DISCOUNT RATES AND SUSTAINABILITY

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All of these issues have created considerable difficulties in the theory of optimal development. Recently a more fundamental challenge has arisen from advocates of ‘sustainable development.’ The notion of sustainability is somewhat imprecise. Indeed the lengthy list of definitions provided by Tisdell (1988a, b, 1993a) is not exhaustive — further definitions are discussed by Lélé (1991).

The most common interpretation of sustainabilty is that development policies should be constrained so as to leave stocks of natural resources at their original level. There is also, as observed by Tisdell (1988b), a rather vague notion of risk-aversion at work. The sustainability approach is presented as an alternative to the standard benefit–cost analysis approach to the question of intergenerational equity, in which the welfare of future generations counts only insofar as it is reflected in the preferences of the present generation. Hence, the issue of sustainability is closely related to the long-standing controversies in the benefit–cost analysis literature concerning discounting for time and risk.

The present paper has two main objects. The first is to argue that the difficulties associated with discounting, equity and uncertainty all arise from a common source. This is the failure to adopt an explicit interpersonally comparable cardinal utility function as the basis for normative analysis. The second is to suggest that sustainability criteria are best interpreted as rule of thumb modifications to standard benefit–cost analysis procedures. Under appropriate conditions, the imposition of sustainability constraints will yield an outcome closer to the utilitarian optimum than that attained using standard procedures. This possibility arises because the discount rate used in standard benefit–cost analysis gives insufficient weight to the welfare of future generations. The imposition of sustainability constraints offsets this tendency without requiring the formulation of a new objective function involving explicit trade-off between the welfare of the present generation and that of future generations. There are, however, situations in which the sustainability rule of thumb will perform poorly.

The paper begins with a review of the discount rate controversy, sustainability theory and optimal growth theory, followed by a historical discussion of the background to the decline of growth theory and the rise of sustainability theories. The main section of the paper presents the rule of thumb interpretation of sustainability criteria. This is followed by a discussion of the implications of the utilitarian approach proposed here for uncertainty, discounting and social welfare.

The discount rate controversy

The discounting of future benefits has long been one of the most controversial, and in many ways, unsatisfactory, aspects of benefit–cost analysis (for a more general discussion of benefit–cost analysis, see Tisdell 1993b). . The greatest concern has been that, because of the high rates of discount typically used, even large benefits and costs are treated as insignificant if they arise more than, say, thirty years in the future. This concern has been heightened by the rise of the environmental movement and, particularly by the debate over sustainable development. Environmentalists have argued that discounting procedures, particularly as they have applied to environmental benefits, represent unfair treatment of future generations.

A second, more technical, controversy has surrounded the issue of risk adjustment for discount rates. The standard procedure in practice has been to increase discount rates to compensate for risk. Benefit–cost theorists have generally deplored this practice (Little and Mirrlees 1974; Wilson 1982), since it involves a confusion between attitudes to risk and attitudes to time. However, no alternative method of handling risk has had significant acceptance in practice.

A third problem, at first sight unrelated to discounting, arises from the question of income distribution. In standard benefit-cost analysis, benefits and costs are summed, regardless of who receives (or bears) them. A project which further impoverishes a large number of poor farmers in order to benefit one wealthy individual would be approved if the monetary benefit to that individual exceeded the aggregate costs to the losers.

The most popular approach to the incorporation of equity considerations into benefit–cost analysis has been the use of social welfare weights. Individuals who are considered more deserving are given a higher weight than others, and it is the weighted average net benefit that is used to determine acceptance or rejection.

The relationship between social welfare weighting and discounting arises when the treatment of members of future generations is considered. If a $1 benefit arising in 30 years time has a discounted present value (PV) of, say, 10 cents, the consumption of an individual born 30 years from now has, at the margin, a weight of 0.1 relative to that of an individual born today[1]. This has obvious implications for the future welfare of the human species. A policy which generated substantial increases in consumption in the short term but degraded resources to such an extent that living standards declined continuously in the future could easily be found to be beneficial using standard discounting procedures. It is this kind of possibility that has increased concern with the issue of sustainability.

Sustainability

Sustainability is in fashion, and, as with all fashionable terms, it has been used in many ways and in support of many different policy agendas. At one extreme, 'sustainable' has been treated as a synonym for 'organic.' At another, the term has been used to give

[1] As will be shown below, however, this does not imply that the *welfare* of the later-born individual is discounted by a factor of 10. The discount rate applicable to margianl consumption is determined by an interaction between opportunity cost and the degree to which the welfare of future indiviudals is discounted.

a veneer of environmental respectability to policies which are, effectively, 'business as usual.'

At its core, sustainability embodies two main concerns. The first is that the natural environment forms the basis of all human productive activity. This is most obviously true of agriculture, but it applies to all forms of industry. The concern is that pervasive environmental damage might gradually undermine the capacity of the environment to support productive activity. There are numerous historical examples of unsustainable development. Dramatic examples in more developed countries (MDCs) have included the dustbowl of the US Great Plains in the 1920s and 1930s and a number of failed attempts to extend the boundaries of cropping in Australia. A failure of sustainability that has stretched over millennia is the desertification of North Africa, referred to in Classical times as 'the granary of Europe.' Although the causes of this desertification are not fully understood, it appears that human activity is principally responsible.

Other examples of unsustainable production relate to agricultural systems based on irrigation. Many areas that are initially suitable for irrigation are subject to problems such as rising water tables and salinization, which may take many decades or even centuries to manifest themselves.

The second main theme in the literature on sustainability is the concern that gradual environmental degradation may lead to a reduction in well-being, even if production of food and manufactured goods is maintained and increased. In economic terms, this concern may be related to those services of the environment that are consumed directly rather than being employed in production, and to benefits, such as those yielded by standing forests, that are best viewed in terms of stocks rather than flows (see Dasgupta and Mäler 1990).

Concern with sustainability represents a shift in emphasis from acute local problems such as urban air pollution, to chronic and pervasive problems such as land degradation and acid rain. Pollution control measures implemented from the 1950s onwards have controlled the worst of the local problems, at least in the MDCs. More subtle problems of this kind, such as lead pollution, have taken longer to be recognized. However, in most of these cases, there appear to exist relatively straightforward responses, such as the elimination of lead from petrol and paints. Some of these responses are expensive, but for most acute local pollution problems, they appear to be feasible, given sufficient social and political will.

There is no such optimistic consensus concerning the global problems raised by the debate over sustainability. Action on these problems has been far more limited than that for local pollution problems. In some cases the resolution of local problems has simply converted them into global problems. The classic example is the construction of tall smokestacks, which move pollution away from its point source, but contribute to problems such as acid rain. This is an example of a general sustainability issue, that of the environment's capacity to act as a sink for the waste products generated by human activity.

A critical issue in all of this is uncertainty about the capacity of the environment to absorb the impacts of human activity. A minority of scientists argue that the impact of chlorofluorocarbons (CFCs) on the ozone layer is unimportant. A larger group, and until recently a majority, argued that there was no conclusive evidence of global warming arising from carbon dioxide emissions. On the other hand, it is possible that irreparable damage will be done unless drastic action is taken. This uncertainty creates difficulties for policy formulation.

Concern with sustainability raises a number of issues for economic analysis in general and benefit–cost analysis in particular. Three main questions arise in benefit-cost analysis. The first is the problem of discounting the effects of current decisions on future generations. The second is the appropriate treatment of uncertainty. The third relates to the inadequacy of accounting for environmental goods and services.

The idea of extending traditional accounting systems to include stocks of natural resources appears straightforward in principle. However, there are many practical difficulties and only limited progress has been made thus far. These difficulties will not be addressed here and it will be assumed that appropriate measures of stocks of natural resources, and valuations of the services they yield, are available. Attention in this paper will focused on the first and second issues.

Before considering the implications of sustainability theory, however, it is necessary to consider the main alternative approach to the problems discussed here. This alternative is derived from the theory of optimal growth and development.

Optimal growth and development theory

As is observed by Dasgupta and Mäler (1990), it is impossible to form an adequate understanding of the debate over sustainability without consideration of the theory of optimal economic growth (or optimal development), developed mainly in the 1950s and 1960s. The main concern of this literature was the determination of optimal paths for capital accumulation, and many of the concepts developed in this context have close parallels in the recent debates over sustainability.

The classical problem of growth was posed by Ramsey (1928), who sought to determine the pattern of savings that would maximize aggregate utility. The objective function proposed by Ramsey was a simple additive sum of utility over time

(1) $$W = \int_T U(C_t)\, dt,$$

where

W is the welfare objective;

U is instantaneous utility at time t; and

C_t is consumption at time t.

A noteworthy feature of this objective function is the absence of a discount factor. Ramsey rejected, on ethical grounds, the discounting of future utilities. This turns out to have fundamental implications for the nature of the solution to (1). In particular, unless C_t goes to zero for large t, W is infinite. The usual notion of maximization must therefore be replaced by some form of partial ordering on consumption paths, such as the overtaking criterion (von Weizsäcker 1965).

A particularly interesting special case is that of the logarithmic welfare function

(2) $$W = \int_T \log(C_t)\, dt.$$

The social welfare function here is represented as a sum of individual utility functions, each of which is a logarithmic function of income. The basic notion of *diminishing marginal utility* underlying this utility function was first articulated by Bernoulli in 1738 (Bernoulli, reprinted 1954). It is that an additional dollar is worth more to a poor person than to a rich one. Bernoulli used this idea to explain why people might rationally refuse to take part in a gamble even though its expected value to them was positive.

A wide variety of functional forms, in addition to the logarithmic form proposed by Bernoulli, have this property. However, the logarithmic form has numerous advantages in addition to its historical status. First, it is highly tractable and easy to understand. Second, it possesses the property of constant relative risk aversion, which implies that a person will choose between risks in a manner which depends on the size of the risk relative to her current wealth. This property has considerable empirical support. Finally, within this class, it is generally accepted that the critical parameter, the coefficient of relative risk aversion, has a value near 1. The logarithmic form has a coefficient of relative risk aversion equal to 1. While the choice of a logarithmic functional form is in some sense arbitrary, it is no more so than the convention of treating income increments equally, regardless of to whom they accrue. It is less arbitrary than the usual convention of treating income increments to the current generation equally and discounting income increments for future generations.

The problem posed by Ramsey was to choose the optimal path C subject to the condition

$$C_t = F(K_t, L) - \dot{K}_t \, , \tag{3}$$

where

L is the population (assumed constant in simple versions of the problem); and

K_t is the capital stock.

The optimization problem may be solved using the theory of optimal control, which reduces to choosing the control C so as to maximize the associated Hamiltonian. It is straightforward to show (see, for example, Dasgupta and Heal 1979) that a necessary condition for an optimum is given by the Ramsey rule

$$\eta \, \dot{C}_t = F_K/K_t, \tag{4}$$

where

$\eta = -U''(C_t)C_t/U'(C_t)$ is a measure of aversion to intertemporal variations in consumption.

The result is simplest under the assumption of a logarithmic welfare function. In this case, $\eta = 1$, and the Ramsey rule is that the marginal productivity of capital should be equal to the rate of growth of consumption.

The basic reasoning follows from the fact that, for the logarithmic utility function, the marginal utility of income is inversely proportional to the level of income. Suppose a planner is deciding whether to reduce consumption in period t, invest the amount saved, and consume the proceeds in period t+1. If consumption in period t+1 is expected to be 5 per cent higher than in period t, the marginal utility of consumption in period t+1 is 5 per cent lower. Hence, the decision to save will be welfare-increasing if and only if the rate of return to capital is at least 5 per cent.

For more general utility functions, the same reasoning applies, using the result[2] that

(5) $$U'(C_t)/U'(C_{t+1}) = \eta\, C_{t+1}/C_t.$$

An important implication of the Ramsey rule is that, even though the problem formulation does not involve any discounting of future welfare, the marginal rate of time-preference (or, equivalently, the opportunity cost of capital) is not, in general, zero. In particular, whenever $\dot{C}_t$ is positive, so is the opportunity cost of capital.

Under appropriate conditions, the solution path (4) will converge over time to a 'golden rule' path in which output, consumption and capital stock attain the maximum levels feasible for a steady-state equilibrium. As will be discussed below, there is a close analogy between the 'golden rule' steady state and the concept of 'maximum sustainable yield' for fisheries and other renewable natural resources.

If the objective function (1) is replaced with a discounted present value function

(6) $$W = \int_T e^{-\delta t}\, U(C_t)\, dt.$$

where δ is determined by the preferences of the current generation, the Ramsey rule becomes

(7) $$\delta + \eta\, \dot{\mathrm{C}}_{\mathrm{t}} = F_K/K_t.$$

[2] This equation holds exactly for the constant relative risk aversion class of utility functions. Provided consumption is a continuous function of t, it holds approximately in a neighborhood of any t.

When $\delta > 0$, the marginal productivity of capital at the optimum is higher than for the case of no discounting. It follows that the optimal path implies higher initial consumption, lower investment and lower growth in output and consumption. If members of the present generation have preferences of the form (6), equation (7) represents the competitive outcome, assuming an absence of externalities, non-convexities and distorting taxes.

The critical feature to note is that the opportunity cost of capital applicable to marginal capital investments is endogenously determined by the initial choice of objective function. The higher the discount rate applied to future welfare, the higher the opportunity cost of capital in the optimal solution. In particular, the utilitarian criterion (1), which gives equal weight to future and present generations, implies a lower opportunity cost of capital than the competitive equilibrium (7). In the latter equilibrium, future generations matter precisely to the extent that the individual choices of members of the current generation take them into account. Members of future generations have no independent standing in this solution. Although this is inconsistent with classical utilitarianism and with most forms of 'conservationist' ethics, the implications of (7) are wholeheartedly embraced in other ethical systems, notably that of Nozick (1974).

The problem described here can be elaborated in many ways. For example, it is possible to allow for technical progress, capital depreciation and population growth without making fundamental modifications to the solution described here. It is also possible to make the technology stochastic, as in the work of Brock and Mirman (1973). This replaces the optimal control problem with a stochastic dynamic optimization problem, but does not alter the basic character of the solution.

The End of Growth and the End of Growth Theory

The debate over economic growth changed radically in the 1970s. Growth theory had flourished in an environment where growth was taken to be natural and, short of gross mismanagement, inevitable, and where the possibility of fine-tuning the path of growth appeared plausible. The breakdown of Keynesian macroeconomic management, the collapse of economic growth rates in many countries and the declining appeal of medium and long term economic planning reduced many of the problems considered in growth theory to academic exercises. In a situation where governments have so little control over the economy that they cannot even ensure positive economic growth, the complexities of turnpike theorems are of little practical interest.

Also around 1970, increasing concern over the environmental implications of unconstrained economic growth led to dissatisfaction with growth-theoretic models that excluded the natural environment from consideration. As has already been noted, there is no technical obstacle to the inclusion of renewable and exhaustible resources in growth models, and such models have been developed. However, the main stream of environmental economics has been divorced from growth theory, despite important theoretical relationships (discussed below). The growth-theoretic concerns of the 1950s and 1960s have largely been subsumed in development theory and, as noted by Dasgupta and Mäler (1990), the development economics literature has been almost totally silent on environmental concerns.

Two more transitory factors had a major effect on the debate in the early 1970s. The first was discontent, expressed primarily[3] in the more developed countries (MDCs), with the materialistic, consumption-based culture of which mainstream economics was a representative. A popular work expressing this viewpoint was Schumacher's *Small is*

[3] The Islamic reaction against Westernization, especially in Iran, includes a significant anti-materialist element.

Beautiful. These concerns have generally faded along with the prospect of rapidly rising material living standards, as real wages have stagnated, most notably in the United States, since about 1970.

The second transitory factor was the dislocation of world commodity markets, the most dramatic expression of which was the rise of OPEC. The shift of power from buyers to sellers, especially in the oil market, created widespread apprehension that natural resource stocks were being consumed at an excessive rate and would be exhausted in the near future.

All of this led to a positive climate for the publication of *The Limits to Growth* (Meadows et al 1972), a work arguing that unless economic growth was stopped, disaster in the form of resource depletion and environmental collapse was inevitable. The centerpiece of The Limits to Growth was a 'world model' incorporating exponential growth and a number of feedback processes. It included estimates of exhaustion dates for the key resources used in industrialized societies (the most extreme projections had metals such as lead, mercury and copper being exhausted in the 1990s).

As a modelling exercise, *The Limits to Growth* had little to commend it. The large scale (for the day) computer model was simply window dressing for a reiteration of Malthus' famous argument on the geometric growth of population. The model ignored technical progress, factor substitution and price incentives to energy efficiency. All of these faults were pointed out by critics such as Nordhaus (1973). In particular, the central claim, that resources such as metals and fossil fuels are in danger of exhaustion, is no longer taken seriously.

Despite its technical inadequacies, *The Limits to Growth* fundamentally altered the terms of the debate. Critics such as Robinson (1975, p.55) demolished naive concerns about resource depletion, but concluded that "if one is looking for 'physical limits' to growth it is likely that the earth's capacity to assimilate wastes will become a constraint before there is any question of 'running out of energy.'" It is this issue that has become the centre of the debate over sustainability. This is reflected in the increasing salience of trans-border pollution problems such as acid rain, and in the rise of concern over the global pollution issues associated with emissions of carbon dioxide, CFCs and other pollutants that affect the earth's atmosphere and climatic systems a whole, rather than in localized problem areas. Although these problems remain the subject of vigorous debate, they cannot be dismissed as easily as a claim that the industrialized world is about to run out of copper, lead and mercury[4].

The second effect of *The Limits to Growth* debate was to increase the prominence of distributional issues. First, the debate raised the possibility that future generations might be worse off than ourselves in significant ways, and this concern has not been allayed. Issues of intergenerational equity were largely of philosophical or mathematical interest in the optimal growth literature, since they primarily concerned the question of how much better off our children should be than ourselves. The problems become sharper when we consider the possibility of welfare declining over time.

Second, problems of distribution within the current generation, and particularly between rich and poor nations were raised. The argument of *The Limits to Growth* implied that growth should be stopped as a matter of urgency. Not surprisingly, this policy found a more receptive audience in countries that were already wealthy, and particularly in the middle and upper classes of those countries. The anti-growth camp presented the argument that the end of growth would force society (and the world) to confront issues of distribution, rather than relying on growth as a universal solvent. However, the general perception generated by calls for zero growth was that distributional issues were of secondary importance given the overriding need to prevent collapse of the entire system. This aspect of the debate created considerable resistance in LDCs (still not

[4] Indeed, especially for lead and mercury, for which the constraint on the earth's ability to assimilate wastes is already sharp, it seems far more likely that we will run out of permissible uses.

fully broken down) to the recognition that environmental problems were not merely preoccupations of the rich but were substantial problems for development.

Finally, the debate sharpened the existing perception of an inherent conflict between growth, economic welfare, and the environment. This perception has been challenged repeatedly, but remains influential, particularly in the consideration of issues relating to discounting. As is shown below, much of the opposition to an optimal growth-theoretic analysis of environmental problems stems from a misperception of the relationship between growth (as it is interpreted in an optimizing framework) and environmental goods.

The Rise of Sustainability

The authors of *The Limits to Growth* called for an end to growth, but gave little consideration to the nature of the economic system in which their prescriptions might be implemented. These issues have been explored, most notably by Daly (1974). Although Daly's ideas have been influential, the main stream of current economic thinking about sustainable development can be traced back to the work of Solow (1974, 1976) and Hartwick (1977, 1978).

Solow (1974) drew on the work of Rawls (1971) to consider the implications of a maximin criterion for intergenerational equity[5] The most obvious implication is that consumption should be constant over time[6]. Otherwise, maximin welfare can be increased by reducing the consumption of all but the worst-off generation in order to benefit that generation. More precisely, consumption should be set at the maximum feasible constant level.

[5] It is not clear whether Rawls intended his fairness criterion to apply to problems of distribution between generations. However, the maximin criterion is of interest, independently of these exegetical concerns.

[6] Exact equality need not hold if some goods are free at some points in time but not at others. However, 'free' must be interpreted in a very strict sense. Not only must current use be unconstrained by availability, but it must not affect the availability of the good for future generations. The classic examples of free goods (air and water) are unlikely to fit this interpretation.

Interpreted in the context of growth theory, this does not seem very appealing (at least in an ethical sense). The implied policy is that the present generation should increase its consumption so as to cut off the possibility of improved living standards for future generations. Solow (1974, p.41) observes that the maximin criterion 'requires an initial capital stock big enough to support a decent standard of living, else it perpetuates poverty, but it cannot tell us why the initial capital stock should ever have been accumulated.'

The ethical appeal of the maximin criterion increases if it is supposed, instead, that depletion of natural resources, and, in particular, the capacity of the environment to act as a sink for pollution, is proceeding at a rate that will, or may, cause future generations to be worse off than ourselves. Solow (1974), Hartwick (1977, 1978) examined the implications of this position in a model in which human-made and natural capital could be substituted. Hartwick showed that the maximin criterion would be satisfied if the rents from depletion of natural capital were invested in human-made capital. The effective value of the total capital stock would remain unchanged under this rule.

Criticism of the Solow-Hartwick approach has focused on the assumption of substitutability between natural and human-made capital. Given the tremendous growth in human-made capital over the past century, the substitutability assumption, as embodied, for example, in the CES production function, carries the implication that natural resource stocks could be driven to a tiny fraction of their current levels without reducing human welfare. As natural resource stocks declined, the marginal rate of substitution between human-made and natural capital would rise, but this would not matter if the supply of human-made capital were large enough.

Advocates of the use of sustainability criteria, most notably Barbier and Pearce, have argued that the Solow-Hartwick constraint, that capital stocks not be reduced, should be applied to stocks of each type of environmental capital separately, rather than to the aggregate of natural and human-made capital. Barbier, Markandya and Pearce (1990) propose an extended form of benefit–cost analysis incorporating these constraints.

They consider a weak sustainability rule (in which the present value of all changes to each stock of environmental capital is required to be non-negative) and a strong sustainability rule, in which changes to each stock of environmental capital should be non-negative in every period. Other than this, the benefit–cost analysis criterion they propose is the standard one of maximizing the net present value of consumption, at the market discount rate.[7] As already noted, they explicitly reject the notion that the discount rate should be adjusted to take account of the interests of future generations. On the other hand, Barbier, Markandya and Pearce are sympathetic to the use of distributional weights within the current generation (and, implicitly, within future generations).

The effect of the sustainability rule is to impose an additional constraint on the optimization problem, which may be captured by a shadow price associated with the benefit from relaxation of the constraint. The weak sustainability rule yields a constant shadow price and the strong sustainability rule yields a price that increases at the discount rate.

An obvious difficulty with these sustainability criteria, pointed out by Dasgupta and Mäler (1990) is that, if applied to non-renewable resources, it implies that the resources can never be used and have zero value. More generally, Dasgupta and Mäler accuse Barbier, Pearce and Markandya of

> "a 'category mistake', the mistake being to confuse the *determinants* of well-being (for example, the means of production) with the *constituents* of well-being (for example, health, welfare and freedoms)" (emphasis in original).

They continue

> "The point is not that sustainable development, even as it is defined by these authors, is an undesirable goal. It is that, thus defined, it has negligible information content. (We are not told, for example, what stock

[7] Or, in the presence of distorting taxes, the associated shadow price of capital derived as in Marglin 1963a, 1963b).

levels we ought to aim at). This is the price that has to be paid for talking in terms of grand strategies. The hard work comes when one is forced to do the ecology and the economics of the matter."

Dasgupta and Mäler conclude that the theory of optimal development, outlined above, produced much sharper prescriptions than the recent literature on sustainable development.

There is merit in the criticisms put forward by Dasgupta and Mäler, but their verdict is too harsh. The sustainability criteria proposed by Barbier, Pearce and Markandya may best be understood as rule of thumb modifications to standard benefit–cost analysis procedures, to be applied when the standard procedures differ from the prescriptions of optimal development theory. In most, though not all, cases, these modifications will move the outcome closer to the optimum.

Sustainable and optimal use of a renewable resource

The relationship between the recent sustainability literature and the theory of optimal growth may be illustrated by consideration of the problem of managing a renewable resource, discussed by Dasgupta and Heal (1979, Chapter 5) whose analysis is followed here. An identical analysis applies to the case of a non-renewable resource in the presence of resource-augmenting technical change. It is impossible to pursue a sustainable policy for a non-renewable resource in the absence of technical change. For this reason proposals for sustainable use of non-renewable resources have generally been based on a model similar to that given here.

Let Z denote the stock of the resource, and assume that the rate of natural regeneration of the resource is given by the quadratic illustrated in Figure 1.

(8) $$\dot{Z}_t = R(Z_t) = -\alpha + \beta Z - \gamma Z^2.$$

As illustrated in Figure 1, the stock has two stationary points at $\underline{Z}$ and $\bar{Z}$. The stationary point $\underline{Z}$ is unstable. If the stock falls below $\underline{Z}$ it will inevitably head towards extinction, while if it rises above $\underline{Z}$ it will converge, in the absence of harvesting, to $\bar{Z}$.

Consider first the problem of choosing a harvesting policy C_t to maximize an objective function of the form

(9) $$W = \int_0^\infty e^{-rt}\, U(C_t)\; dt$$

Several features of this objective function are worthy of comment. First, harvesting costs are ignored. Second, no value is given to the stock of the resource *per se*. Third, the use of the term $U(C_t)$ rather than a market price as in Dasgupta and Heal (1979) reflects the notion that the benefits of the resource enter utility in a direct and additively separable fashion, permitting no substitution with human-made capital. Fourth, Inada conditions may be imposed to ensure that U' approaches infinity as C approaches zero. Thus, each stock is ‘essential’. The Inada conditions are satisfied by the logarithmic and power functions used here. Finally, the discount rate r may be positive, negative or zero.

First, consider stationary solutions. Dasgupta and Heal show that the optimal stationary solution involves choosing $Z^* \in [\underline{Z}, \tilde{Z}]$ such that $R'[Z^*] = r$. If such a Z^* exists, it is unique. That is, the own rate of return on the resource stock must be set equal to the rate of discount. In particular when $r = 0$, the optimal stationary policy is that of maximum sustained yield. This is analogous to the ‘golden rule’ of optimal growth theory. If, however, $R'[Z] < r \;\; \forall\; Z$ (note that this will be true if and only if $R'(\underline{Z}) < r$), there exists no interior optimum and the optimal stationary policy is one that sets the resource stock to zero.

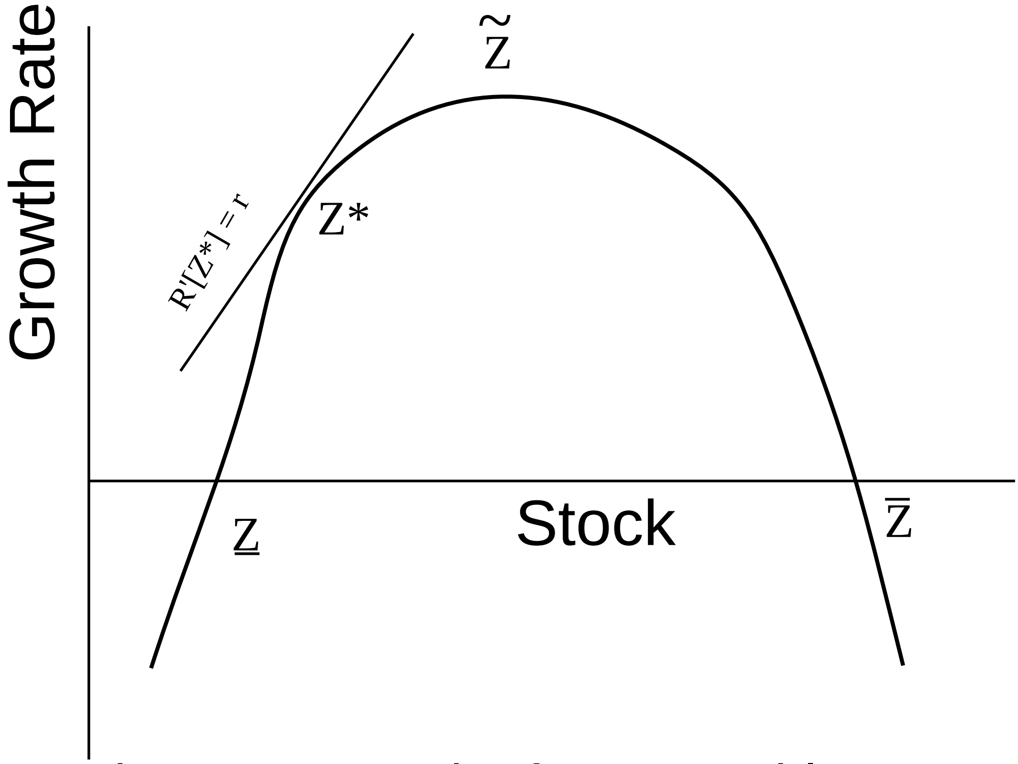

Figure 1: Growth of a renewable resource (Heal and Dasgupta)

With a linear objective function, as in Dasgupta and Heal, the complete optimal solution is obtained by the most rapid route to the stationary optimum. If the initial stock Z_0 is greater than Z^*, the optimal policy is a “pulse” policy in which an amount Z_0 - Z^* is harvested instantly. If $Z_0 < Z^*$, the optimal policy is to refrain from harvesting until the stock Z^* is attained.

With the utility maximizing objective proposed here, the optimal solution is essentially identical to that of the optimal growth problem. This solution may be described using optimal control theory.

The Hamiltonian is

(10) $$H_t = e^{-rt}\, U(C_t) + \lambda_t(R(Z_t) - C_t),$$

with solution conditions

(11) $$U'(C_t)\, e^{-rt} - \lambda_t = 0$$

and

(12) $$\dot{\lambda}_t = R'(Z_t)\lambda_t.$$

Hence,

(13) $$\partial/\partial t\, \{U'(C_t)\, e^{-rt}\} = U''(C_t)\partial C/\partial t\, e^{-rt} - rU'(C_t)\, e^{-rt} = R'(Z_t)U'(C_t)\, e^{-rt},$$

or

(14) $$R'(Z) = \quad -U''(C_t)/U'(t)\, \partial C/\partial t + r$$

$$= \eta\, (\dot{C}_t\, /C_t) + r,$$

which is just the Ramsey rule.

The term $\eta(\dot{C}_t\, /C_t) + r$ is the opportunity cost rate for a marginal project, expressed in terms of the services of the resource stock. Whenever $(\dot{C}_t\, /C_t)$ is less than the rate of growth of consumption of the services of human-made capital, the opportunity cost rate for the services of the resource stock is less than the general discount rate (or, equivalently, the shadow price of the services of the resource is rising over time). Thus, if this condition holds, the claim that environmental goods should have a lower rate of discount is supported in this model.

Consider now the optimal path yielded by this model when there is no stationary solution with a positive stock. If $\lim_{C\to 0} U'(C) = \infty$, the optimal path will involve consumption declining steadily towards 0 as the stock approaches $\underline{Z}$. If $\lim_{C\to 0} U'(C)$ is finite, the stock will be driven to zero in finite time (Clark 1973). Although these paths are optimal in the context of the model as specified they are unsustainable in any meaningful sense of the term.

From a classical utilitarian perspective, the reason for this unsustainable outcome is clear. These solutions can only arise if the discount factor *r* is positive, implying that the interests of future generations are inappropriately downgraded. The correct solution is that which yields a path leading to the maximum sustainable yield. Such a path could be obtained either by direct public control of the resource or by the use of a tax policy that closed the gap between private and social costs associated with the ‘defective telescopic facility’ of the present generation. This would eliminate the term in *r*, with respect to both the problem of optimal use of the renewable resource and the general problem of optimal savings, investment and growth.

More generally, it might be argued that, although some degree of discounting is appropriate, the use of the market rate places excessive weight on the preferences of the current generation. Norgaard (1991) presents a series of simulations showing how the discount rate reflects the intergenerational allocation of property rights. The more property rights are allocated to future generations, in the form of obligations on the current generation to bequeath capital stocks, the lower is the resulting discount rate. Thus, intergenerational equity requires an increase in the total stock of all kinds of capital passed on to future generations. This would generate a reduction in the equilibrium interest rate that would be used in the evaluation of marginal projects.

There are several reasons why an optimal solution of this kind might not be adopted. First, few governments now attempt central planning and most make only indirect attempts to control the level of aggregate savings and investment. Second, the determination of the optimal solution requires a complete valuation of the services of the resources, and only limited progress has been made in this direction. Finally, questions of sustainability are of particular interest to lending agencies such as the World Bank, which must, in many cases, evaluate individual projects taking the overall settings of national economic policy as given. There are also a number of pressures that lead lending agencies to prefer a fixed and fairly high rate of discount in project evaluation (for further discussion on this point see Quiggin and Anderson 1990).

In these circumstances, it may be desirable to use the market rate of interest *r* and to impose constraints that partially compensate for the excessive discounting of future welfare. In the simple problem outlined above, there is no difference between the weak and strong sustainability criteria. If the unconstrained optimal solution calls for a final $Z^* > Z_0$, the sustainability constraint will not be binding. If the unconstrained optimum has $Z^* < Z_0$, the sustainability constraint is binding in every period and the solution is $Z_t = Z_0$, $\forall\, t$. The use of the sustainability constraint is equivalent to replacing the discount rate *r* with $\min(H'(Z_0), r)$.

The imposition of the sustainability constraint must increase welfare, according to the classical utilitarian objective function, whenever $Z_0 \leq \tilde{Z}$. The imposition of the constraint will reduce welfare for sufficiently large $Z_0 > \tilde{Z}$. In particular, when $Z_0 = \bar{Z}$, the constraint forbids any harvesting of the resource. Since this version of the problem is based on the assumption that the stock *per se* has no social value, the constraint is inappropriate in this case.

From the discussion above, it is possible to derive a modified constraint that will always increase the value of the classical utilitarian welfare function relative to the unconstrained competitive optimum. The modified constraint requires that if the initial stock is greater than the level $\tilde{Z}$ that generates the maximum sustained yield, then the stock should be driven down to $\tilde{Z}$ along the path satisfying (14), and thereafter maximum sustained yield should be maintained. If the initial stock is less than $\tilde{Z}$, the sustainability rule should be applied.

The modified constraint proposed here will not yield the optimal outcome. However, it produces a strict improvement in welfare relative to the weak and strong sustainability constraints whenever the two differ. That is, whenever $Z_0 > \tilde{Z}$, the level of harvest is greater in every period under the modified constraint.

The argument is unchanged in essentials if it is supposed that the stock itself yields services independent of harvesting (for example, the services of forests in water catchment areas). The Hamiltonian now includes a term in Z, and the optimal utilitarian solution will have $Z^* > \tilde{Z}$. This increases the likelihood that the imposition of the sustainability constraint in the discounted benefit–cost analysis will lead to an increase in the value of the utilitarian objective function.

More interesting results arise when harvesting costs are included. We define the cost of harvesting by a function of the form $M(C, Z)$. In general, harvesting costs will depend on the size of the stock, with a larger stock corresponding to reduced harvesting costs, so that $\partial M/\partial Z < 0$. The effect once again is to increase the optimal value of Z^*. Given the assumption that the services of the environmental resource are separable, the objective function may be rewritten as

(15) $$\int_0^\infty e^{-rt} \left(U(C_t) - M(C_t, Z_t)\right) dt.$$

For a stationary solution, $C = R(Z)$ and we may define a stationary cost function $\phi(Z)$. The stationary optimum has

(16) $$r = R'(Z) - \phi'(Z)/U'(R(Z)),$$

so that $R'(Z) < r$. In particular, for the zero discounting case, this implies that the optimal stationary stock will be higher than that which generates the maximum sustainable yield.

However, as is shown by Cropper (1988), the existence of harvest costs may generate the outcome that the unconstrained competitive optimum involves driving the resource to extinction, even though $H'(Z_0) > r$. The optimum is now determined by the net returns from harvesting, and a sustainable optimum will arise only if this return increases at a rate r. If costs do not decline sufficiently rapidly, the net return may rise too slowly, and the competitive solution may drive the stock to zero. These effects increase the probability that the imposition of a sustainability constraint will increase welfare.

The other interesting cases arise when the marginal cost of harvesting is a decreasing function of the amount harvested. Here the results are not so favorable for sustainability constraints. The optimal utilitarian and competitive solutions involve pulse harvesting, in which the stock is allowed to build up and then a large amount is harvested. This approach is inconsistent with strong sustainability constraints. The strong sustainability constraint involves zero harvesting and hence zero welfare in every period.

On the other hand, the weak sustainability constraint may be too weak in this case. If the average rate of growth of net returns is less than the discount rate r, the competitive optimal policy will involve leaving the stock alone until its value exceeds the cost of harvesting, then harvesting the entire stock in a single pulse. Since the result is a series of increases in the stock followed by a large reduction, the weak sustainability constraint will be satisfied provided r is sufficiently large. Thus, weak sustainability does not guarantee the stock against extinction.

In summary, the examples discussed above represent simple cases in which the application of the market rate of discount may yield an outcome that is both unsustainable and, from a utilitarian viewpoint, sub-optimal. It has been shown that, in most cases, the imposition of a sustainability constraint will improve welfare, although it will not yield the optimal outcome. The main exceptions are cases where the resource has not been heavily exploited in the past, so that Z_0 is near $\bar{Z}$, and cases where there are economies of scale in harvesting.

Uncertainty

The uncertainty associated with natural resource depletion has been a major concern of the sustainability literature. However, no really satisfactory solution has emerged.

Two main themes have been pursued. The first, which is theoretically fairly well understood, concerns irreversible decisions. As was first observed by Arrow and Fisher (1974), there is a cost (now usually referred to as option value) associated with making an irreversible decision under uncertainty, rather than delaying the decision and obtaining more information.

The most obvious example of an irreversible outcome (one discussed by Arrow and Fisher) is extinction. For some parameter values, the competitive optimum derived above involves driving the resource to extinction. The simplest response to uncertainty is to assume that uncertain parameters are equal to their mean values and derive the ‘certainty equivalent’ solution. This response is inappropriate in the case of extinction. The costs of preserving the stock while waiting for further information are likely to be small relative to the costs of driving the stock to extinction, and then discovering that it should have been preserved. The imposition of sustainability criteria may be regarded as a simple *ad hoc* adjustment to take account of these quasi-option values.

The choice between extinction and preservation is the simplest illustration of quasi-option value, but perhaps the least relevant. It is rare, nowadays, that a conscious decision would be made to drive a stock to extinction. (Note, in particular, that such a policy can never be optimal in the classical utilitarian case.) This raises the issue of resilience. Under uncertainty, a policy that drives the stock close to the estimated critical value $\underline{Z}$ involves the risk that the stock will fall below $\underline{Z}$ and then go to extinction.

The approach most consistent with the sustainability literature is a further application of maximin. That is, the policy adopted should be that which will yield the best return in the worst possible state of the world. This rule of thumb is superficially attractive. However, there are fundamental difficulties which render it unworkable in all but the simplest problems.

First, the worst possible state may be one in which the stock is already doomed to extinction. The optimal policy in this case may be of little relevance to the case when the stock is near to, but above $\underline{Z}$. Second for a continuous distribution, the minimum outcome is not defined. In practice, applications of maximin and safety-first criteria generally involve the arbitrary selection of a cut-off point (such as the 5th percentile) which is treated as if it were the minimum. In the absence of any higher-level criterion for choosing the cut-off point, we are left with little more than a general injunction to risk aversion. In particular, the use of an arbitrary cut-off such as 5 per cent may be excessively cautious in some contexts (such as routine investment projects) and not cautious enough in others (such as nuclear reactor design).

The rule of thumb corrections that have usually been employed in benefit–cost analysis are, if anything, even more unsatisfactory. The most common procedure for dealing with risk is an upward adjustment to the discount rate. The *ad hoc* nature of this response, and the potential for biases against long-lived projects has been pointed out on a number of occasions (Little and Mirrlees 1974; Wilson 1982). Nevertheless, for typical projects, increasing the discount rate in response to risk has the right general effect, namely that fewer risky projects are undertaken. This effect depends entirely on the fact that most projects consist of an initial known expenditure, followed by an uncertain stream of positive returns.

In the resource use problem, this is not the case. The risky activity involves consuming more in the present with a resulting uncertain flow of reductions in future consumption. Raising the discount rate in response to uncertainty will only worsen the problem.

The critical problem here is the failure to realize that the desirable opportunity cost rate of discount is endogenous. From the Ramsey rule (4), the opportunity cost rate is lower, the lower is the rate of growth of consumption. In particular, in the classical utilitarian case, if future consumption is lower than present consumption, the opportunity cost rate is negative.

The approach may be illustrated in the a simple discrete-state model. The state of nature is determined by the capacity of the environment to yield a flow of services and absorb the by-products of human activity. The state of nature is unknown in period 1 and is known in all subsequent periods. Let the sustainable rate of growth in state *i* be denoted by r_i. Now consider the evaluation of a small project that involves a change c_0 (which may be positive or negative) in initial consumption and a stream of benefits c_{it}, $1 < t \leq T$. That is, if state *i* is realized, the increment to consumption in period *t* is given by c_{it}. Utility maximization requires that we maximize the sum

(17) $$c_0 U'(C_0) + \sum_{i=1}^{n} \sum_{t=1}^{T} p_i U'(e^{r_i t} C_0)\, c_{it}$$

where p_i is the probability of state *i* and C_0 is the initial level of consumption. Assuming a constant relative risk aversion utility function, this is equivalent to maximizing

(18) $$c_0 + \sum_{i=1}^{n} \sum_{t=1}^{T} p_i\, e^{-\eta r_i t}\, c_{it}$$

That is, for each state of the world, *i*, a discount rate ηr_i is applied to the stream of benefits (or costs) associated with the project in that state[8].

The effect is to place a greater weight on worse states of the world, particularly when these states involve reduced (or negative) growth in consumption over a long period. Consider, for example, a simple two-state model. Suppose that $T = 20$, and that $r_1 = 0.05$, $r_2 = -0.02$, $\eta = 2$. Then the weight on final year benefits in state 2 will be about fifteen times that on final benefits in state 1.

The approach used here is quite similar in spirit to that of Wilson (1982). However, Wilson was concerned with the case where random returns from the project are correlated with stochastic fluctuations in aggregate consumption about a known level or trend. In this case, we are concerned with a correlation between returns to the project and the

[8] The utility maximizing solution is derived on the assumption that there is no inherent discounting of future welfare *per se.* A term δ may be added to account for any inherent preference for the present over the future. However, as has already been noted, this appears to be inconsistent with the spirit of the sustainability critique.

trend rate of growth of aggregate consumption. Because the trend is assumed to continue over a long period, the effects of risk aversion (concavity of the utility function) are much greater in this case than in most of the examples considered by Wilson.

The use of an endogenous discount rate appears to be a natural way of incorporating the concerns with resilience expressed by writers such as Pearce (1987). The greater is the risk of long term damage to the resource, the lower is the endogenously determined discount rate and the more weight is placed on new projects or modifications to existing projects that will help to preserve the resource.

There are two main difficulties with the utilitarian approach advocated here, in which the marginal utility of consumption is calculated separately for each state of the world, thereby generating an endogenous set of weights for any given level of risk aversion. The first is a familiar one — the need to specify a probability distribution over the states over the world and a mapping from states to consequences for any given project. In most project analysis, the informational requirements of this task have been found to be too great, and *ad hoc* methods of dealing with risk have been preferred. In the present case, uncertainty is so essential to the problem, and the usual *ad hoc* methods are so unreliable, that some attempt at formal modelling seems justified.

The second problem is that the constant relative risk aversion function used here puts an infinite negative value on the extinction of the resource. In a deterministic setting, this seems to be appropriate — it would be a undesirable to accept a policy that deliberately drove any resource to extinction. However, the issue is less clear in the case of uncertainty. There is always a possibility that some resource will become extinct, even with the most conservative policies. It may be necessary to put some explicit, finite cost on extinction. As noted previously, the same difficulty arises in the context of the maximin rule used by most advocates of sustainability criteria.

The use of some form of utility function is implicit in most existing treatments of risk in benefit–cost analysis. The explicit approach recommended here makes the analysis simpler and more transparent. In some cases, as with the necessity to accept non-zero probabilities of extinction, this transparency reveals hard choices that may be blurred by the use of *ad hoc* risk adjustment methods. The guiding spirit of benefit–cost analysis is precisely that such hard choices should be made explicit.

Income Distribution

The treatment of sustainability offered here has been based on a concern with equity between generations. Such a concern cannot be taken seriously, particularly in a development context, unless it also embraces equity within the present generation It is *prima facie* inconsistent to apply a discounting procedure of the kind presented here to the income of future generations while simply adding up costs and benefits wherever they fall within the current generation. This inconsistency might be justified if there were a lump sum procedure available for redistributing wealth among the current generation. In fact, not only is there no lump sum procedure, there is no procedure that is even approximately lump sum, at least at the margin. This is true within countries and even more so between more and less developed countries

The appropriate procedure is to employ a social welfare function consistently throughout the analysis. This provides a way of handling the problem that environmental preservation for future generations may be provided at the expense of income redistribution to the poor in the present generations. This is particularly troubling if, as in the case of global warming, the poor have enjoyed little benefit from the consumption activities that created the problem. The approach advocated here provides a positive weight on transfers from the better off to the worse off regardless of when or where they live.

The more usual treatment of equity issues is based on the use of distributional weights. Like the imposition of sustainability criteria, this may be seen as a rule of thumb approximation to the utilitarian optimum. In this case, the relationship is fairly straightforward. The preferred distributional weights are given by the ratio of marginal utility of income between different individuals. In the constant relative risk aversion case, this is simply the ratio of income multiplied by the risk (or inequality) aversion parameter η.

At a formal level then, there are no difficulties with the adoption of a consistent utilitarian framework. However, it is clear that such a framework calls for redistribution within the current generation, and particularly between rich and poor nations on a scale that is unlikely to be realized. Is it useful, then, to apply an analysis of this kind to issues of intergenerational equity ?

A closely related line of argument is put forward by Kay and Mirrlees (1975, p.163)

> ... we think that the use of natural resources now to benefit Englishmen instead of in a hundred years' time to benefit Indians is of a piece with the other ways in which all factors of production are unequally applied to the good of Englishmen and Indians and believe that restraint in using resources would actually be a very expensive way of shifting the balance.

The converse position seems defensible. In particular, observation of international negotiations such as those that produced the Montreal protocols limiting CFC emissions suggests an alternative analysis. The starting point is that the present generation in the MDCs has, by accidents of timing, greater access to resources than the present generation in less developed countries or future generations in all countries. However, the global nature of the environmental problems associated with the notion of sustainability means that the status of future generations will be determined by the choice made by both poor and rich countries in the present generation. A decision by MDCs to exercise restraint in using CFCs is of little value if less developed countries expand the use of these chemicals. Hence, if the present generation in the MDCs wishes to act on its concern for future generations, it can only do so through a policy program that takes account of the claims of less developed countries to a fairer share of the world's resources.

Substitution and the general rate of discount

In the previous analysis, attention has been confined to the case of a single resource stock with no available substitutes in production or consumption. The analysis could be extended to the case of several independent stocks. A number of interesting issues arise from this consideration.

First, if there are several separate stocks, the optimal endogenous rate of discount will be different for each stock, and will be directly related to the feasible rate of growth of consumption of the services of that stock. This conclusion will presumably be attractive to environmentalists, who have long argued that a separate low rate of discount is appropriate for environmental goods, for which the available flow of services is bounded and unlikely to grow rapidly. On the other hand, a number of considerations favor the use of a common rate of discount in project appraisal. It may be observed that an identical effect is obtained if the discount rate is set at some fixed rate δ and it is assumed that prices for the services of each stock will grow at a rate equal to the difference between δ and the optimal endogenous discount rate for that stock. The use of changing relative prices, rather than separate discount rates is particularly attractive if the assumption of zero substitutability is to be relaxed.

Second there is nothing in the argument presented here that draws specifically on the fact that natural resource stocks are natural. Indeed, the basic ideas were developed in an attempt to determine the optimal management of produced capital stocks. Hence the intergenerational equity concerns that motivate the issue of sustainability have implications for the appropriate rate of discount for the economy as a whole.

Before considering the desirability of lower discount rates, it is necessary to observe that we are concerned with the endogenous discount rate arising from a given investment program, and not directly with the choice of a discount rate for the evaluation of public projects. In an economy where all investments were planned, the two would essentially be equivalent. This is not the case, however, when both private and public investment are present. In this case, a simple reduction in the rate of discount applicable to public projects, without any increase in aggregate investment, may lead to the 'crowding out' of more productive private projects.

The ideal policy mix in a situation of this kind might involve a set of policies aimed at achieving a suitable level of aggregate savings and investment, combined with public investment policies aimed at ensuring optimal management of those stock, particularly natural resource stocks, where market prices yield inappropriate signals. The higher the rate of aggregate savings and investment, the lower the rate of discount for investment in general. As has already been argued, the flow of services from vulnerable renewable resources would typically be discounted at a rate lower than that for investment in general (or, equivalently, the relative price of these services would be expected to rise over time).

The notion of lowering the rate of discount for investment in general has raised a number of difficulties. In a paper devoted to the proposition that depletion of natural resources is, if anything, too slow, Kay and Mirrlees (1975, p.163) observe

> There may be a general bias in the economy to consume now and leave too little to our children or our future selves. If so, it would be reflected in high rates of interest, which will lead to somewhat more rapid depletion of resources.
>
> Many conservationists might take the view that this did describe their position: that the rate of interest was too high as a result of society's 'defective telescopic facility' (as Pigou described it). But if this is so, it implies that we are undertaking too little investment of all kinds. And this in turn carries the implication that the present rate of economic growth is too low and that we should increase the investment ratio in an effort to raise it. It is our impression that rather few of those who worry about excessive resource depletion would accept that conclusion: but, if not, they must find some other basis for their intuition.

Kay and Mirrlees' argument is directed against those who object to growth *per se*, a group that was rather larger at the time the statement was originally written than it is today. However, at this level, the argument is simply *ad hominem*. It does not refute the view that the environment has been degraded as a result of inadequate concern for the future.

The general validity of the argument appears to turn on the interpretation of 'growth.' The simplest interpretation is 'the rate of increase of GNP as currently measured.' This is obviously an inadequate welfare measure, since environmental consequences are ignored. Much of the intuitive appeal of the Kay-Mirrlees argument derives from the fact that environmentalists would generally, and correctly, be opposed to policies aimed at maximizing measured GNP growth. Increased growth in this sense will be achieved by an inefficient increase in human-made capital at the expense of natural capital, rather than by an increase in capital stocks generally. Hence, it is incorrect to suggest that increased concern for future generations must imply higher growth in this sense.

A second interpretation, which appears to be embraced by Kay and Mirrlees, is that growth means 'more of the same.' It is true that increased concern for future generations must imply higher aggregate savings and investment — this is simply the other side of an equilibrium involving lower discount rates. But this does not imply that investment of all kinds must increase. In particular, investments with positive short-term payoffs and negative long run consequences (for example, those that generate long-lived, intractable wastes) will be made less attractive.

In considering the validity of the notion that a lower general rate of discount is antithetical to environmental preservation, it is necessary to consider both short and long run impacts. In the short run, a lower rate of discount implies reduced consumption and higher investment. Obviously, this will have favorable effects as it applies directly to natural resource stocks. The effects of the lower discount rate for general investment depend on whether the production of capital goods is more or less environmentally damaging than the production of consumer goods. There does not appear to be any *a priori* basis for a judgement on this point.

In the long run, the lower discount rate implies a larger aggregate stock of capital, both natural and human-made. Although it is not necessarily true that stocks of every kind of capital will increase, it is likely that the aggregate stock of human-made capital will increase along with the stock of natural capital. Human-made capital typically enters production in a complementary fashion with the flows of services from natural capital stocks, such as energy. Hence, a larger capital stock will imply a higher rate of throughput of natural resources services and therefore more rapid depletion (or less rapid growth) of natural resource stocks, at least relative to the case when effective discount rates are lowered for natural, but not for human-made capital (see Barbier et al 1990).

This reasoning seems plausible in a static context. However, in a dynamic context, the higher the rate of growth of the stock of human-made capital, the more rapid the rate of increase of the value of natural services and the greater the opportunity cost of using them rather than preserving them. It therefore seems reasonable to conclude, contrary both to Kay and Mirrlees and to Barbier et al, that environmental depletion can be explained by inadequate concern for future generations, and that effective policies to raise the level of investment in both human-made and natural capital, and to lower the endogenously determined discount rate, would generate more sustainable outcomes.

The Choice of Discount Rate

The analysis so far has dealt with the theoretical implications for discounting of concepts of sustainability and intergenerational equity. However, no explicit values for discount rates have been discussed, except as illustrations. Before discussing numerical values, it must be emphasized once again that what is being considered is the endogenous discount rate determined by a program of capital accumulation, and not a choice of discount rate for the evaluation of some subset of possible projects.

A useful first step is provided by the application of the Ramsey rule to the aggregate capital stock, without taking account of concerns about environmental sustainability. The empirical literature on risk suggests that the risk aversion parameter η should take a value in the range [0.5, 2]. Rates of growth of consumption have varied widely, but values in the range [0, 0.05] seem to be predominant. This implies a range of possible discount rates from 0 to 10 per cent, with the most plausible values being in the range from 3 to 5 per cent.

For the MDCs, especially during the period of rapid growth from 1950 to 1970, this does not seem implausible, at least if bond rates are used as the basis of analysis. Nominal rates of return on US Treasury bonds never exceeded 7 per cent and real rates never exceeded 4 per cent over this period. Expectations of inflation may have been incorrect, but it is unlikely that bondholders anticipated deflation over the post-war period. Hence, by an obvious arbitrage argument, the rate of 7 per cent seems a reasonable upper bound for the expected rate of return to private capital and a rate of 4 to 5 per cent seems more plausible.

Rather higher estimates of opportunity costs are obtained from a study of returns to equity capital. Two separate measures of this return are available. One is to examine the returns available to an ordinary investor 'buying the index.' These returns are a combination of dividends and capital gains. This approach has been adopted by Ibbotson and Sinquefield (1979). Alternatively, the profits of companies (along with interest and tax paid) may be measured and compared to an estimate of capital stocks. This approach has been adopted by Gorman (1972) and Stockfisch (1982). Stockfisch and Gorman estimate nominal rates of return well over 10 per cent. However, the bond rate seems to be the most appropriate measure of the opportunity cost of capital.

The fact that the opportunity cost of capital was roughly in line with that suggested by the Ramsey rule over the period 1950–70 implies that aggregate savings and investment over this period did not reflect a bias against future generations. The environmental problems that emerged over this period may therefore be traced to ignorance and failure to deal appropriately with externality problems, rather than to a conscious decision to leave the problem to future generations.

Since the highly inflationary period of the mid-1970s, rates of growth of consumption have generally fallen and real interest rates have generally risen. This has been accompanied by widespread concern, in a number of MDCs, about inadequate rates of private and public sector savings. Reference to a Ramsey rule suggests that this concern is well founded. It might be suggested that recent concerns about sustainability in the more developed world reflect a more general concern that the economic dislocation of the 1970s and 1980s is producing an excessively short term orientation for all kinds of economic and environmental decisions.

The opportunity cost rates discussed above are substantially smaller than those typically used in project evaluation. The US Treasury supports a rate of 10 per cent and the World Bank has recently favored a rate of 14 per cent. Quiggin and Anderson (1990) argue that the use of such high interest rates represents an *ad hoc* adjustment to take account of the fact that *ex ante* benefit-cost analyses is typically based on excessively optimistic estimates of returns. This view is supported by the empirical evidence. Pohl and Mihaljek (1992) show that the mean estimated *ex post* return on a sample of World Bank projects was 16 per cent compared to an average predicted return of 22 per cent (medians were 14 and 18 per cent). Pfefferman and Bond (1989) report an even wider divergence. Even the estimated *ex post* returns are not definitive, and may well be over-estimates. Quiggin and Anderson criticize the use of adjustments to the discount rates as a method of compensating for over-optimism, and argue instead for a more detailed treatment of uncertainty. As has been shown above, the use of discount rate adjustments is particularly inappropriate when projects involve long term environmental costs.

Even allowing for all of these factors, however, it seems likely that the marginal return to capital in LDCs is often well above that which would be consistent with a Ramsey rule, and the rate of capital accumulation correspondingly below the optimal level. Because of the many problems of externality and inadequately defined property rights, it is likely that the divergence is even more severe for stocks of natural capital.

Concluding Comments

The recent literature on sustainability has been criticized by Dasgupta and Mäler (1989) as an inferior substitute for a theory of optimal development. The present paper has been formulated within an optimal development framework. It has been motivated by Solow's suggestion that sustainability criteria may represent workable rule of thumb approximations to optimal policies in cases where the discounting criteria used in benefit–cost analysis involve inadequate concern for future generations. It is shown that, in the simplest case of exploitation of a renewable resource under certainty, the imposition of sustainability criteria will usually lead to an improved outcome. Problems may arise however, in the presence of scale economies in harvesting.

Sustainability criteria are not the only rules of thumb used in benefit–cost analysis Issues of income distributions are frequently handled using distributional weights. Adjustments to discount rates are used to account for uncertainty. Each of these approaches has been the subject of a large literature, and neither can be regarded as entirely satisfactory.

In this paper, the analysis of sustainability as a rule of thumb has been extended to suggest a consistent treatment of all of these issues. One of the greatest, and least exploited, merits of the consistent use of a utilitarian objective function is that it permits a unified treatment of the three central problems of benefit–cost analysis — distribution of benefits over time, between individuals and across states of the world. A great deal of work remains to be done, however, before this theoretical unity can be reflected in practical benefit-cost analysis, let alone in policy.

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