



**AgEcon** SEARCH  
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search  
<http://ageconsearch.umn.edu>  
[aesearch@umn.edu](mailto:aesearch@umn.edu)

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

## EVALUATING LONG-LIVED PROJECTS: THE ISSUE OF INTER-GENERATIONAL EQUITY

R. YOUNG

*CSIRO, P.O. Box 225, Dickson, Act, 2602, Australia*

The role of the discount rate in benefit-cost analysis is reviewed, and its impact considered. A positive rate clearly 'tilts the balance overwhelmingly against generations in the distant future'. In this context, the issue of inter-generational equity is discussed, and it is concluded that although a positive rate representing social time preference or opportunity cost is appropriate when considering questions of economic efficiency, this is not the case when equity questions are being examined. In the case of irreversible change, an extreme example of inter-generational inequity, there may be no alternative to a constrained optimisation approach, where the constraint is determined by an ethical decision. A range of approaches for analysing the issue of inter-generational equity are canvassed and it is concluded that efficiency and equity questions need to be dealt with separately. If the analysis of the options on each issue are set out clearly, then policy makers will be better placed to make an informed and responsible decision.

### *Introduction*

The view that the market can adequately look after problems of resource use and depletion (see for example Kay and Mirrlees, 1975; Treasury 1973<sup>1</sup>) has given way to a more interventionist approach in dealing with externality problems of degradation and pollution, and related equity problems. In part this reflects growing sensitivity to the issue that 'those who "vote" today, both politically and through the market, are a small subset of those who are affected' (Lloyd, 1991).

The issue of the efficient allocation of resources over time is fundamental to economic thought, and has been considered in two main strands of analysis. One is macro-oriented and concerns optimal growth modelling and the application of optimal control theory (for examples, see Solow, 1974, 1986; Hartwick 1977, 1978a, 1978b;

\* The views expressed are those of the author and not necessarily those of CSIRO. Grateful acknowledgement is made with the usual caveat to Ray Trewin, Nico Klijn, Clem Tisdell, Mick Common, Alan Lloyd and three anonymous referees for helpful comments on an earlier draft.

<sup>1</sup> To be fair, the Treasury paper also considers externality situations where intervention may be warranted.

Krautkramer 1985, 1986; Perrings 1991). The other main strand is typically project based and concerns the application of benefit-cost analysis (see Mishan 1976; Lind 1982c).

The benefit-cost approach is founded on utilitarian welfare economics which uses Pareto efficiency criteria to determine which activities generate the greatest gain for society, (see Mishan 1976 [Part vii]; Randall 1982). The potential Pareto improvement, for example, is defined in terms of the benefits accruing to gainers being more than sufficient to compensate the losers, without compensation necessarily being paid. Benefit-cost analysis, however, ignores distributional effects (see Lind, 1982a, pp. 12-13; Cory 1985; Bockstael and Strand 1985) and the question arises whether benefit-cost analysis is adequate for evaluating intergenerational streams of benefits and costs. If it is not, what modifications or constraints need to be added or does the approach need to be jettisoned when issues of equity arise?

The issue of intergenerational equity is closely related to the choice of discount rate, an issue which continues to be a topic of unresolved debate in the economics profession. Use of a positive discount rate in benefit-cost analysis discriminates against future generations<sup>2</sup> and effectively means that such projects are evaluated only from the viewpoint of the present generation (Layard 1972; Ferejohn and Page 1978; Quiggin 1992).

There appears to be growing concern amongst members of the economics profession about the capacity of the existing body of mainstream economic thought to resolve issues of sustainable development and intergenerational equity (Jayasuriya, 1992). Examples include: Norgaard (1989, p. 48) who quotes Hicks's 1979 reference to 'the phenomena with which economics deals are so narrow that economists are continually butting their heads against its boundaries' and calls for 'methodological pluralism' to overcome 'methodological poverty'; Turner (1991, pp. 209-10) who refers to the narrowness of conventional economic analysis and the inadequacy of a market-based economics paradigm to deal with questions of valuation, fairness and compensation in relation to climate change and biodiversity; Friend (1990) who calls for a new paradigm to replace the neoclassical framework which is out-of-phase with social and economic realities; Christensen (1989) who charges that the basic biophysical principles are in conflict with the marginal physical and technical assumptions which underpin modern economic theories; Common and Perrings (1992) who conclude that economic (Solow) sustainability and ecological sustainability 'are largely disjoint'; Dasgupta and Maler

<sup>2</sup> An anonymous reviewer has pointed out that the discount rate should not only be positive but greater than the rate of productivity growth to effect discrimination against future generations. To the extent that productivity growth is non-discriminatory, this will be true. Whether productivity growth is neutral in this context is by no means certain, particularly for example if environmental damage results.

(quoted in Jayasuriya, 1992) who point to the absence of reference to environmental and non-renewable resource issues in the extensive literature on development economics, despite the fact that resource depletion and environmental degradation are major issues in developing countries; and Mishan (1977, p. 399) who concludes that 'no economic criterion can produce acceptable answers to the distribution problem'.

In the context of benefit-cost analysis, Layard (1972, p. 39) asks 'Is it really right that projects should be judged exclusively in terms of their effects on those now living?'; Lind (1990, p. S-21) considers that in the absence of the possibility of intergenerational compensation, the benefit-cost logic is much less compelling; and Ferejohn and Page (1978, p. 274) suggest that 'discounting requires fundamental rethinking as a choice rule'.

The aim in this paper is to review the role of the discount rate in benefit-cost analysis and the impact of the net present value efficiency criterion on long-lived projects. Issues of intergenerational equity and irreversibility are considered, and approaches are canvassed. Finally, the paper ends with a summary and conclusions in which it is recognised that the underlying aim of project evaluation is more informed decision making.

### *The Role and Impact of the Discount Rate*

The most commonly used investment criteria in benefit-cost analysis (BCA), viz., the net present value (NPV), the benefit-cost ratio (B/C) and the internal rate of return (IRR), can be shown to generate equivalent outcomes. Preference, however, is usually given to using NPV and B/C for a number of reasons (see Mishan 1976, ch. 29 for a discussion of this issue). If funds or resources are limited, IRR and the other two BCA criteria may not be equivalent (Tisdell, 1972, ch. 21) and inconsistent rankings may result (Pearce, 1983).

The discounting of net benefits in each future time period back to the present allows ready comparison of the NPV of different projects at a common point in time. In effect the discounting process is equivalent to assigning temporal weights to benefits and costs as they accrue over time. The fact that these weights decline into the future is at the core of the debate about the relevance of BCA to the analysis of intergenerational equity.

The rationale for the use of the discounting process on efficiency grounds is quite clear. Individuals invariably will prefer \$1 today rather than \$1 at a given time in the future. One reason for this preference is that a \$1 today can be invested and earn a return, so that it will with accrued returns be worth more than \$1 at a given time in the future. A second and related reason is that individuals as consumers regard \$1 worth of consumption now as being of greater value or utility than the same \$1 worth of consumption at a given time in the future. It should be noted that these \$1 values are expressed in real terms. In

nominal terms, present values would be preferred to an even greater degree by rational individuals than the same values in the future because of the effect of inflation. Therefore, the discount rate may be viewed as the price of postponing consumption to some future date, given that savings and investment are equivalent to and act as the vehicles for postponing present consumption.

To measure the economic cost or price of an activity, it is the opportunity cost which is relevant in economic analysis. The question then arises as to whether the rate of discount representing the opportunity cost of public investment should be preferred to the discount rate representing the postponement of consumption by society, i.e. the social rate of time preference. In an ideal economy, characterised by perfect competition, certainty, no transactions costs, no taxes, and no restrictions on credit, the two rates would be equal. Indeed, not only would market prices be a measure of opportunity cost in such an economy, but the consumption rate of interest (i.e. the marginal rate of time preference for individuals) would equal the marginal rate of return on investment, represented by the market rate of interest. Assuming each individual had the same consumption rate of interest, then the social rate of time preference would also equal the market rate of interest. In other words, evaluation of public investment using the NPV criterion could make use of the market rate of interest as the discount rate.

In the second-best world in which we live, however, BCA is not quite so straightforward. Market imperfections and constraints in the economy cause the allocation of resources to be sub-optimal. The presence of corporate taxes and personal taxes causes a marked divergence between the after-tax rate of return, which may be taken as a measure of the marginal rate of time preference, and the equivalent return which corporations must earn (i.e. the marginal rate of return on private investment) to yield that after-tax return. Lind (1982b, pp. 28-35) discussing this issue shows with a simple example that given a corporate tax rate of 50% and an average personal tax rate of 25% a private firm would need to earn at least 16% on its investment to yield an after-tax return of 6%. To the extent that 6% represents a risk-free return on say long-term government bonds, then private firms whose operations are necessarily risky in nature would require to earn an even higher return for typically risk-averse investors.

It may be concluded that with the present tax system there will be inevitably a gap between private rates of return on investment and the social rate of time preference or consumption rates of interest of individuals. It does not necessarily follow, however, that the opportunity cost of public investment is significantly higher than appropriate rates of time preference and hence that the relevant social rate of discount should also be correspondingly higher.

The crowding out of private capital investment is generally seen as a key issue in the choice of discount rate (Lind, 1990). But the

opportunity cost of public investment will depend on the type of private expenditure which is displaced, viz., consumption or investment expenditure.<sup>3</sup> Lind (1982b) argues that a lower rate of interest should be used for evaluating public investment that displaces consumption than for public investment which displaces private investment. He also makes a case for public investment in projects with a lower rate of return than the marginal rate of return in the private sector. To support his argument, Lind cites the following factors:

- the existence of corporate and personal tax rates, which result in divergence between the consumption rate of interest and the marginal rate of return in the private sector;
- the range of investments considered appropriate for government being restricted, with many of these yielding less than the marginal rate of return in the private sector; and
- effective, politically acceptable policies for increasing private investment to optimal levels not being available, i.e., private investment levels remaining sub-optimal as long as the prevailing tax regime continues.

Lind (1982b, p. 35) also argues that both consumption and investment will be displaced by public investment because the macroeconomic conditions required for a one-to-one displacement of private investment invariably will not be met. Given fixed corporate and personal taxes, and deficit financing, a one-to-one displacement will occur only if (a) there is full employment, (b) consumption is unaffected by changes in the interest rate and (c) money supply is adjusted to maintain equilibrium between the money market and the market for goods at the full employment level.

It may be concluded that the opportunity cost of public investment will generally be (but not always) a combination of displaced consumption and displaced investment. The view that the social rate of discount should be an appropriately weighted average of the consumption rate of interest and the marginal rates of return on private investment has wide support (Dasgupta and Maler, 1989, p. 237; Harberger, 1972; Lind, 1982b, p. 35; Marglin, 1963a, 1963b; Mishan 1976, ch. 40; Sjaastad and Wisecarver, 1977).

However, Feldstein (1964, 1972) opposes the use of a weighted average rate on practical grounds. He argues that the search for a 'perfect' formula to specify the social time preference rate is futile. In the presence of corporate and personal taxes, there is no single rate that can represent both time preference and opportunity cost. In addition, Feldstein observes that a social time preference function must

<sup>3</sup> Feldstein (1972) makes a distinction between the opportunity cost in the ideal situation and a predictive opportunity cost in the second-best situation by pointing out that the opportunity cost is not the value of resources in the best alternative to which these resources *could* be put, but the actual opportunity cost is their value in the alternative use to which they *would* have been put.

reflect public policy and social ethics as well as judgement about economic conditions.

A major problem is that neither the impact of public investment decisions on private capital formation, nor how government investment affects individual savings and investment decisions is fully understood (Lind 1982b, pp. 91-92). Lind acknowledges (p. 90) that '... to use the benefit-cost methodology in the policy process, we have to give up elegance, generality, and to some degree the pursuit of optimality.'

He goes on to point out (pp. 90-91) that 'the practical problem ... is that in a second-best world, where different projects may be undertaken under various sets of conditions and where risk is taken into account, it may well turn out that every project will require a different discount rate. This situation is simply not consistent with the practical requirements for the use of benefit-cost analysis' (see also James *et al.*, 1989; Lind, 1990). This issue also arises with optimal growth models. Different discount rates may be generated for different projects (Lind, 1990) and for different resources (Quiggin, 1992).

Thus, essentially there are two approaches which might be adopted for taking account of opportunity cost and risk:

- adjustment of the rate of discount; and
- adjustment of benefits and costs.

The adjustment of the discount rate to deal with uncertainty in assessing the long term benefits of resource use is an approach advocated for example by Gijsbers and Nijkamp (1988). The social rate of discount would vary over different time periods, different projects and different effects. However, Quiggin (1992) argues that this approach is particularly inappropriate when projects involve long-term environmental costs. This is an issue which is taken up again in the following sections.

Lind (1982b) concludes that for practical reasons it is preferable to adjust benefits and costs and to use a risk-free rate of discount. He states (p. 22) 'it can be demonstrated that the appropriate adjustments for risk and the opportunity cost of capital frequently cannot be made correctly by a straightforward adjustment in the discount rate' and concludes 'if the social discount rate were set equal to the social rate of discount in a riskless world then the opportunity cost and risk associated with a public investment could alternatively be accounted for by making the appropriate adjustments in the benefits and costs rather than further adjustments in the social rate of discount' (p. 22). This view is supported by James *et al.* (1989); Markyanda and Pearce (1988); and Pearce *et al.* (1989, ch. 6).

On this basis the approach proposed by Lind is to scale up that proportion of public expenditure which displaces private capital formation, using a shadow price of capital as the multiplier. The social rate of discount is set equal to the consumption rate of interest measured as the after-tax rate of return based on market securities

available to investors. Feldstein (1964, p. 247) also argues for use of the social time preference rate, on the basis that the social opportunity cost '*must also itself reflect the STP function*' (italics in original), and the use of a shadow price mechanism to allow for the social opportunity cost of funds.<sup>4</sup> In terms of practical evaluation, this approach possesses advantages over the alternative of adjusting the discount rate, and goes some way to defusing the debate over choice of discount rate. Scaling up costs would be broadly equivalent in impact on the NPV to increasing the discount rate  $r$ .

The use of the social time preference rate as the social discount rate encounters the practical problem of measurement. Marglin (1963a) observes that a private market rate is inadequate for measuring the time preferences of individuals and because of externality effects, has 'no normative significance' (see also Lind, 1990). Feldstein (1964, p. 247) also concludes that the social time preference rate cannot be derived on the basis of existing market rates, but 'must be administratively determined as a matter of public policy.'

An alternative approach taken by Kula (1984c) is to estimate empirically rates of social time preference. On the basis that 'risk of death appears to be the most powerful case for discounting future utilities' (p. 880; see also Feldstein, 1964; Munasinghe and Lutz, 1991, p. 32), he uses average annual mortality rates to generate average probabilities for survival. These are then used to derive social time preference rates for the United States and Canada.<sup>5</sup>

The proposal by Lind (1990) is perhaps more helpful for benefit-cost analysts seeking a readily available social discount rate. He proposes using the government's borrowing rate as the discount rate 'for most government projects', whilst for privately funded capital costs he recommends use of the 'appropriate private rate of interest'. This proposal is based on the observation that 'recent evidence' indicates 'one can make a strong argument that it is appropriate to analyze public investment and expenditure decisions as if they do not have a significant impact on investment through crowding out' (pp. S15-16).

Estimates to illustrate the impact of choice of discount rate and length of project life on NPV values are presented in Table 1. Two aspects are evident from the data in the Table. With a positive rate of

<sup>4</sup> Ritson (1977, p. 294), in advocating use of an STP rate, comments 'What meaning can be attributed to a decision which takes into account the welfare of unborn individuals in any way other than the collective concern of the present generation for the welfare of future generations (which can be thought of as welfare enjoyed by the present generation because of knowledge that future generations will receive some expected degree of satisfaction).' He suggests that 'the interests of future generations can be recognised by the use of a social time preference rate which is lower than market rates, and which reflects the present generation's view of the needs of unborn generations.' In the absence of the use of a shadow pricing mechanism for opportunity cost and risk, such a proposal may be regarded, however, as a further example of discount rate adjustment.

<sup>5</sup> Kula (1985) has also estimated a social time preference rate for Britain.



discount, the NPV declines at a constant proportional rate, with the absolute rate of decline decreasing over time. A second aspect is that NPV declines as the discount rate increases, with the decline again being at a constant proportional rate, and the absolute change decreasing as the discount rate increases. It can be seen that the combined impact of a high discount rate and a long time horizon on NPV is severe with a project life in excess of 30 years and a discount rate of 10% or more rendering the present value of distant benefits to be virtually zero. The data in Table 1 illustrate the validity of the observation by Dasgupta (1982, p. 278) that 'a positive rate of pure time preference tilts the balance overwhelmingly against generations in the distant future'.<sup>6</sup>

TABLE 1  
*Impact of Selected Discount Rates and Project Life on NPV of  
\$1000 Payable at End of Project*

Project Life (years)	Discount Rate			
	0%	5%	10%	15%
	\$	\$	\$	\$
20	1000	377	149	61
30	1000	231	57	15
40	1000	142	22	3
50	1000	87	9	1
100	1000	8	0.07	–

Up to this point in the paper, the focus has been on the goal of efficiency in the allocation of resources. In this context it has been concluded that the social rate of discount to be used in evaluation of public investment projects should be at least as high as the marginal rate of time preference (MRTP). If the social discount rate is adjusted for opportunity cost and risk, it may be substantially higher. A second conclusion has been that use of such a positive social discount rate (either MRTP or the adjusted rate) discriminates against future generations and that investment decisions based on the NPV criterion will favour shorter-term projects over longer-lived projects which generate the same undiscounted total benefits.

<sup>6</sup> In this sense, discrimination can be interpreted as the biasing of choice towards projects which generate benefits for the present generation. An anonymous reviewer has offered two alternative meanings of discrimination. One is that a positive discount rate disenfranchises future generations; the other that it reduces the consumption set of future generations. The latter is not of course a necessary outcome of efficient discounting by the present generation, whilst the former is consistent with the view taken here. It is not clear how future generations can be enfranchised however. This reviewer also makes the interesting observation that the composition of future generations is a function of the present generation's policies (Parfit's paradox), and perhaps reinforces the view that the rights of future generations must be determined in any case by the current generation.

Nevertheless, the use of a positive discount rate for achieving the efficiency goal cannot be faulted. To quote Sharefkin (1982, p. 320) 'Not wanting to discount is, in a sense, like a government not wanting to have a fiscal policy — a logical impossibility'. This view is supported by Chisholm (1986), Kirby and Blyth (1987) and Pearce *et al.* (1989) who argue strongly in favour of a positive discount rate. The critical question is whether an efficiency-based approach to the choice of discount rate can accommodate the goal of intergenerational equity.

### *The Issue of Intergenerational Equity*

Intergenerational equity is concerned with fairness and justice between generations (see Rawls, 1971), and is frequently used interchangeably with sustainable development (Pezzey, 1989). Definitions of intergenerational equity relate to maintenance between generations of welfare or utility, typically expressed in terms of per capita consumption, or endowment of resources or capital stock (for a review, see Pezzey, 1989, Appendix 1). Solow (1986) for example, building on the work of Hartwick (1977, 1978a, 1978b) and Solow (1974) shows that the maintenance of a constant consumption stream is, with appropriate assumptions including the re-investment of rents from extraction of exhaustible resources, equivalent to the maintenance of a constant asset base (see Perrings, 1991; Quiggin, 1992 for further discussion).

The allocation of resources between generations is clearly a distributional question which inevitably involves ethical values. Solow (1986, p. 141) poses the 'basic' question 'how much of the world's — or a country's — endowment of nonrenewable resources is it fair for the current generation to use up, and how much should be left for generations to come who have no active voice in the contemporary decisions?' He goes on to comment (p. 142) that such a question is 'dangerously narrow' since the current generation does not 'especially owe its successors a share of this or that particular resource'. The composition of the intergenerational bequest, Solow claims, is 'more a matter of efficiency than equity', although he makes an exception in the case of the preservation of natural beauty which is 'more a question of direct consumption than of instrumental productive capacity'. He concludes that 'recognition of substitutability or fungibility converts a matter of "simple justice" into a complicated question of resource-allocation.' The issue of substitution lies at the heart of the intergenerational equity and sustainability debate because it impinges directly on the nature of the compensation which the current generation makes to future generations for resource use and depletion.

There is a view that we need not be overly concerned with the interests of future generations since future generations will be far better off materially than the present generation. Mishan points out (1976, p. 200) 'this would be so even if the rate of net investment were to fall to zero provided technological innovation, which is chiefly responsible for per capita growth in economically advanced countries,

continued into the future'. Sweeney (1982, p. 309) makes a similar point in stating 'Only a relatively small rate of technological progress is needed to insure against doom in the economy'. Rosenberg (1976, p. 280) takes up this theme by observing that 'the potential flexibility and adaptability of advanced industrial economies is vastly underestimated' and refers to the 'dynamic interactions between technological change and natural resources' and 'the whole range of additional adaptations which are a mixture of pure technological change, redesigning and substitution.'<sup>7</sup>

Although critics of the 'Doomsday School', exemplified by Meadows *et al.* (1972), effectively countered the naive concerns about resource depletion, (see Lloyd, 1980 for references), by pointing to factors such as technical progress, factor substitution, exploration and greater efficiency as responses to price incentives arising from increasing scarcity, Quiggin (1992) identifies a number of positive outcomes from the Limits to Growth debate — the shift of attention from resource depletion to the absorptive capacity of the planet to assimilate waste and the increased prominence given to distributional issues, particularly inter-generational equity, and the gap between rich and poor nations. It is in this context that Lind (1982a, p. 13) rejects the view that future generations will be wealthier because of technical progress. Resource depletion, major environmental degradation and the impact of wastes, effluent and residues 'have dampened our optimism about the prospects of future generations. We no longer believe that they, necessarily, will be wealthier than we are'. Whilst research and development has the potential to produce substitutes for the depleted resource base, R and D with only distant benefits will not be economic under BCA. In addition, the BCA criterion does not seem appropriate for evaluating an option which imposes catastrophic environmental costs in the distant future because a very low weight would be placed on such a consequence.

To analyse the issue of the intertemporal allocation of resources, Solow (1986, p. 142) proposes the standard optimal growth model as a 'natural vehicle for an economics theorist' (see also Industry Commission, 1991, p. D32). Whilst this approach has been useful in providing 'intuitively appealing "rule of thumb" policy implications' (Jayasuriya, 1992), including the efficient investment of resource rents (the Hartwick rule), the lack of empirical realism of the assumptions has attracted criticism.<sup>8</sup>

<sup>7</sup> Rosenberg also comments that 'the main tradition in economics has never paid extensive attention to technological change' (1986, p. 19), and 'most thinking about the role of natural resources in economic growth continues to be excessively static' (1976, p. 280).

<sup>8</sup> The Industry Commission (1991) for example expresses the view that the simplification and information requirements of optimal growth models are so burdensome that conclusions can only be considered robust in their most general form. For an attempt to overcome these problems using optimal control techniques, see Chapman, 1987.

The assumption of substitutability between natural and reproducible (man-made) capital has been perceived as a major limitation, and implies that natural resource stocks could be 'driven to a tiny fraction of their current levels without reducing human welfare' (Perrings, 1991). In addition, the treatment of risk and uncertainty is viewed by Quiggin (1992) as unsatisfactory, whilst Barbier (1989) draws attention to the narrow focus of conventional optimal growth analysis. He suggests (p. 87) a broader view is needed to encompass not only depletion but also degradation, pollution and the provision of essential services. Three key environmental functions need to be considered — the provision of materials and energy, the assimilation of waste and the provision of essential consumptive and productive services, e.g. recreation, life support, ecological and climate maintenance, and biodiversity, which are mainly non-market and characterised by discontinuous threshold effects. The work of Krautkramer (1985, 1986) and Maler (1974) has broadened the conventional approach by incorporating environmental preservation and environmental quality, but a more comprehensive approach is required which integrates the economic and environmental systems (Barbier, 1989, p. 94).

Common and Perrings (1992) comment that the Hartwick rule is 'less a criterion for sustainable development than a condition for the efficiency of intertemporal resource allocation'. They conclude that the conditions for Solow sustainability and those required for ecological stability are 'largely disjoint', and suggest that the role and rights of present individuals must be circumscribed by the requirements of the ecological system where the latter are threatened by the former. This tension between global and local rights is exemplified currently by the debate on ozone depletion and climate change.

The limitations of the optimal growth approach have led Pearce *et al.* (1989) to extend the intertemporal equity criterion (that capital stocks should not be reduced) to apply to stocks of environmental resources at a disaggregated level in recognition of the limited degree of substitutability between man-made capital and many forms of natural resources. Such disaggregation opens the possibility for the insights of the optimal growth and sustainability literature to be applied at the project evaluation level, and perhaps a basis to respond constructively to the question of the adequacy of benefit-cost analysis to encompass intergenerational equity concerns, and in particular the role of the discount rate.

The question of equity raises a series of distributional and ethical issues which are ignored by the efficiency criterion embodied in BCA, which in turn is based on the Pareto efficiency criterion of utilitarian welfare economics. To quote Sharefkin again (1982, p. 320) 'Pareto efficiency may be an inappropriate restriction in computing discount rates appropriate to fair intertemporal plans'.

The inadequacy of utilitarian welfare economics to address equity issues is effectively illustrated by Sen (1982, p. 346) using an example

of the potential Pareto improvement criteria applied to torture.<sup>9</sup> Sen concludes that the evaluation of investments and the choice of relevant social discount rates requires a deliberate ethical exercise. It is not sufficient merely to undertake BCA. This view is supported by Dorfman (1982, p. 358) and Lind (1982c, p. 457). The question then arises whether the BCA approach can be refined or adjusted to take account of inter-generational equity concerns.

Given that a positive discount rate discriminates against future generations, Lind (1982a) poses the question (p. 12): 'if we were egalitarian among generations living now and in the future, wouldn't this require that we use a zero rate of discount in benefit-cost analysis?'. In addressing this question Mishan (1976) takes an affirmative stance (p. 209): 'whenever inter-generation comparisons are involved, as they may be in determining the rate of depletion or destruction of a non-renewable asset, it is as well to recognise that there is no satisfactory way of determining social worth at different points in time. In such cases a zero rate of time preference, though arbitrary, is probably more acceptable than the use today of existing individual's rate of time preference or of a rate of interest that would arise in a market solely for consumption loans'. The use of a zero discount rate in evaluating long-lived projects to avoid disadvantaging future generations is also supported by Ramsey (1928) and Hatch (1985).

Mishan (1976) however qualifies his position in discussing the evaluation of a project to establish a national park (pp. 284-285). He sees no justification for discounting future benefits to be enjoyed by generations to come in the exceptional case where the land in question has no alternative use. 'If on the other hand, there are indeed alternative uses for the piece of land, or if resources have to be diverted from the production of other goods in order to create a desirable park the case is otherwise'. Mishan goes on to recommend use of the private yield on investment as the appropriate rate (p. 285).

This apparent confusion may however be explained by returning to the distinction between issues of efficiency and equity. It seems clear

<sup>9</sup> Sen's example is reproduced as follows:

Given  $W_h(t), W_h(s), W_i(t), W_i(s)$   
 where  $W$  = level of welfare or utility  
 $h$  = heretic  
 $i$  = inquisitor  
 $t$  = social state with torture  
 $s$  = social state without torture

then the social state  $t$  with torture will make  $h$  worse off, and  $i$  better off than the social state  $s$  without torture i.e.  $W_h(t) < W_h(s)$  and  $W_i(t) > W_i(s)$ . But suppose  $W_i(t) - W_i(s) > W_h(s) - W_h(t)$ , i.e. the torturer gains more than the heretic loses from being tortured. Under the potential Pareto improvement criterion, torture would be supported.

that Mishan (1976) was addressing the efficiency question in relation to the national park evaluation, whilst his comment on inter-generational comparisons is directed to the question of equity.

In the context of environmental resources, the issue of irreversible change provides an extreme example of intergenerational inequity. Accepting that BCA with a positive discount rate is not appropriate for dealing with distributional issues, then we may ask whether BCA with a zero discount rate could be used for evaluating projects or activities involving irreversible change. In so far as the stream of benefits and costs can be measured, and to the extent that future generations are not discriminated against by use of a zero discount rate, then this may be a possible option. However, there is no or only very limited information on the values which will be held by the next generation, far less subsequent generations<sup>10</sup> and that a zero discount rate is, as Mishan observes, an arbitrary choice. Page (1977a, p. 152) for example argues that a zero discount rate is not necessarily egalitarian because of productivity growth, and that if the discount rate is set equal to the rate of productivity growth, then the optimal growth of consumption through time is 'totally egalitarian'.

The use of a zero discount rate in effect provides an extreme example of adjusting the discount rate. The earlier discussion on adjusting the discount rate to account for risk and uncertainty applies with equal force to proposals to adjust the discount rate for reasons of equity or environmental resource preservation. However, this has not deterred analysts from making such proposals — see for example Gijssbers and Nijkamp (1988).

One approach which has been presented and elaborated on in a series of papers by Kula (1981, 1984a, 1984b, 1985, 1986) has been labelled the sum of discounted consumption flows (SDCF). The SDCF approach applies a modified discounting procedure to the stream of benefits and costs over the life of a project. The modification is based on the premise that individuals in the population who receive benefits from the project will not discount future benefits before they are born, and hence different discount factors  $(1/(1+r)^t)$  will apply to new recruits to the population over time, compared with the individuals living at the date of commencement of the project. For computational purposes, individuals in the population are grouped by age cohort and a weighted average discount factor computed for each year. Population composition projections for future years are derived on the basis of life expectancy data. The weighted average discount factor for each year is then used to discount the estimated net benefits for that year, and the discounted net benefits are summed over the life of the project. The social discount rate used is a social time preference rate. Each

<sup>10</sup> Dasgupta and Maler (1989, p. 236) in acknowledging that the preferences of future generations are unknown, comment that 'this is a problem we have to live with, quite irrespectively of the discounting procedures'.

generation is treated equally using the SDCF approach, Kula claims, and hence the discriminatory approach of BCA is avoided. A graphic comparison of the discount factors  $(1/(1+r)^t)$  for each of the BCA and SDCF approaches corresponding to the estimates presented in Table 1 for a 10% discount rate, is shown by Kula (1984a) and the difference between the two is labelled the 'discrimination gap'. The discrimination gap represents the difference in the values of the discount factor used in BCA for each year in the life of the project and the corresponding discount factor used in SDCF. The difference reflects the fact that for SDCF, discounting for new recruits to the population commences only from the date of entry to the population rather than from the date of the commencement of the project, as in BCA. The outcome is that the NPV computed under SDCF will be larger than under BCA, and longer-lived projects in particular will be more favourably treated.

The approach developed by Kula is a highly innovative attempt to examine simultaneously the efficiency and equity issues in project evaluation. Inevitable assumptions are made about the value sets of individual members of future generations. Essentially these are set equal to those of the present generation, just as for BCA. A potential problem with the SDCF approach is the heavy data requirement for identifying those members of society who will benefit from a project, and how that group's composition will change over the life of the project. It is also not clear that the SDCF approach provides an adequate analysis of both the equity and efficiency issues.<sup>11</sup> From society's viewpoint, the goal of efficient resource allocation requires only the selection of projects which will generate the maximum net benefits to society. The use of opportunity cost measures will ensure that the evaluation procedure achieves this goal for a given point in time. The distribution of benefits among the individuals who make up the population now and in the future has been viewed conventionally as an equity question and has been considered separately from the efficiency question. Age is not the only factor which enters the equity calculus. Other factors such as income and wealth and the identification of gainers and losers are also usually deemed to be important. To the extent that BCA is consistent with the efficiency criterion it would be preferred to the SDCF approach because it is less demanding of data. Similarly, to the extent that equal treatment of generations is desirable in evaluating the net benefits of a project, the use of a zero discount rate will achieve that aim and is again less demanding of data than SDCF. On the other hand, resolution of the equity question requires more information than is provided by SDCF.

<sup>11</sup> An anonymous reviewer (see also footnote 4) notes that the SCDF has unusual ethical properties in that a society seeking to maximise the present value of future consumption will choose an extreme pro-natalist policy — maximising the birth rate and eliminating all people beyond reproductive age, subject to competition for human resources between child rearing and production of goods and services.

A more serious criticism, which applies to all proposals for lowering the discount rate with the intention of reducing discrimination against future generations, is that the outcome will be to undermine the achievement of the efficiency and equity goals. At the stroke of a pen, a lower or zero discount rate will make a range of development projects economically viable which previously, under an appropriate higher discount rate, would not have been undertaken. In addition, Pearce *et al.* (1989) observe that such an outcome is likely further to degrade the environment and hence use of lower discount rates will be counterproductive to the goal of inter-generational equity. Common (1988, ch. 8) provides an example in which it is demonstrated that lowering the discount rate can increase the net present value of an environmentally damaging project. In other words, modifying the discount rate in this way will tend to worsen rather than improve the situation.

An alternative is to view the underlying problem as one of valuation rather than of discounting (Industry Commission, 1991, p. D32). Dasgupta and Maler (1989, p. 236) for example comment that if the environment has a very great value for the current generation, that will be reflected in the value of the benefits. Presumably, this valuation would reflect the desire of the current generation to bequest to future generations a certain level and quality of environmental resources.

More typically however, the benefits and costs associated with irreversible change in environmental resources cannot be measured because they are unpriced, or because estimates of value in terms of willingness to pay to preserve the resource in question are not available.<sup>12</sup> In such a situation, Bishop (1978) has advocated that a safe minimum standard (SMS) be adopted for the renewable resource in question. In other words, the benefit of the doubt should be given to preservation and against the alternative involving irreversible change, unless the social cost is unacceptably high (see also Chisholm, 1986, p. 16). Such an approach is consistent with the conservative approach implied by the concept of quasi option value in the environmental economics literature, and the 'basic insight' that 'continued preservation is more likely to be optimal if the passage of time can be expected to yield more information about the resource preserved' (Clarke, 1991, p. 8).

The SMS approach may be viewed as in accord with the desire of individuals to leave a minimum legacy for their offspring and would be equivalent to applying a constraint on the goal of efficient resource allocation. Such a proposal is also clearly in accord with the views of Sen (1982) and Dorfman (1982) that ethical decisions cannot be avoided to resolve issues of this kind. The SMS approach, however,

<sup>12</sup> For a review of approaches to measuring willingness to pay for unpriced environmental resources, see Pearce *et al.* (1989, ch. 3) and Young, R. (1992).



represents 'a philosophy rather than a specific evaluation procedure since it provides, at best, only an incomplete decision criterion' (Clarke, 1991, p. 49; see also James *et al.*, 1989). For example, strict application of SMS may have prevented the industrial revolution and the development of modern commercial agriculture because of species extinctions and habitat destruction, and Clarke (1991, p. 54) wonders whether such developments were 'unambiguously a mistake'. Unconvinced, he suggests (p. 55) a 'better general approach may be to use conventional cost-benefit analysis . . . but to impose constraints on the choice set which rule out particularly risky options.' Examples cited include 'the establishment of wilderness reserves, quotas on pollution emissions and other types of restrictive quotas (perhaps based on biological rather than specifically economic information) which guarantee that resource use will not exceed threshold levels where catastrophic effects are anticipated.'

Pearce *et al.* (1988, 1989) also advocate a constrained maximisation approach to resource use choices by application of weak or strong sustainability criteria. Under the weak sustainability criterion, the discounted PV of the sum of environmental damage across a set of projects making up a program would be required to equal zero or be negative on the basis that it would not be feasible for such a constraint to be applied to each project. For the strong sustainability criterion, environmental damage is constrained to be non-positive for each project *and* for each period of time.

The sustainability criteria are thus incorporated in the BCA as side constraints. Pearce *et al.* (1989, p. 128) attempt to give an operational definition of sustainable development in terms of maintaining the capital base. The BCA formula which might then be applied to a portfolio of *i* projects would become:

$$\sum_t \sum_i (B_{it} - C_{it} - E_{it}) \cdot (1 + r)^{-t}$$

$$\text{s.t. } \sum_j PV(A_j) \geq \sum_i PV(E_i) \text{ for } E_i < 0$$

in the case of the weak sustainability constraint;

$$\text{or } \sum_j A_{jt} \geq \sum_i E_{it} \text{ for all } t \text{ and all } E_i < 0$$

in the case of the strong sustainability constraint

where: *E* are environmental costs or benefits  
( $E_i < 0$  are environmentally depleting projects); and

$A_j$  is the value of the *j*th environmentally compensating project.

If the net benefits of a program of development projects are positive and some of the projects in the program incur environmental damage, then compensation would be required in the form of environmentally enhancing projects.

As an exercise in constrained optimisation, the computational and data problems may present major barriers to practical application of these criteria, even if all variables including constraints can be ex-

pressed in value terms (see Pearce *et al.*, 1988).<sup>13</sup> For practical evaluation purposes, it seems likely that a number of sustainability constraints will be required to represent the sustainability/inter-generational equity goal, and that one or more of these will be expressed in physical rather than value terms. If inter-generational equity, for example, is expressed in terms of maintenance of the capital asset base, then a number of overlapping dimensions to that base can be described. These include renewable and non-renewable resources, natural and man-made capital, and global and local environmental resources. The constraints by which each of these would be represented are likely to differ and will vary between projects. Given that a general equilibrium approach may not be feasible, it may be necessary to order the constraints hierarchically to make a BCA operational, although as Hoehn and Randall (1989) point out, component benefits are not unique and vary with the valuation sequence. In other words, the value of benefits will be influenced by the priority ordering of the constraints.

In the case of depletable resources, there is the possibility of applying the Hartwick rule. An attempt is made by Mikesell (1989) to make it operational as a way of achieving the goal of inter-generational equity in a BCA framework.<sup>14</sup> The depletable component of the resource rent is re-invested to avoid capital consumption and is defined by Mikesell (p. 293) as 'the difference between the present value of the annual net revenues assumed to continue *ad infinitum* and the present value of the annual net revenues to the termination of the project'. This definition of exhaustion rent does not explicitly take account of substitutes for the non-renewable resource, and the values referred to will presumably reflect the presence or potential of such substitutes. Lloyd (1991) cites induced innovation and backstop technology as determinants of exhaustion rent, while Krautkramer (1986, p. 146) comments that 'the survival of the economy and the optimality of permanent preservation will depend upon continuing flows of substitute inputs for the non-renewable resource from either backstop technologies or renewable resources'.

The constraint of not reducing the capital asset base implies the need to maintain an inventory of non-renewable resources and encounters

<sup>13</sup> In a recent analysis, Hoehn and Randall (1989) demonstrate that conventional BCA systematically overstates net benefits. This is because, in practice, the productive capacity of an economy imposes a bound on the valid measure of net benefits over all proposals and this bound is not taken account of in conventional BCA since BCA proposals are typically evaluated independently of each other. In citing the example of species preservation, Hoehn and Randall (p. 550) point to 'the nontrivial benefits for each of a limited number of representative species' and the fact that there are 'literally hundreds of thousands of species in danger of extinction'. To overcome the problem of bias, they suggest a coordinated approach to BCA evaluation is necessary.

<sup>14</sup> Surprisingly, Mikesell makes no reference to the optimal growth literature in his paper.

the historical experience of resource substitution, a factor which has been effectively used to counter the predictions of the so-called Doomsday School (see Lloyd, 1980). Lloyd (1991) questions the value of generating such an inventory, particularly because many resources which may possess significance in fifty or more years have not been identified yet as being resources, and cites the case of bauxite, for which a wide range of mineral clays now substitute in the production of aluminium. Such a view, however, is in conflict with the advocates of natural resource accounting (see, for example, Repetto, 1988; Australian Bureau of Statistics, 1990; and Young, M. D., 1990) who argue the need for such an inventory to help avoid the inclusion in national measures of welfare of items of income which are in fact capital consumption, e.g. natural resource depletion.

For most environmental resources there is a dearth of data on the status of such resources, far less what constitutes a sustainability criterion or standard. A major scientific effort will be required to resolve this problem.<sup>15</sup> However, at least conceptually, one might proceed to evaluate projects in a staged analysis. The first stage could be devoted to the identification of relevant sustainability constraints, and the second stage might be the identification of the efficient set of projects which pass the sustainability criteria.<sup>16</sup> Quiggin (1992, p. 14) observes that such procedures 'are far from meeting the prescriptions of optimal development theory', but concedes that 'in most, though not all, cases, these modifications will move the outcome closer to the optimum'.

Pending the resolution of data and computing problems, there may be little choice other than to opt for compensating policy adjustment.<sup>17</sup> Compensating policy adjustment essentially amounts to adopting a rights approach for looking after the interests of future generations. The National Conservation Strategy of Australia (1983) advocates a stewardship role by the present generation in managing environmental resources. Such a role provides an affirmative response to the question raised by Sen (1982, p. 344): 'Do future generations have a *right* to enjoy natural resources that the present generation is depleting rapidly?'

In this context, Page (1982, p. 375) makes the plea: 'If we could define environmental rights for future generations and if our energy and other long term planning were designed to protect these rights,

<sup>15</sup> The ESD process initiated by the Commonwealth government and the work on the enhanced greenhouse effect by the Intergovernment Panel on Climate Change (see Industry Commission, 1991, Appendix C for references) provide examples of what is currently being done.

<sup>16</sup> Page (1977b) proposes a procedure which deals with the two stages in the reverse order to that suggested here.

<sup>17</sup> In similar vein, Young, M.D. (1992) refers to a search being on for 'overlapping consensus about the types of social and economic policies that promote sustainable forms of investment and resource use.'

then, I think the criticism of discounting, on the grounds of intertemporal equity, would largely disappear'. He makes the qualifying observation that 'A rights approach does not mean that we abandon discounting; it simply means we have a place for both'.

The adoption of this type of approach amounts to the application of a policy constraint on traditional project evaluation. In terms of confronting the inter-generational equity issue this would amount to taking the 'deliberate ethical' decision referred to earlier. Given that the Australian Commonwealth and State Governments, with the exception of Queensland, have endorsed the National Conservation Strategy of Australia, there exists an in principle demonstration of the ethical decisions having been made. In the case of the Murray-Darling Basin, the Ministerial Council for the Basin has explicitly announced resource management goals relating to conservation of environmental resources and preservation of sensitive ecosystems. The more recent ratification of the Montreal protocol on ozone depletion, the adoption of an interim planning target to stabilise emissions of greenhouse gases, subject to no net adverse economic impacts, and various other initiatives at Commonwealth and State levels (see Industry Commission, 1991, Appendix B) provide substantial signs that the interests of future generations are not being ignored and that the stewardship role is being taken seriously.

The adoption of explicit sustainability criteria to circumscribe pursuit of the efficiency goal as well as a compensating policy adjustment approach amount to acknowledgement that the efficiency and equity goals need to be addressed separately. The use of multiple objective or criteria models thus provide a further framework for considering project evaluation in the context of the efficiency and equity goals (Munasinghe and Lutz, 1991, pp. 27-31; Resource Assessment Commission, 1992). Indeed, the idea of treating equity and efficiency as dual criteria is by no means new. Little (1950) proposed a Pareto test and a distribution test for the economic criterion and the non-economic criterion respectively. The adaptation of the scoring framework developed in CSIRO for research priority assessment as discussed by Young, R. (1990) provides a relevant example.

More generally, Clarke's exhortation (1990, p. 58) that resource conservation issues should not be avoided because they are 'complex and profoundly ambiguous with ethical and empirical problems compounding each other', and that 'the imperative of reaching decisions does not justify substituting philosophical speculation for difficult and inconclusive analysis' seems particularly appropriate and worthy of support. Whilst such a situation may be perceived as implying a reduced role for professional economists in the decision making process, there are in fact likely to be major opportunities available for those wishing to widen their horizons and to work in collaboration with professionals from other disciplines.

### *Concluding Comments*

Despite unresolved questions relating to the use of BCA, there is widespread acceptance of the usefulness of BCA for assessing economic efficiency in project evaluation. 'In short, benefit-cost analysis is not a precise tool but rather, is a crude tool that can identify projects that are clearly losers or winners' (Lind, 1982b, p. 88). Where the economic decision is not clear, 'it is perhaps appropriate that the decision be made on political grounds'.

On the question of inter-generational equity, Lind (1982c) points out that 'benefit-cost analysis by itself has never been a tool for resolving issues of equity' (p. 457). The ethical question is unavoidable and information additional to that provided by BCA is required.

On the basis of the assessment of the approaches canvassed earlier, some conclusions may be drawn about their usefulness in analysis. Of the approaches involving a modified or adjusted discount rate, including the use of a zero rate of discount, there appears to be broad agreement that an adjusted rate is not appropriate for analysing *efficiency* questions related to project evaluation. There seems to be a fair degree of agreement that the discount rate should be represented by a social time preference rate, and that a shadow pricing mechanism should be used to take account of factors such as opportunity cost, and risk and uncertainty. The social time preference rate might be measured by the relevant government borrowing rate.

An appropriately adjusted rate may have potential merit *a priori* for examining *equity* questions because discrimination against future generations in benefit-cost comparisons seems to be avoided. Such a rate does not ensure, however, that the bequest of resources to the next generation is of equivalent quantity and quality to that enjoyed by the present generation and hence its application in relation to issues of inter-generational equity is of doubtful validity.

The adjustment of the net benefits stream appears in principle to be a viable alternative to adjusting the discount rate. It was pointed out earlier that the scaling up of costs to account for risk and opportunity costs was equivalent to increasing the discount rate for the same purpose. Similarly, the net benefits could be scaled up in a manner equivalent to reducing the discount rate to allow for inter-generational equity. The absence of any concrete basis for a scaling-up factor, however, would place heavy reliance on sensitivity analysis without any clear prior guideline as to which alternative is preferable. The observation that the problem is one of valuation rather than discounting may assist in giving greater credibility to BCA, but the focus is still the efficiency goal. More accurate valuation of environmental resources will not avoid the fact that discounting discriminates against future generations, and hence the equity problem is not directly confronted.

The option of adopting a safe minimum standard (SMS) applies most clearly to preservation cases and situations of irreversibility. The

approach advocated by Bishop (1978) does not specify any explicit evaluation of benefits and costs. However, the constraining contingency of unacceptable social cost implies the necessity of undertaking project evaluation. Randall (1985) advocates the application of the SMS logic to every preservation issue with the qualification that decisions be made with full cognisance of the opportunity costs of maintaining SMS and the results be made public. Essentially, the SMS approach can be viewed as a constrained BCA approach in the sense that BCA in the context of the efficiency goal should be applied to preservation issues, subject to the constraint that the SMS level be maintained. An ethical judgement is required to resolve the equity question of whether the SMS will actually be adopted.

A further approach under the constrained BCA option is the application of sustainability criteria as proposed by Pearce *et al.* (1988, 1989) and others. At the present time, it seems unlikely that the data demands and the computational requirements will easily be met in an optimisation framework. A more feasible approach may be to specify that an ecologically sustainable environment is a binding goal or constraint on the pursuit of an economically efficient maximum. In choosing amongst resource use options, sustainability criteria could be applied in a pragmatic way, for example, by adjusting a program of investments which has met the extended BCA criterion such that overall net environmental damage is as close to zero as possible, as a result of adopting into that program particular projects which generate environmental benefits to offset any damage which is incurred. Until agreed standards or rules on sustainable resource use and relevant supporting data become available, this more pragmatic approach is essentially equivalent to a compensating policy adjustment approach under which rights are assigned either explicitly or implicitly to future generations, and efficiency outcomes are circumscribed by the results, for example, of environmental impact assessments. This type of approach approximates some of the resource-use, decision-making processes currently in place.

To move to a more informed process of decision making, priority will need to be given to the collection of primarily non-economic data. There are encouraging signs from the recent inquiry concerning resource use conflicts in the forests of southeastern Australia by the Resource Assessment Commission (1991) that the community is prepared to be persuaded by well-presented hard data. To take the further step of identifying optimal outcomes will require a major advance in modelling techniques. Again there are encouraging signs with the planned development of a dynamic model of the economy such as the Monash model<sup>18</sup> to encompass technological and environ-

<sup>18</sup> A team led by Professor Peter Dixon, Director of the Centre of Policy Studies at Monash University, is currently developing the Monash model, a dynamic successor to the ORANI model.

mental components, and the prospect of links with complementary modelling efforts such as the refinement of the MENSA model by the Australian Bureau of Agricultural and Resource Economics.<sup>19</sup>

In the meantime, for purposes of empirical analysis, there would seem to be no alternative to continuing to examine the goals of efficiency and equity separately. For decision making, the two issues should of course be considered together. Weighing one against the other is an ethical responsibility which lies with the decision maker. The responsibility of the analyst is surely to make the decision maker as fully informed as possible by contributing to and guiding rather than pre-empting the decision which is ultimately made.

### References

- Australian Bureau of Statistics (1990), 'Natural Resource and Environmental Accounting in the National Accounts', in *Australian National Accounts, National Income and Expenditure*, Cat. No. 5206.0, Australian Bureau of Statistics, Canberra.
- Barbier, E. B. (1989), *Economics, Natural Resource Scarcity and Development: Conventional and Alternative Views*, Earthscan, London.
- Bishop, R. C. (1978), 'Endangered Species and Uncertainty: The Economics of a Safe Minimum Standard', *American Journal of Agricultural Economics* 60(1), 10-18.
- Bockstael, N. E. and Strand, I. E. (1985), 'Distributional Issues and Nonmarket Benefit', *Western Journal of Agricultural Economics* 10(2), 162-169.
- Chapman, D. (1987), 'Computation Techniques for Intertemporal Allocation of Natural Resources', *American Economic Review* 77, 134-42.
- Chisholm, A. H. (1986), 'Sustainable Resource Use: Uncertainty, Irreversibility and Rational Choice', paper presented at Fourth World Congress of Social Economics, Toronto, 13-15 Aug.
- Christensen, P. P. (1989), 'Historical Roots for Ecological Economics — Biophysical versus Allocative Approaches', *Ecological Economics* 1(1), 17-36.
- Clarke, H. R. (1991), 'Risk, Uncertainty and Irreversibility: Implications for Sustainable Development', paper prepared for Intersectoral Issues: Second Technical Workshop, Ecologically Sustainable Development Working Groups, ANU, Canberra.
- Common, M. (1988), *Environmental and Resource Economics: An Introduction*, Longman, London.
- Common, M. and Perrings, C. (1992), 'Toward an Ecological Economics of Sustainability', *Ecological Economics* 6, 7-34.
- Cory, D. C. (1985), 'Income-Time Endowments, Distribution Equity and the Valuation of Natural Environments', *Western Journal of Agricultural Economics* 10(2), 183-186.
- Dasgupta, P. (1982), 'Resource Depletion, Research and Development, and the Social Rate of Return', in R. C. Lind *et al.*, *Discounting for Time and Risk in Energy Policy*, Resources for the Future Inc, Washington DC, 273-305.
- Dasgupta, P. and Maler, K-G. (1989), 'Social Cost Benefit Analysis and Soil Erosion', ch. 13 in F. Archibugi and P. Nijkamp (eds), *Economy and Ecology: Towards Sustainable Development*, Kluwer, Dordrecht, 221-259.
- Dorfman, R. (1982), 'Comment', in R. C. Lind *et al.*, *Discounting for Time and Risk in Energy Policy*, Resources for the Future Inc, Washington DC, 354-358.

<sup>19</sup> The MENSA model is a multiperiod linear programming model of the Australian energy sector which has been used, for example, in the analysis of issues associated with climate change (Jones, 1991, 1992).

- Feldstein, M. S. (1964), 'The Social Time Preference Discount Rate in Cost-Benefit Analysis', *Economic Journal* 74, 360-79, reproduced in R. Layard (ed.), *Cost-Benefit Analysis*, Penguin, Harmondsworth, England, 245-69.
- Feldstein, M. S. (1972), 'The Inadequacy of Weighted Discount Rates', in R. Layard (ed.), *Cost-Benefit Analysis*, Penguin, Harmondsworth, England, 311-32.
- Ferejohn, J. and Page, T. (1978), 'On the Foundations of Intertemporal Choice', *American Journal of Agricultural Economics* 60(2), 269-75.
- Friend, A. M. (1990), 'Economics, Ecology and Sustainable Development: Are They Compatible?', Institute for Research on Environment and Economy, Ottawa, mimeo.
- Gijsbers, D. and Nijkamp, P. (1988), 'Non-Uniform Social Rates of Discount in Natural Resource Models: An Overview of Arguments and Consequences', *Journal of Environmental Systems* 17(3), 221-35.
- Harberger, A. C. (1972), 'The Opportunity Costs of Public Investment Financed by Borrowing', in R. Layard (ed.), *Cost-Benefit Analysis*, Penguin, Harmondsworth, England, 303-10.
- Hartwick, J. (1977), 'Intergenerational Equity and the Investing of Rents from Exhaustible Resources', *American Economic Review* 66, 972-4.
- Hartwick, J. (1978a), 'Substitution among Exhaustible Resources and Intergenerational Equity', *Review of Economic Studies* 45, 347-54.
- Hartwick, J. (1978b), 'Investing Returns from Depleting Renewable Resource Stocks and Intergenerational Equity', *Economic Letters* 1, 85-88.
- Hatch, J. (1985), 'The Management of Living Resources: The Economist Friend or Foe?' in *Conservation and the Economy Conference 1984, Summary Report and Proceedings*, Australian Government Printing Service, Canberra.
- Hoehn, J. P. and Randall, A. (1989), 'Too Many Proposals Pass the Benefit Cost Test', *American Economic Review* 79, 544-51.
- Industry Commission (1991), *Costs and Benefits of Reducing Greenhouse Gas Emissions*, Draft Report, Canberra.
- James, D. E., Nijkamp, P. and Opschoor, J. B. (1989), 'Ecological Sustainability and Economic Development', ch. 3 in F. Archibugi and P. Nijkamp (eds), *Economy and Ecology: Towards Sustainable Development*, Kluwer, Dordrecht, 27-48.
- Jayasuriya, S. (1992), 'Economists on Sustainability', paper presented to Australian Agricultural Economics Society Workshop, 'The Sustainability Debate: Has It Affected Our Way of Thinking and Our Policy Advice?', ANU, Canberra.
- Jones, B. (1991), 'The Application of MENSA, an Energy Systems Model, to Climate Change Issues', *Climate Change Newsletter* 3(3), 4-5.
- Jones, B. (1992), 'UN Convention on Climate Change: Effects on Australia's Energy Sector', *Agriculture and Resources Quarterly* 4(2), 186-95.
- Kay, J. A. and Mirrlees, J. A. (1975), 'The Desirability of Natural Resource Depletion', ch. 9 in D. W. Pearce and J. Rose (eds), *The Economics of Natural Resource Depletion*, MacMillan, London.
- Kirby, M. G. and Blyth, M. J. (1987), 'Economic Aspects of Land Degradation in Australia', *Australian Journal of Agricultural Economics* 31, 155-74.
- Krautkramer, J. A. (1985), 'Optimal Growth, Resource Amenities and the Preservation of Natural Environments', *Review of Economic Studies* 52(1), 153-70.
- Krautkramer, J. A. (1986), 'Optimal Depletion with Resource Amenities and a Backstop Technology', *Resources and Energy* 8(2), 133-49.
- Kula, E. (1981), 'Future Generations and Discounting Rules in Public Sector Investment Appraisal', *Environment and Planning A* 13, 899-910.
- Kula, E. (1984a), 'Discount Factors for Public Service Investment Projects Using the Sum of Discounted Consumption Flows — Estimates for the United Kingdom', *Environment and Planning A* 16, 689-694.
- Kula, E. (1984b), 'Justice and Efficiency with the Sum of Discounted Consumption Flows Method', *Environment and Planning A* 16, 835-838.



- Kula, E. (1984c), 'Derivation of Social Time Preference Rates for the United States and Canada', *Quarterly Journal of Economics* 99(4), 873-82.
- Kula, E. (1985), 'An Empirical Investigation of the Social Time Preference Rate for the United Kingdom', *Environment and Planning A* 17, 199-212.
- Kula, E. (1986), 'The Developing Framework for the Economic Evaluation of Forestry in the United Kingdom', *Journal of Environmental Management* 20, 365-376.
- Layard, R. (1972), 'Introduction', in R. Layard (ed.), *Cost-Benefit Analysis*, Penguin, Harmondsworth, England, 9-70.
- Lind, R. C. (1982a), 'Introduction', in R. C. Lind *et al.*, *Discounting for Time and Risk in Energy Policy*, Resources for the Future Inc, Washington DC, 1-20.
- Lind, R. C. (1982b), 'A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options', in R. C. Lind *et al.*, *Discounting for Time and Risk in Energy Policy*, Resources for the Future Inc, Washington DC, 21-94.
- Lind, R. C. (1982c), 'The Rate of Discount and the Application of Social Benefit-Cost Analysis in the Context of Energy Policy Decisions', in R. C. Lind *et al.*, *Discounting for Time and Risk in Energy Policy*, Resources for the Future Inc, Washington DC, 443-457.
- Lind, R. C. (1990), 'Reassessing the Government's Discount Rate Policy in Light of New Theory and Data in a World Economy with a High Degree of Capital Mobility', *Journal of Environmental Economics and Management* 18(2), S-8 - S-28.
- Little, I. M. D. (1950), *A Critique of Welfare Economics*, OUP, Oxford.
- Lloyd, A. G. (1980), 'Energy and Australian Agriculture', *Journal of Australian Institute of Agricultural Science* 46, 164-69.
- Lloyd, A. G. (1991), personal communication.
- Maler, K-G. (1974), *Environmental Economics: A Theoretical Inquiry*, Johns Hopkins University Press, Baltimore.
- Marglin, S. A. (1963a), 'The Social Rate of Discount and the Optimal Rate of Investment', *Quarterly Journal of Economics* 77, 95-111.
- Marglin, S. A. (1963b), 'The Opportunity Cost of Public Investment', *Quarterly Journal of Economics* 77, 274-89.
- Markyanda, A. and Pearce, D. W. (1988), *Environmental Considerations and the Choice of the Discount Rate in Developing Countries*, Environment Department Working Paper No 3, World Bank, Washington D.C.
- Meadows, D. H., Meadows, D. L., Randers, J. and Behrens W. (1972), *The Limits to Growth*, Universe Books, NY.
- Mikesell, R. F. (1989), 'Depletable Resources, Discounting and Intergenerational Equity', *Resources Policy* 15(4), 292-96.
- Mishan, E. J. (1976), *Cost-Benefit Analysis*, Praeger, New York.
- Mishan, E. J. (1977), 'Economic Criteria for Intergenerational Comparisons', *Futures* 9(5), 383-403.
- Munasinghe, M. and Lutz, E. (1991), *Environmental-Economic Evaluation of Projects and Policies for Sustainable Development*, Environment Department Working Paper No 42, World Bank, Washington D.C.
- National Conservation Strategy for Australia, (1983), *Living Resource Conservation for Sustainable Development*, AGPS, Canberra.
- Norgaard, R. B. (1989), 'The Case for Methodological Pluralism', *Ecological Economics* 1(1), 37-58.
- Page, T. (1977a), *Conservation and Economic Efficiency*, Johns Hopkins University Press, Baltimore.
- Page, T. (1977b), 'Discounting and Intergenerational Equity', *Futures* 9(5), 377-82.
- Page, T. (1982), 'Comment', in R. C. Lind *et al.*, *Discounting for Time and Risk in Energy Policy*, Resources for the Future Inc, Washington D.C., 367-376.
- Pearce, D. W. (1983), *Cost-Benefit Analysis*, MacMillan, London.
- Pearce, D. W., Barbier, E. B. and Markyanda, A. (1988), *Sustainable Development and Cost-Benefit Analysis*, Paper No 88-01, London Environmental Economics Centre.

- Pearce, D. W., Markyanda, A. and Barbier, E. B. (1989), *Blueprint for a Green Economy*, Earthscan, London.
- Perrings, C. (1991), 'Ecological Sustainability and Environmental Control', *Structural Change and Economic Dynamics* 1(1), (forthcoming).
- Pezzey, J. (1989), *Economic Analysis of Sustainable Growth and Sustainable Development*, Environment Department Working Paper No 15, World Bank, Washington D.C.
- Quiggin, J. (1992), 'Discount Rates and Sustainability', paper presented to Australian Agricultural Economics Society Workshop, The Sustainability Debate: Has It Affected Our Way of Thinking and Our Policy Advice?, ANU, Canberra.
- Ramsey, F. (1928), 'A Mathematical Theory of Savings', *Economic Journal* 38, 543-59.
- Randall, A. (1982), 'Economic Surplus Concepts and Their Use In Benefit Cost Analysis', *Review of Marketing and Agricultural Economics* 50(7), 135-163.
- Randall, A. (1985), 'An Economic Perspective on the Valuation of Biological Diversity', mimeo.
- Rawls, J. (1971), *A Theory of Justice*, Harvard University Press, Cambridge, Massachusetts.
- Repetto, R. (1988), *Natural Resource Accounting for Countries with Natural Resource-Based Economies*, Australian Environment Council, Canberra.
- Resource Assessment Commission (1991), *Forest and Timber Inquiry: Draft Report*, AGPS, Canberra.
- Resource Assessment Commission (1992), *Multi-Criteria Analysis as a Resource Assessment Tool*, Research Paper No 6, AGPS, Canberra.
- Ritson, C. (1977), *Agricultural Economics — Principles and Policy*, Student Edition, Granada, London.
- Rosenberg, N. (1976), *Perspectives on Technology*, Cambridge University Press, Cambridge.
- Rosenberg, N. (1986), 'The Impact of Technological Innovation: A Historical View', in R. Landau and N. Rosenberg (eds), *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, National Academy Press, Washington D.C., 17-32.
- Sen, A. K. (1982), 'Approaches to the Choice of Discount Rates for Social Benefit-Cost Analysis', in R. C. Lind *et al.*, *Discounting for Time and Risk in Energy Policy*, Resources for the Future Inc, Washington D.C., 325-353.
- Sharefkin, M. (1982), 'Comment', in R. C. Lind *et al.*, *Discounting for Time and Risk in Energy Policy*, Resources for the Future Inc, Washington D.C., 359-366.
- Sjaastad, L. A. and Wisecarver, D. L. (1977), 'The Social Cost of Public Finance', *Journal of Political Economy* 84(3), 513-547.
- Solow, R. M. (1974), 'Intergenerational Equity and Exhaustible Resources', *Review of Economic Studies* 41, 29-45.
- Solow, R. M. (1986), 'On the Intergenerational Allocation of Natural Resources', *Scandinavian Journal of Economics* 88(1), 141-49.
- Sweeney, J. L. (1982), 'Comment', in R. C. Lind *et al.*, *Discounting for Time and Risk in Energy Policy*, Resources for the Future Inc, Washington D.C., 306-314.
- Tisdell, C. (1972), *Microeconomics: Theory of Economic Allocation*, Wiley, NY.
- Treasury (1973), *Economic Growth: Is It Worth Having?*, Economic Paper No. 2, AGPS, Canberra.
- Turner, R. K. (1991), 'Environment, Economics and Ethics', in D. Pearce, E. Barbier, A. Markandya, S. Barrett, R. K. Turner and T. S. Swanson, *Blueprint 2: Greening of the World Economy*, Earthscan, London.
- Young, M. D. (1990), 'Natural Resource Accounting', in *Proceedings of National Workshop, 'Moving Towards Global Sustainability — Policies and Implications for Australia'*, CRES, ANU, Canberra.
- Young, M. D. (1992), 'Sustainable Investment: The Economic Challenge', *Impact of Science on Society* 42(2), 111-19.

- Young, R. (1990), 'Valuation of Environmental Attributes', in *Proceedings of National Workshop, 'Moving Towards Global Sustainability — Policies and Implications for Australia'*, CRES, ANU, Canberra.
- Young, R. (1992), 'The Economic Significance of Environmental Resources: A Review of the Evidence', *Review of Marketing and Agricultural Economics* 59(3), 229-54.