany reductions in CO_2 emissions. Price (1995) argues that Nordhaus overestimates the CO_2 uptake by oceans. Chapman *et al*. (1995) argue that Nordhaus underestimates the rise in temperatures. Neumayer (1999) does a comprehensive critique and attacks the central assumption inherent in Nordhaus, which is the assumed substitutability between natural capital and man-made capital. Neumayer also does an excellent job not only of reviewing the work of other critics, but of dealing with both intergenerational and intragenerational equity issues, which are the key to the whole debate over global warming. But most critics fail to realize that Nordhaus' work is nothing more than a *specific* thought experiment which uses specific and special functional forms: he uses a logarithmic utility function for the representative consumer and a Cobb-Douglas production function. These are specific functional forms, and different functional forms will yield different results.

When is it possible to use a production function? What are the necessary and sufficient conditions for the existence of a production function? Are these conditions satisfied by Cobb-Douglas forms? What is the merit of a particular set of functional forms? One could perform a whole battery of thought experiments, with a variety of functional forms of the utility function and the production function, and each experiment will produce a different 'optimal policy'. Is there any guarantee that these optimal policies would converge? Absolutely not; each thought experiment reflects its special character. And we have said nothing about the parameters used: the choice of prices of land (Ayres and Walter, 1991), the choice of agricultural costs (Cline, 1996), additional arguments in the utility function of the representative consumer (Tol, 1994), or choice of discount rates (Azar and Sterner, 1996). All these choices also determine the so-called 'optimal policy'.

What do physicists say about a model when a variety of functional forms do not lead to a convergent result? Let us consider this question in detail. Economists are in general familiar with dynamic stability, but with few exceptions, the implications of *structural stability* are only just beginning to be analysed by economists. As physicists know, it is structural stability that establishes the degree of generality of a model, or indeed the domain of validity of any model, including the basic general equilibrium economic model. The concern with structural stability (SS) in nonlinear dynamic analysis is nothing new. Not surprisingly, the concept comes from physics. The Maxwell-Duhem concept of SS (Duhem, 1906; Maxwell, 1877) is that SS is a required property of a model that is *adequate*. A model is adequate in terms of prediction and verification if for some perturbation within the (relevant) domain of perturbation, the ability of the model to predict outcomes remains intact. If the perturbation destroys the ability of the model to yield sensible results, then according to Maxwell, the model is no good; it is inadequate. In the physical sciences, it would then be necessary to go back and build a better model of the underlying reality that is being studied. In the physical sciences, experimentation is the ultimate criterion of the validity of a model. Unfortunately experimental verification of the general equilibrium model is impossible. Consequently economists do not feel it necessary to consider an alternative model.

The question of structural stability of the basic economic model is important and is taken up later in this paper. It will be shown that structural stability can be assured only if it is assumed that the representative consumer has homothetic preferences[1]. In turn, homothetic preferences also produce an invariant measure of value. As stated above, without the assumption of homotheticity, there are *three* standards of value in neoclassical economics: consumer surplus (CS), willingness to pay (WTP) and willingness to accept (WTA). Each can be expressed in terms of money. In a modern neoclassical context, the problem of an *invariant measure of value* has been elegantly restated by Chipman and Moore (1980), to which we now turn.

4. The Chipman-Moore Conditions

Chipman and Moore (1980) ask a very important question that goes to the heart of the determination of an *invariant measure of value*, a subject much discussed in the history of economic thought. The general conclusion of this historical debate on an invariant measure of value was that the classical labour theory of value was a special case. In neoclassical economics, it was generally assumed that the problem of reconciling two different measures of changes in value, namely the reconciliation of WTP and WTA, was a 'partial equilibrium' problem, which would not arise in general equilibrium analysis. But clearly that is no longer true, even if it ever were the case, as Saari finds that the Chipman-Moore restrictions are necessary for convergence of the price adjustment equation to a zero. It would therefore be instructive to take a closer look at the Chipman-Moore conditions.

The important question that Chipman and Moore ask is the following: under what conditions on preferences, and on admissible pairs of income and prices under comparison, do the Marshallian and Hicksian consumer surpluses yield a common and acceptable integral measures of welfare change? In other words, when do the WTP and WTA *coincide*, so as to give a common and an *invariant measure of value?*

The authors provide three possible answers, depending on what restrictions are placed on prices ($\boldsymbol{p}$) and changes in incomes ($\boldsymbol{Y}$):

CM-1 If there are no restrictions imposed on pairs of prices and income $\boldsymbol{p}^1$, $\boldsymbol{Y}^1$, and $\boldsymbol{p}^2$, $\boldsymbol{Y}^2$, under comparison, then there are *no* conditions under which the Marshallian consumer surplus yields an acceptable measure of welfare change. Nor can consumer surpluses be added to determine if the gainers can compensate the losers (Boadway, 1974).

CM-2 If in the comparison of $\boldsymbol{p^1}$, $\boldsymbol{Y^1}$, and $\boldsymbol{p^2}$, $\boldsymbol{Y^2}$, a restriction is imposed so that income is unchanged (i.e. $\boldsymbol{Y^1} = \boldsymbol{Y^2}$), then the Marshallian consumer surplus is an acceptable measure of welfare change if and only if the underlying preferences are homothetic.

CM-3 In the comparison of $\boldsymbol{p^1}$, $\boldsymbol{Y^1}$, and $\boldsymbol{p^2}$, $\boldsymbol{Y^2}$, let $p_1^1 = p_1^2$. This means that if income and all other prices are deflated by the price of Commodity 1 in each period, then the Marshallian consumer's surplus is an acceptable measure of welfare change if and only if preferences are parallel with respect to Commodity 1. Parallel preferences mean that the Engel curve is vertical and parallel to the axis of Commodity 1.

Furthermore Chipman and Moore show that the above results also hold if we substitute Hicksian or 'compensated demand' for 'Marshallian' consumer surplus. In other words, CM-1 to CM-3 apply to the problem of deriving an *invariant measure of value*. But the conditions under which an invariant measure is obtained are restrictive, which makes the invariant measure a very special case. That will become even clearer if we reconsider CM-2 and CM-3 in terms of the marginal utility of income (MUI).

It is simpler to interpret the Chipman-Moore conditions in terms of the marginal utility of income, as this ties in well with the received doctrine of consumer theory.

5. The Marginal Utility of Money and the Chipman-Moore Conditions

For clarity, it might be useful to start with some standard notation. Suppose the consumption bundle of quantities is $\boldsymbol{x} = (\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots, \boldsymbol{x_n})$, and the consumer's utility function is $\boldsymbol{u}(\boldsymbol{x})$. Let the price vector be $\boldsymbol{P} = (P_1, P_2, \ldots, P_n)$. From standard optimization, we can obtain the demand functions:

$$x_i = x_i(P_i, Y) \text{ and } \lambda(P, Y) \ , \tag{1}$$

all of which are homogeneous of degree zero in $\boldsymbol{P}$ and $\boldsymbol{Y}$. Next define the indirect utility function:

$$U(P, Y) \ . \tag{2}$$

Suppose we wish to find the welfare impact of a change from $\boldsymbol{Q^0}$ to $\boldsymbol{Q^1}$. The change in total utility is given by the total differential:

$$dU = \sum_{i=1}^{n} U_i dP_i + U_Y dY \ . \tag{3}$$

The welfare impact (ΔU) of the changes in prices and incomes may be defined as the line integral[2]:

$$\Delta U = \int_{Q^0}^{Q^1} \left[\sum_{i=1}^{n} U_i dP_i + U_Y dY \right] . \tag{4}$$

From the Slutsky matrix and the envelope theorem, we can substitute and rewrite Equation (4) in terms of the marginal utility of income as the following:

$$\Delta U = \int_{Q^0}^{Q^1} \left[\sum_{i=1}^{n} (\lambda x_i)\, dP_i + \lambda dY \right] , \tag{5}$$

where $\partial U/\partial Y = \lambda$. In general λ depends on both ***P*** and ***Y***. So we need some assumptions about the constancy of λ in order to evaluate the integral in Equation (5). Following Samuelson (1947), we can try three possible avenues:

1. Suppose we assume that λ is constant for all values of ***P*** and ***Y***. This leads to a contradiction, as $\boldsymbol{U}_\mathbf{y}$ is homogeneous of degree –1 in ***P*** and ***Y***. Therefore λ cannot be constant for all values of ***P*** and ***Y***.
2. Suppose we assume that λ is invariant to all changes in all prices, i.e.

   $$U_Y(P, Y) = \sigma(Y) \tag{6}$$

   Equation (6) is then equivalent to homothetic preferences, or CM-2 above. Thus we can reinterpret CM-2 as the assumption that the marginal utility of income does not change with changes in prices.
3. The third possibility is to assume that λ is independent of all income and all prices except Commodity 1, the numeraire commodity. Indeed this is how Hicks interpreted Marshall's concept of consumer surplus. With this assumption, we can write:

   $$U_Y(P, Y) = \rho(P_1) . \tag{7}$$

   Equation (7) is equivalent to parallel preferences, or CM-3. We can reinterpret CM-3 as the assumption that the marginal utility of income is independent of the level of income and all prices except that of Commodity 1.

Thus we have shown that the neoclassical invariant measure of value is obtained only by assuming the constancy of the marginal utility of income, either with respect to all prices, so that it is a function of income alone, or the marginal utility of income is independent of all income and all prices except one. The assumption of complete independence of all income and all prices is not possible because that involves a contradiction. The constancy of marginal utility of income means that it is the same both a rich person and a poor person, an implicit and unintended interpersonal comparison of utility. In a sense this makes the utility approach dictatorial, again an unintended consequence. The problem arises from the single dimensional utilitarian approach, in which it is assumed *exogenously* that each individual must maximize his or her utility rather than leave the decision to the individual to pursue her own goals, whatever they may be. The requirement that each individual must maximize his or her utility is imposed from the outside. It is this exogenous imposition of utilitarianism which is objectionable to theorists like John Rawls (1971)[3].

The above conclusion on the required conditions for an invariant measure of value suggests that either way it must be assumed that the marginal utility of income is constant. Alternatively, we may say that the invariant measure of value exists only when severe restrictions are placed on the nature of the underlying consumer preferences. This really makes the neoclassical criterion of value a special case. In consumer theory, the constancy of the marginal utility of money can be locked up in a *ceteris paribus* clause. But if the same restrictions are necessary in *general* equilibrium analysis in order to have the price adjustment differential equation reach an equilibrium, then clearly the theory of value rests on very tenuous grounds.

6. The Single Dimension and Structural Stability of the Basic Economic Model

It turns out that the restrictive nature of preferences needed for an invariant unidimensional measure of value is also required for the structural stability of the basic economic model. Let us show that in detail.

It is assumed that the basic model is very general indeed and that it is not restricted to any particular number of goods or any particular number of traders, or to a particular structure of preferences, and that only a few innocuous axioms are involved. It is this assumed generality that this paper seeks to refute: in fact studies in the structural stability of the basic model show that it is very special, and not so 'general' at all.

To begin, suppose that the *number* of commodities and hence of prices in the excess demand function in the basic model were restricted to being less than or equal to three. Let the price adjustment process be governed by the differential equation:

$$\dot{p} = z(p) , \tag{8}$$

where $z(p)$ is the excess demand function, and p is the price vector. Then it is well known that the initial conditions of the above differential equation will in general not pose any difficulty. But when the number of commodities is greater than three, not only do initial conditions matter, but the evolution of the system (Equation (8)) can become unpredictable. However, a quick review of some mathematics is necessary before proceeding.

Any dynamical system has three kinds of behavior (see Dore, 1993). These are: (a) unchanging (or equilibrium) state; (b) a behaviour that repeats itself periodically – called a *limit cycle*; and (c) behaviour that is complex or chaotic. In terms of the phase space of the above differential equation, (a) above translates into a *fixed-point attractor*; (b) becomes a periodic attractor, i.e. a stable limit cycle. If the number of commodities $n \leq 2$, then all behaviour will be either a fixed point attractor or a periodic attractor. Together these are called *simple attractors*.

Now, if Equation (8) has $n > 3$ and is nonlinear, then the higher dimensional analogue of a periodic attractor (when it exists) is called a *strange attractor*. But the trouble is that there may be more than one strange attractor, and a very slight perturbation in the initial condition may cause the behaviour to 'switch' from one strange attractor to another.

As mentioned earlier, the early proponents of the basic economic model relied on some fixed point theorem, such as the Kakutani theorem to assert the existence of a 'zero', i.e. a point where all excess demands $z(p) = 0$. Thus an equilibrium is said to exist, but as to how these prices tend towards that equilibrium is not spelled out[4]. Furthermore, the existence of an equilibrium is guaranteed only with an infinity of traders or agents. If the number of agents is finite, then according to the Gibbard-Satterthwaite theorem (Gibbard, 1973; Satterthwaite, 1975), it would be possible for agents to collude and force the outcome away from a competitive equilibrium. But with an infinity of agents, the dynamics of price adjustment are not tractable. The rest of this paper therefore considers adjustment of prices when both the number of agents and the number of commodities is finite.

Suppose we ignore the Gibbard-Satterthwaite theorem. With a finite number of commodities and agents, can we say that the invisible hand story holds, and do prices tend towards some local attractor? Even if it is assumed that $z(p)$ are homogeneous of degree zero and that Walras' Law holds, and it is further assumed that all chaos generating properties are ruled out, even then additional restrictions will have to be imposed on $z(p)$. Specifically Sonnenschein (1973) provided the additional restrictions that would be required, and Mantel (1972) improved on it. Debreu (1974), however, simplified the proof of this theorem on excess demand functions. The theorem states, roughly, that for $n \geq 2$ and some neighbourhood of the price, the mapping is 'onto' if and only if the number of agents j is not less than n, the number of commodities. In other words, if $j = n$, then there is no guarantee that prices would converge even to some limit cycle. This would be true even if an equilibrium existed.

Other approaches of putting even more structure on Equation (8) have been tried. Replace Equation (8) by

$$\dot{p} = M(z(p), J_p(z)) , \tag{9}$$

where M is piecewise smooth, and such that the dynamics stop if and only if $z(p) = 0$, and J_p is the Jacobian of the excess demand functions. But this formulation by Smale (1976) requires an enormous amount of information, an obvious contradiction of the informational efficiency of the invisible hand. Let us be clear on the economic interpretation of the Jacobian. It says, for example, how the price of any one good varies with the price of all other goods. For example, how the price of jet turbines varies with the price of chewing gum! Thus all cross partials must be known in advance.

But there is more bad news. Saari (1985) replaced Equation (9) with a discrete version, and analyzed the minimum conditions on the price mechanism M required to ensure convergence to some equilibrium price vector. He found that for $n \geq 2$, no mechanism M can guarantee convergence to an equilibrium: for any choice of M, there exists a large variety of excess demand functions and a large set of initial conditions for which convergence never occurs. This result has a parallel: according to Saari (1985) the same impossibility holds for numerical methods used to find the real roots of real polynomials. This is also confirmed by Bala and Keefer (1994).

It is a paradox that experiments on the theoretical workings of the invisible hand now show that not ‘free markets’ but *regulated* markets might achieve equilibria, as shown by Saari and Williams (1986). This entire line of research (Saari, 1992) suggests that apart from technical restrictions, convergence of differential equations of excess demands to a ‘zero’ (i.e. to an equilibrium) requires that: (a) the number of agents must be greater than or equal to the number of commodities, and (b) severe restrictions on the nature of preferences must be placed. These restrictions are analogous to the restrictions on preferences that are required by Chipman and Moore (1980) in order to obtain an exact and an invariant measure of consumer surplus, which is the measure and standard of value in neoclassical economics.

Clearly condition (a) above is very restrictive and was unknown until the dynamics of excess demand were investigated, largely by mathematicians who do not have an ideological stake in neoclassical general equilibrium theory.

7. Conclusion: Lessons for Remediation of Environmental Damage

What do the results obtained above mean for (a) the valuation of environmental damage and (b) the determination of the remediation of environmental damage? Let us begin by summarizing the key findings before proceeding.

The above analysis shows that whether the approach is a standard environmental economic approach or whether it is 'ecological economics', the fundamental basis of valuation is the same: the technique of valuation is based on some measure of consumer satisfaction, either 'consumer's willingness to pay' (WTP), or consumer surplus (CS), or 'willingness to accept' (WTA), The divergence between WTP and WTA could be in the interval $(0, \infty)$. These three measures of value coincide only under specific assumptions about preferences. But in general, we know that WTP < CS < WTA. The above analysis was confined to prices changes only. If quantity changes are considered, then the conclusion is further strengthened with WTP = 0 and WTA = ∞. For further details, see Randall and Stoll (1980), and Hanneman (1991). This consumptionist approach requires the assumption of a representative consumer, who is assumed to be maximizing his/her utility. The utility maximizing model yields a demand curve. A measure of this consumer's well-being (or 'advantage') is the integral under the demand curve. In order to get an invariant measure of value, it is necessary to assume that this representative consumer has 'homothetic preferences'. This is incidentally patently false because the best established law in economics (called Engel's Law) shows that preferences are *not* homothetic. Furthermore, in order to obtain a numerical estimate of either WTP, CS, or WTA, one needs to use specific functional forms of the demand curve. Thus any numerical estimate of value will depend on the specific functional form used to represent the demand curve. Experimenting with a variety of functional forms does not lead to a convergent optimal policy, as the based economic model is structurally unstable.

According to neoclassical economics, any environmental remediation can be justified only in terms of increases in some measure of the consumer's well-being, such as consumer surplus (CS). But any environmental remediation will have a cost. Therefore, at the margin, the optimal amount spent on environmental remediation and restoration will be determined by equating the marginal increase in CS to the marginal costs to the representative consumer. Hence the remediation can never by *total*, unless it can be achieved at zero cost, which is extremely unlikely. At the margin, the amount spent on remediation must equal marginal benefits with marginal costs.

Can global climate change be regarded as a marginal change? Nordhaus treats it as marginal only because the large non-marginal change will be spread over a period of 100 to 300 years. When the annual marginal costs and benefits (to the representative U.S. consumer) are spread over hundreds of years *and* discounted, the discounted net stream benefit of reducing GHG reduction appears small. It is therefore not surprising that he concludes that the benefits are also so small that the optimal policy is to reduce GHGs by 13.4% by 2075.

We have also shown that most calculations of the sort carried out by Costanza or Nordhaus are really thought experiments, with specific and arbitrary functional forms. Varying the functional forms or the parameters used in them do not lead to convergent, error reducing estimates. The reason for this non-convergence is that the basic economic model is not structurally stable. When scientists encounter models that are not structurally stable, they abandon them and search for better models that represent reality. But economics and ecological economics do not have empirical and scientific criteria for model verification and validation. To be content with thought experiments based on a single dimension is not enough, and exclusive reliance on them is grossly misleading.

We conclude that a unidimensional metric of consumer surplus measured in dollar terms can only trivialize the problem of policy towards global climate change. Indeed it follows logically that neoclassical economics is not a solution; it is in fact part of the problem. Having concluded that neoclassical economics is unhelpful in dealing with global environmental problems, is there an alternative approach that might be useful? The short answer is that the theory of social choice (developed by Nobel Laureates Arrow, and Sen, and others) offers a much better foundation. A full treatment is outside the scope of this paper, but see Dore and Mount (1999) for an introduction on how the results in the theory of social choice can be used for public policy. See also Arrow and Raynaud (1986).

Acknowledgements

We are grateful to David Etkin, and to anonymous referees of this journal for help in preparing this version of the paper. All remaining errors are our own.

Notes

[1] A preference relation R is homothetic if $x^1 R x^2$ *iff* $\lambda x^1 R \lambda x^2$ *for* $\lambda > 0$.

[2] It is well known that this line integral is path independent. For the mathematical theory behind this assertion see Apostol, 1967, pp. 276–293.

[3] In the political philosophy literature, this outside imposition of utility maximization is called a ‘God’s Law’. Liberals like John Rawls argue that this is in effect ‘dictatorial’ and therefore incompatible with liberalism. Individuals must be free to pursue their own goals, irrespective of what they may be. These goals could include some altruistic activity which is precluded in the (selfish) utility maximization approach. If person A’s utility also depends on the utility of person B, then the Standard general equilibrium solution is not possible: the two utility functions must be independent of each other. For a further discussion of the issue of God’s Law, see Binmore (1994), or Dore and Mount (1999).

[4] For those people who are content with the assumption of a fictitious and a costless neutral auctioneer who will guide the economy to the competitive equilibrium, *by assumption*, the rest of the analysis of this paper will be irrelevant.

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