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THE METHODOLOGY OF COST BENEFIT ANALYSIS - WITH PARTICULAR REFERENCE TO THE OZONE PROBLEM

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I. Introduction: State of Physical Problems

The ozone layer which mantles the planet is the result of an equilibrium process by which the natural disintegration of ozone into oxygen molecules is continuously being offset by the creation of ozone from the action of sunlight on free oxygen in the stratosphere. It is believed that this stratospheric ozone shields life on earth against biologically harmful ultra-violet radiation from the sun and helps to maintain the heat balance of the globe.

The initial threat to the ozone layer was seen as arising from the nitrogen oxide produced by supersonic flights. More attention today is paid to the threat posed by free chlorine atoms acting as catalysts in the destruction of ozone. The largest potential source of chlorine in the statosphere comes from a class of chemicals designated as "fluorocarbons" (FC), or more formally as chlorofluorocarbons, and are derivatives of methane. The two most common of these are used as propellants in spray cans (or aerosols) and are known as $FC_{11}(C.Cl_2.F_2)$ and $FC_{12}(C.Cl_3.F)$. "Fluorocarbons" are also used as refrigerants and foaming agents.

A rough break-down by use (not by effect) is:

spray cans	50%
refrigerants	30%
other	20%

In 1974 several scientific groups were led to the hypothesis that the introduction of chlorine compounds into the stratosphere could destroy ozone on a scale having potentially harmful consequences for life on earth. Since there is, as yet, no adequate model of the stratosphere, there is a major problem in the attempt actually to measure the magnitude of the effect of nitrogen oxide and "fluorocarbons" on the ozone layer. The problem is exacerbated by fluctuations in ozone concentrations which occur naturally and are large and frequent.

The length of time involved in the chain reaction catalysed by a chlorine atom is currently believed to be at least ten years. After production and use it may take scores of years for fluorocarbons to enter the stratosphere (there appear that there are no natural sinks for fluorocarbons other than the stratosphere and a conservative assumption is that virtually all fluorocarbons, including refrigerants, eventually end up in the stratosphere). Because of the long time delays involved, another 50 years may be necessary before scientists can reasonably be certain of the extent of the damage done to the ozone layer and of the range of ecological consequences. In his summary of the technical information on ozone depletion, Choi [1978] devotes 12 pages to critical areas of research currently being undertaken by agencies and universities in the United States.

In the meantime, the possibility that supersonic flights, and the use today of aerosols, refrigerant liquids, and other postwar products, will act to dissipate over time the ozone shield that protects life on this planet from solar ultra-violet radiation is one that is being taken increasingly seriously, at least in the United States. Inasmuch as a decision to reduce the extent of supersonic travel and to curb the production of suspect products in order to diminish the risk to which unchecked development of such activities would expose humanity entails costs and

benefits, the problem ostensibly has an economic aspect. In particular, it may seem to lend itself to cost-benefit techniques.

In this instance, where the alternative under most consideration is that of curbing in some degree existing commercial activities suspected of causing ecological damage, the costs in question are believed to be those which arise from foregoing the benefits associated with such commercial activities. The benefits, on the other hand, would appear to consist of the reduction of the risk of ecological damage to which existing and future generations are exposed.

II. The Aims of the Present Paper

The present paper is to be regarded as a preliminary investigation into some of the more critical concepts which inform allocative economics with the object of determining the extent to which a cost-benefit analysis and related techniques can throw light on the ozone problem and so make an economic contribution to the decision-making process of society.

Within the broad field of welfare economics, a distinction is to be made between, on the one hand, the more ambitious and more abstract approach to social welfare comprehended by the notion of a "Social Welfare Function" (SWF) for society that has, somehow, to be derived from each individual's SWF and, on the other hand, the traditional principles of resource allocation closely associated with the development of neoclassical economics. Attention to the former approach has given rise to a mathematically sophisticated literature about the possibilities for deriving from individual ordering of alternative social states an ordering for society as a whole that meets a number of conditions deemed reasonable by that society. Furthermore, and more importantly for our purposes, this former approach may yield insights as to the nature of the problem of intergenerational equity. Intergenerational equity can be viewed as the

problem of choosing "fair" rules of aggregation of interests or preferences across time, and we will discuss how the social choice literature is related to the ozone depletion problem in its equity aspects.

The former approach does not, however, lend itself to project evaluation in the sense that it does not seek, as do allocative techniques such as cost-benefit analysis, to produce figures that have an economic interpretation - which figures may then be submitted as an economic contribution to society's decision-making process. As things stand at present only restriction to conventional allocative principles can yield specific figures which can be interpreted as meeting, or failing to meet, an acceptable economic criterion. Most of the economic analysis of the ozone depletion problem has been in terms of this latter approach and we will turn most of our attention to this approach as it applies to the ozone depletion problem.

There are, of course, many facets of a cost-benefit analysis that are fascinating in themselves and that would interest the informed public. But since there is broad agreement, at least among the theorists in the subject, about most of these facets, little purpose is served by expounding them in this paper. We have chosen instead to focus attention on the likelier points of controversy that will arise in the attempts of economists to apply cost-benefit and other allocative techniques to the ozone problem. The task we have chosen has impelled us to re-examine the fundamental concepts on which these economic techniques are raised and from which they derive their sanction.

If our conclusions are, in the main, correct they will act inevitably to weaken the faith that can be reposed in a cost-benefit analysis or, at least, to restrict its range of application. Such an outcome is obviously unwelcome to economists including ourselves. But we follow the logic of the arguments wheresoever it leads.

The facts of a cost-benefit analysis to which we address ourselves in this paper are five in number, to wit:

1. The implications of the concept of economic efficiency.
2. Conceptual problems of valuation.
3. The legitimacy of using the discounted present value method (DPV) in ranking public projects.
4. The question of intergenerational equity.
5. The treatment of risk and uncertainty.

These five headings are not arranged in order of importance but, being related to one another, they follow in logical sequence the arguments which we advance in the examination of one problem from observations made in our examination of earlier problems.

III. Implications of the Concept of Economic Efficiency

Since cost-benefit analysis is to be regarded as no more than an extension of the conventional allocative analysis to a proposed economic change, often in the form of a proposed project, it is as well to address ourselves at the start directly to allocative economics - to the criterion by which the economist compares one economic arrangement with alternatives, either in the small or the large.

The singularity of the economic method consists in the adoption of what we may refer to as the basic economic maxim; that the objective data for the economist are the orderings, or the subjective valuations, of the individual members of society, and nothing more. These subjective valuations are usually measured in terms of money; less frequently (and usually for theoretical purposes) in terms of some standard commodity or numeraire. What is more, these valuations are accepted by the economist as relevant data irrespective of the tastes of the individual or the current state of his information. Finally, the phrase "and nothing more" is appended to the above description of the basic maxim in order to obviate any "holistic" interpretation of the idea of social welfare. In other words, there is no abstraction such as "the general good" and no entity such as "the State" to be considered by the economist in addition to the welfare of the individuals

who comprise society - a view that accords with the philosophic position sometimes referred to as methodological individualism.

Since, however, a large number of individuals are generally affected by any economic change, a further criterion is necessary for ranking the alternative economic situations. A criterion that would attract widespread support would be that of an actual Pareto improvement - one for which each member of society is made no worse off by the change and one or more members are actually made better off than before. But changes that meet such a criterion are unlikely to be common in the world we live in. If the economist adopted as his criterion an actual Pareto improvement as described above, the resulting allocative economics would countenance very few changes. Thus, bearing in mind nearly all economic changes raise the welfare of some persons while lowering that of others, the criterion chosen by economists today, and indeed the criterion implicit in neoclassical economics, can properly be described as a potential Pareto improvement: a situation II is ranked above a situation I if, in a costless movement from I to II, the aggregate value of individual gains exceeds the aggregate value of individual losses. Indeed, the excess value of aggregate gains over aggregate losses arising from the specific change is commonly referred to as the social net benefit of that change, and this magnitude is taken to be the economic measure of the resulting change in society's welfare.

Assuming the social net benefit in question to be positive, the recommended change from I to II may be rationalised by the proposition that costless redistributions of the net gains can be envisaged which, were they implemented, could make each individual better off than he was in the I situation.

Clearly, a potential Pareto improvement - which we shall also refer to as the Pareto criterion - is consistent with a change that can make the rich

richer and the poor poorer yet. For this reason, among others, there have been objections to its adoption, and proposals have been made to elaborate the criterion so as to guard against this contingency. Notwithstanding these objections and proposals, the standard allocative criterion employed by economists today is no more than this Pareto criterion. A change that is said to increase "economic efficiency" is nothing more than a change which meets the Pareto criterion - one, that is, which meets a potential Pareto improvement.

Since the weight of the argument to follow turns on this notion of economic efficiency, we spell out carefully its prescriptive implications. The term economic efficiency - when it is not being used by economists simply as a shorthand for $\Sigma v > 0$ (where the v's are individual valuations) - entails a norm by which alternative situations may be ranked. And since alternative economic organisations are agenda that affect the welfare of all members of society, the norm must be one that is acceptable to members of society. One way of expressing society's will with respect to alternative economic forms of organisation is through the political process; in a democratic state through the voting mechanism. But the outcome of a political decision about a set of economic alternatives is not necessarily regarded by the economist as efficient. It follows that the norm of economic efficiency is distinct from, and independent of, an expression of the political will: indeed, that political decisions may properly be criticised by reference to the norms of economic efficiency.

Inasmuch as the sanction for the norms of economic efficiency to be adopted rests ultimately on its acceptability to the society in question, it cannot be grounded in any single individual's value judgement. And since, as indicated, it cannot be grounded either in the political will of that society, but has to be independent of it, the norms of economic efficiency

have to rest on an ethical consensus - or what one of the authors has called elsewhere[1/] "a virtual constitution" that is deemed to be impervious to political fashions and the vicissitudes of political office. It is then wholly appropriate for economists to debate the nature of the relevant components of the prevailing ethical consensus in assessing alternative economic criteria or norms of economic efficiency. In contrast, debate about individuals' value judgements is a separate issue, and is set aside, for this paper.

Assuming, then, that there exists a consensus on which a norm of economic efficiency can be raised, it follows also that not only is it independent of current expressions of the prevailing political will. Inasmuch as society's ethics transcends its politics (a society's politics of course is to some extent an expression of its ethics) the outcome of the norm of economic efficiency transcends the outcome of the political mechanism.

As indicated earlier, there may be little doubt that the adoption of an actual Pareto improvement - a requirement that the change actually makes "everyone" better off - as the norm of economic efficiency would be ethically acceptable to society. But if no less restrictive a norm were acceptable, the economist would have little allocative advice to offer society. Can we then assume the Pareto criterion on which all allocative propositions and recommendations are, in fact, raised is also ethically acceptable?

Although at first glance it is far from compelling, a belief that society as a whole would agree to abide by it can draw upon a number of arguments arising from notions about the actual operation of the economy; for instance, (i) that such changes which are, in fact, potential Pareto improvements do not generally have regressive distributional effects, (ii) that a progressive tax system, in any case, provides a safeguard against pronounced

distributional consequences resulting from any economic change, (iii) that, over time, a succession of economic changes countenanced by this Pareto criterion will not have markedly regressive distributional effects and will, therefore, tend to bring about an actual Pareto improvement, and (iv) that a succession of economic changes that meets the Pareto criterion has a better chance of raising the general level of welfare than a succession of changes that meets any other criterion.

An acceptance of this distinction between the political and the economic does, at least, have the merit of assigning a role to the economist that is independent of the political process. Yet if the economist does in fact give primacy to "economic efficiency" over considerations of distribution, it is not necessarily because he accepts the Kaldor distinction [1939] between the economic efficiency aspect of a change and the distributional aspect which Kaldor declared to be a political issue upon which the economist, qua economist, had no particular competence to pronounce. Nor is it because the economist believes that economic efficiency takes precedence over considerations of distribution or equity. It is simply that, provided the economist is guided by the Pareto criterion, his craft enables him, from time to time, to come up with unambiguous results or with specific numbers. Concern with distributional changes, on the other hand, enables him to come up only with general statements and abstract theorems.

IV. Conceptual Problems of Valuation

The problems grouped under this heading are:

(a) The uses of Compensating Variation (CV) and Equivalent Variation (EV) in measuring allocative changes,

(b) The use of distributional and other weights in a Cost-Benefit Analysis.

(c) "Intangible" externalities and "merit" and "demerit" goods.

(d) Doubts about the existence of the required ethical consensus.

(a) Many cost-benefit studies, explicitly or implicity, base their valuations on the CV concept (with respect to specific changes, the sums which individuals need to pay or to receive in order to restore their welfare to their original levels) rather than on the EV concept (the sums which the individuals have to pay or receive if, spared the specific economic changes, their welfares have to assume the level they would reach if they were actually exposed to those changes). And there are a few cost-benefit studies in which, unwittingly we presume, the authors have used CV for some valuations and EV for others.

It is now accepted that in a general analysis, one in which all prices change, apparently contradictory results can arise according as CV or EV is used. It is possible, that is, for the II situation, represented by a collection of goods, to yield a potential Pareto improvement compared with the I situation when based on the set of prices determined by the actual distribution of the I situation. At the same time, it is also possible for the original I situation to yield a potential Pareto improvement when compared with the II situation, when the comparison is based on the set of prices emerging from the actual distribution of the II collection of goods.[2/] Associating CV and EV respectively with these two paradoxical results, the economist has either to decide in favour of CV or EV or else to reject any public project which does not meet the Pareto criterion when measured in terms both of CV and of EV. The latter policy appears the more prudent course, although it clearly favours the status quo inasmuch as the existing situation I is the one effectively adopted in all cases in which ambiguity precludes a ranking of I and II.

Generally, however, exercises in cost-benefit analysis are conducted within a partial equilibrium framework. Thus, the public project being contemplated is assumed to require so small a proportion of the economy's total resources that the prices only of the goods immediately under scrutiny are perceptibly affected by the alternative projects. For the usual size of such projects, the assumption is not unreasonable, and it enables the economist to circumvent the difficulties associated with the Second Best Theorem and the apparent contradictions, referred to above, that can arise whenever the alternatives being compared involve perceptible changes in many prices.

Nevertheless, even within a partial equilibrium framework contradictory outcomes can still arise when the calculations are done in terms of both CVs and EVs. Yet the contradiction arises for reasons quite different from those indicated above. The contradiction now depends upon the magnitude of the individual's response to the welfare effect of the change in question. Thus, wherever given changes in non-market goods or bads are valued differently by the individual according as the amount he is willing to pay for a good (or to pay for avoiding a bad) differs significantly from the amount he is willing to accept to forgo it, the EV calculation can differ from the CV calculation. A Pareto criterion based on the EV measure can be met by the change which is rejected when the same criterion is based on the CV measure.

The larger the environmental effects of a project, and the more substantial are the welfare effects on the people involved, the greater the likelihood that a project accepted on an EV test will be rejected on a CV test. It is particularly important, therefore, where environmental effects are large, that economists reach a decision on which test is to be adopted. Again, the prudent course to adopt may seem to be one of requiring that

both tests to be made, so effectively favouring the status quo. On the other hand, if there appears to be a consensus bearing on other factors, such as equity or conservation, economists may be able to justify their adoption of the one measure or the other according to the project in question.

(b) There has been a number of proposals to incorporate distributional weights or merit weights in a cost-benefit analysis. With respect to distribution, the weights are chosen to vary inversely with the income levels of the various groups affected by the introduction of the public projects. Such a procedure effectively transforms money estimates of compensating variations into utils. Thus a cost-benefit criterion that is not met in money terms might well be met when the calculation is translated into utility terms, and vice versa.

The particular weighting systems that have been proposed are of necessity arbitrary and all assume, not surprisingly, diminishing marginal utility of income. One method is that of adopting a particular form of the utility-income relation; for example, one that gives a constant elasticity of minus two with respect to income. Alternatively, the weighting system can be made dependent upon the political decisions taken in the past. A method of deriving such weights has been proposed by Weisbrod [1968] and rests on the assumption that all public projects which were adopted despite their failure to meet cost-benefit criteria over a period were adopted because of an implicity set of utility weights attached by the political process to the earnings of different income or regional groups. Another method of deriving these political weights is by a more direct approach to policy makers. Yet another method is that of calculating them from the marginal rates of income tax on the premise that the object of the existing tax system is to share the real burden of any increment of tax equally among all income groups.

Whether bureaucratically or democratically chosen, such parameters, purporting to represent "ultimate national objectives", will vary not only from one country to another. Within any one country they may vary from year to year according to the particular regime in power, or according to the composition of the legislature or, again, according to political fashions and the exigencies of state. Moreover, since it will soon become recognised, in any representative democracy, that some projects which would be accepted on one set of weights, or national parameters, would be rejected on another set, one may anticipate continued lobbying and political in-fighting, both by regional and other group interests, over the weights to be adopted. The resulting vicissitudes and conflict would go far to discredit cost-benefit techniques and, possibly, economists also. Choice of the "appropriate" discount rate, which can be viewed as specifying an inter-temporal set of distributional weights, has been subject to political pressures in the evaluation of public works projects, for example.

Even if it were possible to secure permanent agreement within any one country on the set of distributional weights to be attached to the benefits and losses of different income groups, it could not be counted on to prevent the introduction of a project having a markedly regressive distributional impact. Of the projects that meet a distributionally weighted cost-benefit criterion some might well make the rich richer and the poor poorer if the beneficiaries were rich and many and the losers were poor and few. Such distributionally undesirable outcomes can be avoided only by separate consideration of the distributional impact of any contemplated project.

The proposal to employ politically determined parameters in project evaluation appears, on the surface, to be one arising from the modesty of the economist who overtly recognises the limitations of his craft, and particularly, his inability to place a socially acceptable valuation on a

variety of social phenomena that are influenced by an investment project and that alter people's welfare for better or worse. But it is a modest proposal which issues in more ambitious claims for the resulting technique, one that is then held to "integrate project planning and national policy."[3/] For it purports to reduce to a single critical magnitude a variety of considerations, tangible and intangible.

In contrast, in the conventional (unweighted) valuations used in allocative techniques, the calculation of gains and losses is made on a purely economic principle; that is, by placing a value on them by reference only to the subjective valuation of the persons affected by the project. Thus, if the government calls upon the economist to undertake a cost-benefit study, it presumably expects him to employ economic principles and only economic principles. If for any reason the economist encounters difficulties in evaluating some particular social benefit or cost item, he has the option of leaving its calculation out of the analysis and making it clear that he has done so. If, instead, he attempts to derive a value for this social benefit or social loss by reference to values that are implicit in recent political decisions (assuming they are consistent) he is, in effect, presenting the government with a result that depends, inter alia, on the government's own preferences or valuations and not on those of the individual citizens whose welfare will be affected by the project. The government having referred the problem to the economist for a solution, the economist, by these means, surreptitiously hands it back to the government.

The government, if democratically elected, may of course claim to represent the nation. But it is hardly necessary to remind the reader that the ballot box can produce results very different from those of the market or those reached by an application of the Pareto principle. A majority may well vote in favour of the use of weights or parameters that would justify the introduction of uneconomical projects to be financed by the wealthier minority. Thus, if the present value of the cost of building a funfair for the community were £4 million and the present value of the maximum sums the

members of the community were prepared to pay were equal to £3 million, the funfair project would not meet a cost-benefit criterion. But if a majority wanted the funfair built, it would not be hard to pass it off as a "merit good" so as to attach to each pound of a benefit a weight, say, of two. Alternatively, since the poor would visit the funfair more than the rich, while the rich, through taxes, would pay more than the poor, by judiciously weighting the expected losses and gains of rich and poor, a "utility" cost-benefit criterion could be met and, therefore, the funfair project pronounced economical.

Now there may be some good reasons why the community should have a funfair despite the fact that it cannot meet a purely economic criterion. These reasons could be brought out in public debate and the decision taken to build the funfair. But there is everything to be said for making it abundantly clear that the project does not meet an economic criterion. For by "doctoring" the method of evaluation so as to accommodate current political predilections, the economic facts are concealed from the public which is then misled into the belief that the proposal has the sanction of pure economic calculation, a belief that is likely to influence the course and outcome of any debate on the subject.

We should add in passing that while arguing for the exclusion of politically determined prices or parameters in project evaluation, no inconsistency is committed in simultaneously acknowledging the existence of political constraints. These do not offer to the economist arbitrary or non-economic valuations of goods or bads. They act only to circumscribe the range of choices open to the economist. They can best be regarded as information on how the government is expected to act or react to a change in relevant economic circumstances. In accepting these constraints, the economist does not have to endorse the government's policy. Indeed, he may go on record

as opposing it. In taking into account the expected actions and reactions of the government, the economist is seeking only to discover whether in these circumstances, the introduction of the mooted project will yet realise a potential Pareto improvement. In the endeavour to discover this, however, the economist may not also accept politically determined parameters or prices. He must restrict himself to economic prices - those arising from the subjective valuations of the persons whose welfares are affected by the project.

Once politically determined valuations are believed pertinent to some agenda, there is no obvious case for limiting the extent of political intervention for this purpose. If decision makers can attach weights to merit or demerit goods, why not also to the more ordinary goods on the argument that, as among ordinary goods also, some will have smaller social merit than others? If political decision-makers may attach a valuation to accidents or loss of life, why may they not also attach their own valuations to a wide range of other spill-over effects? And if so much can be justified, there seems to be no logical reasons against going further, and having political decisions override all market prices and individual valuations. There would then seem to be no reason why each and every investment project should not be approved or rejected directly by the political process, democratic or otherwise.

(c) Assuming the economist intends the term "economic efficiency" to have reference to an economic criterion that is independent of the political expression of society, and one therefore that can be sanctioned only by an ethical consensus, a question of consistency arises. Economic efficiency regarded as a normative criterion in this way requires that it be raised entirely on an "ethical base" as distinct from what we might call a

"utilitarion base". Such a requirement, however, leads to some fundamental problems. For example, although we may continue to suppose that society, in its ethical capacity, accepts the Pareto criterion in ordinary circumstances, there can be circumstnaces in which society would reject it on ethical grounds.

The economist who ignores all exceptional circumstnaces of this sort, and continues to base his allocative recommendations entirely on the criterion $\Sigma\Delta v > 0$, is said, here, to be building his allocative propositions upon a "utilitarian base"; which is to say that he restricts himself to the utilities, or welfares, of the individuals affected as expressed in their own valuations (whether declared or inferred), without exception. If he does so, however, his recommendations may no longer claim to be grounded in the ethics of society and, therefore, they may no longer be applicable or relevant to that society. For example, a person B may be willing to sell himself into servitude for the rest of his life to person A for a sum that is smaller than the most person A is willing to pay him. Alternatively, a poor man B may agree to his being flagellated by a rich man A for a sum that ensures mutual gains. The bargain that could be struck in either case would, of course, meet the Pareto criterion: indeed, such bargains would effect actual Pareto improvements. Yet the economist who would, in consequence, recommend that the transaction take place, would be prescribing a course of action that runs counter to the prevailing ethical consensus in the West.

Clearly, if a normative allocation economics is to be a valid instrument, as it can be only if it accords with the prevailing ethics of society, it cannot be raised in all circumstances on a utilitarian base. Ultimately it has to be raised on an ethical base. Thus, in addition to the difficult problems of measurement, which the economist faces in deducing allocative propositions or in calculating net social benefits, he has now

also to view his results in the light of his understanding of society's ethics. Adherence at all times to the Pareto criterion is therefore not enough.

But this is not all. This criterion subsumes the ethical validity also of the basic maxim. Yet there can also be occasions on which society would not regard adherence to the basic maxim as ethical either; it would refuse, that is, to be bound by the individual valuations that comprise the data of $\Sigma\Delta v$. The calculation of externalities in a cost-benefit analysis provides a useful example. Thus a distinction can be made between "tangible" external diseconomies, on the one hand, which cover the range of familiar pollutants that are commonly quoted for illustrative purposes in the economic literature, and on the other hand "intangible" external diseconomics which comprehend people's responses to a change where no physical discomforts are anticipated thereform. A well-known example of the latter is that of the "interdependent utilities" hypothesis, in which each person's welfare is a function also, positive or negative, of the level of welfare or, by extension, of the income or possessions of others.

If a person B is expected to suffer as a direct result of the noise or fume emitted by the automobiles of group A, the cost of the damage he sustains - as measured, say, by his expenditures directed to reducing the damage plus a minimal compensation for the residual inconvenience suffered - should indeed be entered into the $\Sigma\Delta v$ calculation of net social benefit. For it is reasonable to believe that such a cost would be endorsed as a legitimate item in measuring the social value of the project in question. In contrast, if the automobiles of the A group have no effect whatever on person B's health, and cause him no inconvenience, his welfare may yet decline in consequence only of his envy of the A group. If this be the case, it is reasonable to suppose that the considered opinion of society is wholly

unsympathetic to his claim for compensation. Thus, if our allocation economics is erected upon an ethical base, as it should be, this distinction between "tangible" and "intangible" externalities - ignored in an allocation economics erected upon a utilitarian base - can be crucial in the economic calculation of net social benefit.

Clearly this sort of distinction between "tangible" and "intangible" effects is operative also in the field of public works and economic policy generally. If, for example, a project raises the incomes of a group of people, the additional income would be included among the positive benefits of the project. The fact that awareness of this group's material improvement would also cause resentment among members of another group may, in some circumstances, enter strongly into a political decision. But in its ethical capacity, society might well repudiate the idea of counting as costs the envy-claims of the latter group on a par with the claims, say, of financial losses or physical discomforts of some other group. It is possibly true that modern society is one in which the Commandment "Thou shalt not covet thy neighbour's property" is honoured by individuals more in the breach than the observance. But if, as yet, society accepts the Tenth Commandment as part of its ethical code, the inclusion of envy-claims in a calculation of net social benefit violates the ethical consensus.

On reflection, however, it is manifest that we cannot stop here. If, in its ethical capacity, society is deemed to discountenance the envy or resentment experienced by people at the good fortune of others, to the extent of repudiating any claims arising from these "intangible" externalities in an economic calculation of net social benefit, consistency also requires that society's ethical position be extended to cover the individuals' valuations of market and collective goods also. For society may well have strong ethical reservations about the motives which impel people to buy certain

goods - motives such as resentment, spite, hatred, exhibitionism, or merely a desire to keep up with the Joneses. Even where the motives are not deserving of censure, society may regard them with contempt enough, as being too petty or trivial, and rule that their reckoning be dismissed in any calculation designed to determine a reallocation of resources.

(d) Allowing that a normative allocation economics is faced with the problem not simply of describing or calculating the money equivalence of the effects on the welfare of individuals arising from different economic changes but also with the problem of prescribing economic changes for a particular society, we reach the following conclusion. The economist, having to base his normative allocative propositions on an ethical consensus is also saddled with the task of determining the ethical judgements of society with respect to a wide range of possible transactions. Unless he is successful in his endeavours, society will (or ought to) ignore his economic recommendations or calculations. As a corollary, then, the economist will have no criterion of economic efficiency to juxtapose against a politically-determined allocation.

Clearly, such a task is easier to discharge the lower the level of consumption in a society and the slower its pace of change. A society in which goods are scarce in a more literal sense, and in which the patterns of consumption and production are largely determined by tradition, is one for which the economist might prescribe with confidence in the belief that allocative propositions or calculations derived directly from a utilitarian base would be little difference from those derived from an ethical base.

Within a modern growth economy, on the other hand, in which there is ample evidence for the allegation that the "Jones' effect" is growing, or that personal attire is increasingly exhibitionist, or that norms of taste

are declining, or that much of the economy's outputs for mass consumption is increasingly trivial if not regrettable, the task of the allocation economist is not an enviable one. In such circumstances it can reasonably be contended that the ethical consensus to which the normative economist has to defer is itself breaking up. Wherever the consumption of some goods, or the indulgence of some commercially provided activities, are believed by some proportion of the population to be unworthy or degrading and, at the same time, are believed by others to be innocuous if not liberating, the task of the welfare economist becomes impossible.

Therefore, as commonly asserted, the so-called permissive society, the child of affluence, is becoming "pluralistic" in the sense that a traditional or dominant set of beliefs no longer exists; if the tendency is in the direction of each person "doing his own thing" - in effect judging his own activities and those of others in the light of his own privately constituted conscience - then the economist will no longer be able to vindicate his prescriptive statements.

Fragmentation does not, of course, have to proceed to the point where there is a multitude of groups each espousing a particular set of convictions about what is right or wrong, proper or improper. Suffice it that two or more groups differ markedly in their attitudes about the merits and demerits of the products and services of modern society.

For instance, it may be impossible to secure a consensus that more of society's resources should be diverted from their existing employment in order to make available increased outputs of pornographic literature or of "You're Welcome" flash signs for automobiles, or in order to extend the range of tobacco products regardless of expected consumer expenditure on these items.

Reflection on recent developments reinforces the suspicion that, in some respects, the consensus necessary for a normative allocation economics is dissolving. First, there appears to be a growing reluctance today among segments of the public - made explicit in debates between economists, lawyers, and sociologists - to accept without reservation the judgement of the market in the face of substantial expenditures on commercial advertising designed to influence the valuations placed on goods by the buying public. Secondly, there is now the question of rates of depletion of a large number of fuels and materials. Although prior to World War II, the question was one of limited concern to society at large, and of limited importance in economics, the current scale of resource consumption has made it a topic of growing concern to the public at the same time as it has become one of controversy within the ranks of economists themselves.

There can be little room for doubt that there is currently a deep division of opinion among informed members of the public, including economists, about the wisdom of current and proposed economic policies in these respects, which amounts also to a division of opinion about whether the valuations currently attributed to "finite" resources (either under existing economic arrangements or under "ideal" competitive arrangements) has any normative significance. Certainly, a number of reputable economists have argued that the existing valuations of fuels and minerals, and their current rates of consumption, cannot be justified by reference to any criterion that would exclude the opinions of future generations. 4/

Finally, there is a growing agreement that inasmuch as the untoward consequences of consumer innovations - one thinks in this connection of food additives, chemical drugs and pesticides, synthetic materials and a variety of new gadgets - tend to unfold slowly over time, their valuations at any point of time by the buying public (as determined by the market prices

to which individual purchases adjust) may bear no relation whatever to the net utilities conferred over time. Indeed, the very pace of change today with respect to new models and new goods, it can be cogently argued, is such that it is no longer possible for the buying public to learn from its own experience to assess the relative merits of a large proportion of the goods coming onto the market. In consequence, society can have no confidence that the valuations of such goods have any ex post correspondence with people's subjective wants (whether socially approved or not) as to justify them, on the standard argument, as indicators of claims on society's resources.

Assuming this latter belief becomes so widely accepted as virtually to become unanimous, it follows that, for a growing proportion of goods, the subjective valuations, upon which the normative allocation economist has to depend, will no longer be indicative even of the overall subjective utilities of the buyers. On the other hand, the continuance instead of a division of belief about the extent and importance of this development must also act to prevent the would-be normative economist from invoking an ethical sanction for this use of these valuations.

Of course, on particular issues, the would-be normative economist may be able to speak with greater confidence than on others. He may have no hesitation in employing Dupuit's arguments in calculating the net benefits of a bridge, or of calculating the net benefits of a better system of food production or distribution in one of the poorer countries in the world - at least if he were willing to disregard the possible long run effects associated with the growth of population. But for many of the public projects in an affluent society, even where they are designed to provide the population with lower cost inputs of different forms of energy or basic materials, the conscientious normative economist can no longer speak

with authority. For he is amply aware that the values to be placed on such basic inputs are part of a highly controversial topic and, moreover, that such inputs are used in a wide range of items and gadgets about whose social justification the community may be deeply divided.

It follows that if the circumstances described above prevail, the more restricted conception of the role of the economist, as one whose task it is simply to describe the economic consequences expected to follow from the introduction of alternative projects of policies, may become the dominant one. And the calculations of Σv or of $\Sigma \Delta v$, currently used in allocation and cost-benefit analysis, then become no more than a convenient and popular method of presenting the economic effects expected from a proposed policy or project. Such net benefit aggregates, of course, no longer carry independent economic recommendation. They are of value only in so far as they are made use of by the political authority itself as an input into the decision-making process, an input to which any weight (including a zero weight) can be attached.

Terms such as (a) "increased economic efficiency" or (b) "an optimal position", whether used within a partial or general equilibrium context, might, of course, continue to be used by economists, though only as a sort of professional shorthand, respectively, for (a) an economic change for which $\Sigma \Delta v > 0$, or (b) an economic situation for which $\Sigma \Delta v \leq 0$, where the v's refer either to the individual valuation of all of the goods and bads experienced by members of society or else to any specified category of them. After all, there is no good reason why the economist should allow the elaborate structure of allocation economics to go to rust merely because there was no foundation in which to embed it. But if the economist wishes, at the end of his analysis, to be able to conclude that one project is better than another, he needs seek out a broader role by explicitly considering the normative base which ultimately leads to normative policy prescription; moreover, he must be explicit as well about his assumptions concerning the underlying ethical consensus, or lack of

it. These observations apply particularly to the discussion and practice of discounting, which we turn to next.

V. The Legitimacy of Using DPV in Ranking Intragenerational Projects

The ingenuity and conviction with which some professional economists argue the case for the adoption of the device of discounting to the present the stream of net benefits (positive or negative) of a public project is understandable. Were the methods to be discredited, the expertise of the allocation economist might be significantly diminished. Only very recently has this device been challenged. Most of the controversy over the last two decades has turned, instead, on the question of the appropriate rate of discount to use; for instance, whether it should be the common rate of time preference, or the current yield in the private sector, or some other opportunity rate of return; whether it should be weighted composite of such rates and whether it should be lower for public investment than the current yield in the private sector.

The observations that follow are grouped under two main headings; that above, where they are relevant within an intragenerational context, and VI which follows, where they are relevant within an intergenerational context.

For methods of project evaluation that rest ultimately on a Pareto criterion, an unresolved difficulty arises if the lifetimes of the people in the community do not overlap at some point of time common to all of them during the period of the net benefit stream in question. Although there can be factors other than this, such as the growth of uncertainty about the magnitudes of costs and benefits to an intolerable degree after a certain date, the former consideration of itself is warrant enough for the introduction of a finite time horizon, extending from $t = 0$ to $t = T$ in a calculation designed to rank alternative public projects. (In the latter part of this paper, we will consider some of the fundamental aspects of intertemporal equation with the perspective of an unlimited number of generations.)

In order to avoid inessential elaboration, the practice common in the literature, of first setting aside the problem of uncertainty so as to focus on a critical part of the logic of investment criteria, is followed here, as is also the fiction that market values are equal to social values - in particular that the value of an outlay K on the public project is equal, not to the nominal sum transferred for the purpose, but equal to its opportunity cost.

Although the assumption of "full employment" is popular in the literature of investment criteria, it is of no great consequence. "Unemployment" can be dealt with by attributing lower opportunity costs in any project for which a proportion of labour (or other factors) comes from the existing pools of unemployment, while any employment multiplier effects are conceived to generate benefits. Nonetheless, it will be convenient to stay within the convention in this respect and, therefore, to go along with the usual assumption - inapplicable to instances of public projects designed to reduce the level of existing unemployment - that voluntary changes in current savings entail equal changes in private investment.

Let r be the rate of time preference common to all the individuals who are affected by and remain alive over the period in question by the public project, and let ρ be the yield on private investment.

Although it is not strictly necessary that the rate of time preference be common to all individuals in any evaluation of the benefit stream, it should be evident that if, say, all of the gainers from the project have a higher (weighted) rate of time preference then all the losers, or vice versa, the benefit-cost ratio will, in general, vary with the point of time chosen for the evaluation. Moreover, it is entirely possible that for the evaluation taken at, say, the terminal date the benefit-cost ratio would exceed unity at the same time as the evaluation taken at the initial date

would show a benefit-cost ratio below unity. However, since our enquiry goes far beyond this possibility, we may suppose that any weighted rate of time preference is the same both for losers as for gainers or, simpler still, that r is the rate of time preference of all the individuals who are affected by the public project and remain alive over the period in question. The current yield on private investment is taken to be ρ, and for a number of reasons (of which the most obvious is the income tax paid on the return from investment) ρ is taken to be above r. Although there can be many different r's and ρ's (r_i for i = 1,....,n, and ρ_j for j = 1,....,s), and each r_i, ρ_j, can also be dated t = 0,....,T, an analysis conducted in terms of such generality adds only elegant complexity which may obscure the main lines of the argument. We shall therefore continue to regard r and ρ as single magnitudes, and not as vectors or matrices, except to comment on the proposals of others.

Writing $PV_a(B)$, then, as a shorthand for the Present Value of the stream of benefits (some of which can be net outlays, or negative benefits) when discounted at rate a, the four type-(a) criteria to be reviewed are as follows:

(1) $PV_r(B) > K_0$

(2) $PV_\rho(B) > K_0$

(3) $PV_p(B) > K_0$ where $p = \sum_{i=1}^{n} w_i r_i + \sum_{j=1}^{s} w_j \rho_j$ and $\Sigma w_i + \Sigma w_j = 1$

(4) $PV_q(B) > K_0$ $\rho > q > r$

Criterion (1), the staple of textbook instruction, is superficially plausible enough. If r is the common rate of time preference then the community is indifferent as between receiving the stream of benefits $(B) = (B_0,....,B_T)$, and receiving its present value $PV_r(B)$. It is then

convenient to rank the community's preference between any set of alternative investment streams, B^1, B^2, ..., B^g, each of which results from an initial outlay K, according to the relative magnitudes of $PV_r(B^1)$, $PV_r(B^2)$, ..., $PV_r(B^g)$. In particular, any project having a benefit stream that meets the (1) criterion tells us that the present value of that stream of benefits exceeds the present value of its costs and, therefore, represents a potential Pareto improvement for the community.

The rationale for criterion (2), treated in Eckstein's paper of 1957 and also advocated in Baumol's two papers [1968] and [1969], is no less plausible. For it suggests that if funds equal to K_0 are to be spent on a public project, the average yield from the project should be no less than the ρ per annum that the sum K_0 could fetch if it were placed instead in the private investment sector. If, over the period, the benefit stream yields on the average more than ρ, then the $PV_\rho(B) > K_0$ criterion is met, and there is a net gain from adopting the investment project.

Clearly, the (3) criterion is a generalisation of (1) and (2) extended to cover all the different r's and ρ's in the economy. Since the weights, the w's, are the fractions of K contributed by the separable components of reduced consumption and of reduced private investment, the resultant weighted rate of return represents society's actual opportunity yield per dollar of investing a sum K in a public project. In general then, p will vary according as whether K is raised by tax finance, loan finance, or as a mixture of both. Although (3) was originally proposed by Krutilla and Eckstein [1958], it was advanced again by Harberger [1968] in connection with a rise in interest rates in response to government borrowing which is supposed to check both private investment and consumption. With such a weighted discount rate Harberger claimed (erroneously, as we shall see) that "the so-called reinvestment problem disappears" (p.308).

The well-known Arrow-Lind paper [1970] produced criterion (4) as a modification of the popular (2) criterion, $PV_{\rho}(B) > K_0$ when, for their analysis, ρ can be taken as the highest actuarial rate of return corresponding, say, to the riskiest private investment. Accepting without criticism their argument that the risks associated with public projects, when divided among a large population of taxpayers, are felt by each taxpayer to be negligible - in contrast to the sense of risk apprehended by the private investor - a risk premium of $(\rho - q)$ can be attributed to the private investor. Inasmuch then as the investor is indifferent between the riskiest private investment at ρ and a virtual certain return of q on his money, a potential Pareto improvement is effected if funds are removed from this private investment, so forgoing ρ, and placed instead in public investment at a yield greater than q. Hence the proposed criterion $PV_q(B) > K_0$.

However, as they acknowledge in their reply [1972] to critical comments, the crucial assumption on which their criterion rested - that the set of public investment projects excludes opportunities in the private investment sector - did not receive explicit emphasis. And if the assumption is lifted, and the government, permitted to undertake private-sector investment, can avail itself again of the yield ρ, the $PV_{\rho}(B) > K_0$ criterion comes into its own again.

Although the (4) criterion is an interesting variation on the type-(a) criterion, in other respects it is, as stands, subject to the fundamental criticism of this sort of criterion put forward in Part III which follows.

Since the demonstration that follows applies to any of the four criteria, we can use $PV_p(B) > K_0$ to represent the generic type.

Given the stream of benefits $B_0, B_1, \ldots, B_T$, the above criterion is explicated as

$$\sum_{T=0}^{T} \frac{B_t}{(1 + p)^t} > K_0 \quad \ldots . \qquad (1)$$

By multiplying through by a scalar $(1 + p)^T$, we obtain the equivalent inequality

$$\sum_{t=0}^{T} B_t(1 + p)^{T-t} > K_0(1 + p)^T \quad \ldots . \qquad (2)$$

which can be summarised as $TV_p(B) > (K)_p$, where $TV_p(B)$ stands for the terminal value of the stream of benefits when compounded forward to T at the rate p, and $(K)_p$ stands for the terminal value of the outlay K_0 when it is also compounded forward to T and rate p.

If and only if $PV_p(B) > K_0$ does $TV_p(B) > (K)_p$: one form of the criterion that is, entails the other. But the latter form is more revealing. For it makes clear that in order for the criterion to be met, the sum of each of the benefits, $B_0, B_1, \ldots, B_t, \ldots$, <u>when wholly invested</u> and <u>reinvested to time T at rate p</u> must exceed a sum equal to K when wholly and continually reinvested at p to time T. Such a criterion is clearly applicable when <u>in fact</u> both the benefits and the outlays are to be used in exactly this way. If, however, they are <u>not</u> to be used in this way - and it is unlikely that they will be - then a criterion based on such a supposition can seriously mislead. Certainly this $PV_p(B) > K_0$ criterion is misleading when it is applied to public investment projects without information in each case about the actual disposal of the returns to the project, and without information about the uses to which the sum K_0 would have been put were it not used as initial outlay for the project.

To illustrate, suppose it to be the case that the initial outlay K_0 required by a particular public investment is to be drawn entirely from the private investment sector where it would otherwise have been reinvested at

p to reach the value $(K)_p$ at time T, whereas the project's benefits are to be entirely consumed as they emerged over time. The value of these benefits will grow over time only at r, the rate of time preference, reaching a total value of $TV_r(B)$ at time T.[5/] Now, if the sum $TV_r(B)$ is smaller than $(K)_p$, the project is rejected on a Pareto criterion. Society, that is, will be better off leaving the sum K in the private sector than employing it on the public project. However, since p > r, the hypothetical sum $TV_p(B)$ exceeds $TV_r(B)$ and therefore $TV_p(B)$ can exceed $(K)_p$. If so, the project is approved on the $PV_p(B) > K$ criterion even though it is rejected on a Pareto criterion.

Let us return now to the criterion $PV_r(B) > K_0$, regarded as a limiting case of the generic $PV_p(B) > K_0$ criterion. Its transformation into the $TV_r(B) > (K)_r$ form, however, enables us to appreciate immediately the sufficient conditions required for its valid application; namely, that all the returns from the project be wholly consumed as they occur and that the sum K_0 be raised entirely from current consumption. Similarly, transforming the other limiting case, $PV_\rho(B) > K_0$, into the form $TV_\rho(B) > (K)_\rho$ enables us also to appreciate at once that its Pareto validity is assured if, in fact, it is applied to a case in which the benefits, as they occur, are wholly invested and reinvested in the private investment sector at prevailing yield ρ until the terminal date T, and if the sum K_0 raised from the private sector would have been wholly invested and reinvested also at yield ρ until T.

Put otherwise, the correct terminal value of a project's benefit stream, and the correct terminal value of the opportunity cost of its outlay, are both functions of three vectors r, ρ, θ or, in the simplest possible case, of three variables, r, ρ, and θ, where θ is the fraction of any income or investment return that is reinvested in the private sector. In contrast a criterion $PV_p(B) > K_0$ makes the terminal value both of the benefit stream

and the outlay a function only of p, whether p is equal to r, or to ρ, or to a weighted sum of r and ρ.

To anticipate a little, the above stringent conditions for the Pareto validity of the type-(a) criterion are sufficient. They are not strictly necessary however. For instance, where the consumption-investment ratio is the same for all the benefits and also for the outlay, then a (b)-type criterion can, as we shall see later, be reduced to the $PV_r(B) > K_0$ criterion.[6/]

Such simplifications are very agreeable. But one can go further. Under the terminal value approach, there is no need to discount at all. All that matters are the relevant rates at which returns are to be compounded forward to T. Indeed, once this is done, the terminal values can then be discounted at r, or at ρ, or at any conceivable rate, without any alteration occurring in the ranking or in the criterion.

In order to complete this part of the critique, we must also re-examine criteria based on IRR, the internal rate of return. There is a seeming advantage in being able to use the IRR for ranking projects without reference to the prevailing yields or interest rates in the economy. Nonetheless, it is not possible to accept or reject projects on the basis of IRR alone. For this purpose, the IRR has to be compared with whatever is believed to be the relevant opportunity rate.

In fact, letting λ stand for the IRR, the internal-rate-return criteria corresponding to the DPV criteria (1) through (4) are (1') $\lambda > r$, (2') $\lambda > \rho$, (3') $\lambda > p$, and (4') $\lambda > q$.

As a ranking device, the IRR has fallen into disfavour among economists, chiefly because there can, in general, be more than one IRR for a given investment stream.[7/] However, this is the less important reason. The more important reason is that, even in the common case in which all benefits are positive, the unique IRR calculated for an investment stream does <u>not</u>

accord with the true average rate of return over time of the value of that stream. In fact, as conventionally defined, the IRR when used as a criterion has the same defect as the DPV criterion; namely, that a reinvestment rate is entailed that has no necessary relation to the actual rates involved in the particular case.

This defect follows from the standard defintion of the IRR as that λ for which

$$\sum_{t=0}^{T} \frac{B_t}{(1 + \lambda)} t = K \quad .$$

For multiplying through by $(1 + \lambda)^T$ we obtain

$$\sum_{t=0}^{T} B_t(1 + \lambda)^{T-t} = K(1 + \lambda)^T \qquad (3)$$

So explicated, (3) reveals the IRR to be defined as the rate which, when used to compound the benefits forward to T produces a terminal value equal to outlay K when this outlay is also compounded forward at that rate. The resulting terminal value of the benefits is therefore calculated on the implicit assumption that they are wholly invested and reinvested to T at the rate λ - irrespective, that is, of whether this calculated λ is less than r or greater than ρ. Since in any actual project, the disposal of the benefits depends upon behavioural and institutional factors, the actual terminal value of the benefit stream is, again in the simplest case, a function of r, ρ, and θ, and not, in general, of λ alone. In other words, before we can calculate λ as an average rate of growth of the initial investment K over the period to T, we must be able to calculate independently the actual terminal value of the benefit stream by reference to r, ρ, and θ.

A procedure that is free from the above defects is that proposed by Mishan [1967], one that transforms an investment stream, $-K_0$, B_0, B_1,....B_T

into the stream $-K_0$, 0, 0, ..., TV(B). Of the initial return B_0, the amount consumed cB_0 is compounded forward at the relevant rates of time preference, say r, to the terminal date T. The remaining amount sB_0 being divided among the different investment opportunities that are actually anticipated according to one of, say, two alternative political directives, either (1) each investment component is compounded, at its yield, to the following year when it is treated as a receipt along with any other income, or else (2) the investment component is taken to yield equal returns for all successive periods up to T, with the original investment component being included at T. Whether the (1) or (2) assumption is adopted, the sum resulting from the investment component at t = 1 is designated ΔR_1.

Thus at time t = 1, we have returns $B_1 + \Delta R_1$ to dispose of. Again the c proportion of this total $(B_1 + \Delta R_1)$ that is consumed at t = 1 is compounded to T at the rate r, the remainder being allocated among the various investment opportunities anticipated in consequence of the existing political and institutional constraints. Continuing in this way until T, the original benefit stream is transformed into its terminal value.[8/]

A valid ranking of two mutually exclusive projects, X and Y, both of which may be rejected however, requires not only a common terminal date T but also a common initial outlay of K_0. This latter requirement is not restrictive. If, say, Y's initial outlay is 20 less than that of X, the 20 left over from the Y investment can be treated as generating a stream of returns in the private sector of the economy having a terminal value that is to be added to that of the Y stream of benefits.

As for the social opportunity cost of K_0 itself, this is allowed for simply by treating the stream of returns it would generate if left in the private sector, on a par with projects X and Y. For identification, we refer to this alternative as the "reference stream" Z. Using the same rules this stream compounds to terminal value TV(Z).

In this way we end up with three terminal values, TV(X), TV(Y), and TV(Z) from which to choose, all generated by initial outlay K_0. No further operation is required for ranking purposes. If both TV(X) and TV(Y) are less than TV(Z), neither public project is acceptable on a Pareto criterion. If instead, say TV(X) > TV(Y) > TV(Z), then TV(X) is chosen on the Pareto criterion. Any further operation that is acceptable, say, reducing the terminal values to present social values, to present benefit-cost ratios, or to internal rates of return cannot alter this basic ranking.

Thus, corresponding present values for X, Y, and Z, are obtained simply by multiplying each of their terminal values by a scalar, $(1 + r)^{-T}$. Corresponding present value benefit-cost ratios are obtained by multiplying them by a scalar $(1 + r)^{-T}/K_0$. As for the corresponding IRRs, when defined in accordance with the basic concept of an average rate of increase over time of the initial investment K_0, and therefore as that unique value of λ for which $\frac{TV(B)}{(1 + \lambda)} T = K_0$, the resulting equations

$$\frac{TV(X)}{(1 + \lambda_X)} T = \frac{TV(Y)}{(1 + \lambda_Y)} T = \frac{TV(Z)}{(1 + \lambda_Z)} T = K_0$$

entails the ranking $\lambda_X > \lambda_Y > \lambda_Z$.

VI. The Legitimacy of Using DPV in Ranking Intergenerational Public Projects

Extending the simplifying assumption that the time rate of preference r is common to all members of n successive generations that are affected by a public project, the condition under which it is Pareto valid to use DPV or CTV (Compounded Terminal Value) is the existence of a common point of overlap; that is, a point of time at which each person affected is alive.

This can be illustrated in the simplest case of two persons from different generations, each one being capable of making rational decisions

for 60 years, whose rational lives overlap by, say, 20 years. Let person A be alive in this sense from year 0 to year 60, and receive a stream of benefits (positive and negative) that on balance raises his welfare. Let person B be alive from year 40 to year 100 and receive a stream of benefits that on balance reduces his welfare. Since r is the rate of time preference common to both, A's benefit stream can be transformed into an aggregate value of, say, 100 at year 0, or into an equivalent value of $100(1 + r)^t$ for any year t up to year 60. Inasmuch as he is indifferent as between all such sums $100(1 + r)^t$, for t equal to 0, 1, ..., 60, such sums can be represented by a continuous line sloping upward from year 0 to year 60. Such a continuous line may then be interpreted as a time indifference curve, as shown in Fig. 1, with aggregate net benefit - whether on balance gain or loss - measured vertically on a logarithmic scale.[9/]

If r is such that \$1 is worth \$2 in 20 year's time, person B whose stream is equivalent, say, to a net loss of 600 in year 60 is indifferent between this loss and a loss of 300 in year 40, and a loss of 2,400 in year 100.

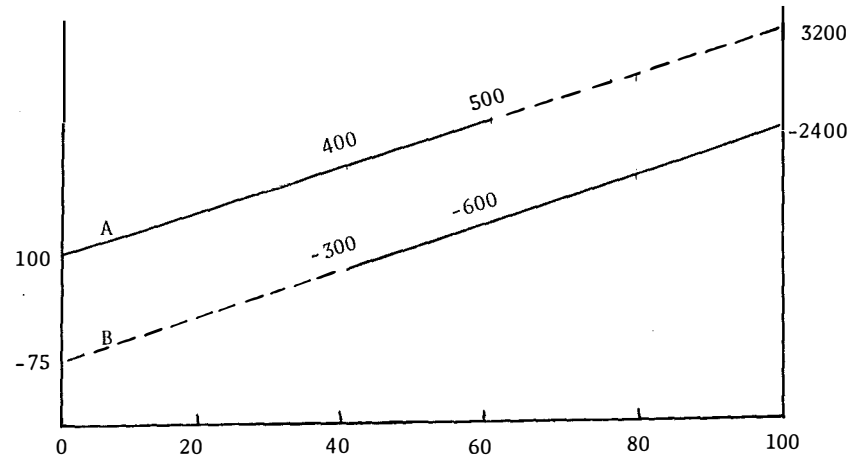


FIGURE 1

As depicted in Figure 1, at any point of time between years 40 and 60, the values placed by persons A and B on their respective net benefit streams are such that the benefit-loss ratio is 4/3. This benefit-loss ratio, being greater than unity, meets a Pareto criterion (A's gain is such that, via costless redistribution, both persons could be made better off), without violating the basic maxim. Adopting this benefit-loss (or benefit-cost) ratio as criterion, discounting to year 0, or alternatively, compounding to year 100, simply multiplies numerator and denominator by a common scalar which, therefore, does not alter the benefit-cost ratio of 4/3.

It follows that if a common point of overlap exists among all individuals of the successive generations, the use of DPV or CTV is indeed Pareto valid. Per contra, if there is no common point of overlap then, since the basic maxim is no longer met, neither can the Pareto criterion. There may well be a large number of overlapping generations over, say, a 1,000 year period. But in such a case there is no direct way of reaching agreement between all persons of those generations about their respective magnitudes of net benefits at some common point of time. If, for example, a third person, D, beginning his rational life in year 100, values the benefit stream conferred on him by the project at $1,000 in year 100, then he is certainly not indifferent as between $1,000 in year 100 and $1,000(1 + r)$^{-40}$ - or $250 in year 60, since he was not alive in year 60. Nor, for that matter will person A be indifferent as between a net receipt of $800 in year 60 and a net receipt of $3,200 in year 100, since he will not be alive in year 100.

Hence, in a time context, the basic maxim requiring economists to accept as their data people's own valuations only of the goods and bads resulting from an economic change poses a problem whenever the time span of the project covers a number of generations. For each person's valuation is now dated over his rational lifetime, and there is no longer a common date

at which each person's valuation can be directly compared and the algebraic sum of their valuations determined.

Two ways of getting around this difficulty have been proposed: (1) that of introducing such "externalities" as altruism or a concern for people yet to be born, and (2) that of introducing intergeneration interventions, either directly or through some institutional mechanism.

The first, (1), it is worth noting, is generally not resorted to in the conventional cost-benefit analysis. Even if incorporated, such externalities cannot be supposed to take such magnitudes as to justify extending the time rate of preference for each person to cover all the time prior to his birth and subsequent to his death. In any case, an admission that such externalities have to be assumed for the inter-generation case reveals the particularity of this recourse, since such externalities are "unnecessary" in the intrageneration case. In the latter case, it can be assumed, and often is, that each person is wholly a selfish being.

The second way around the difficulty, (2), is worth commenting on, if only because the conclusions drawn have been misinterpreted.

With respect to this second line of reasoning, let us consider in turn two possibilities; A, that of government agreements as between generations to transform an existing intergeneration stream of costs and benefits so that, in fact, net benefit comparisons can be made at a common point of time, and B, the use of market mechanisms, in particular investment opportunities for transforming an existing intergeneration stream into one that does, in fact, meet a Pareto criterion.

To illustrate the A case, let a situation involving three persons, X, Y and Z be that depicted in Figure 2 which clearly has no common point of overlap. Of course, the economist might choose year 60 for the comparison of

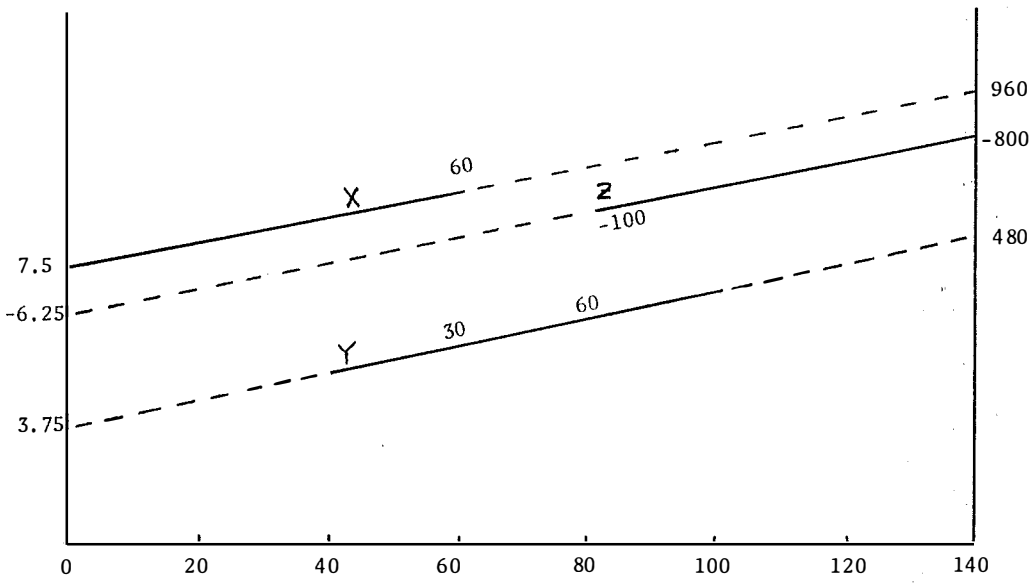


FIGURE 2

the three persons. But since he has no warrant for reducing the -100 of person Z at year 80 to anything smaller (absolutely) than -100 in any year prior to his birth in year 80, he might propose to use -100 also in year 60. If he does this, the algebraic total for the three persons in year 60 comes to -10, and the project appears inadmissible. If, instead, he uses exactly the same procedure in choosing year 80 - and therefore values person X's net gain of 60 in year 60 as equal to a gain of 60 also in year 80 (year 80 being 20 years after X's death), the algebraic total for the three persons is now plus 20, and the project would appear now to be admissible.

In this situation, the economist might envisage government intervention taking the following form: instead of X having 60 and Y having 30 in year 60

(Z not yet born), we could transfer 60 from X to Y. And this 90 now received by Y in year 60 is equivalent for Y to 180 in year 80. In year 80 we then transfer 100 from Y to Z. The net result is that X and Z are no better or worse off than before, while Y is better off by 80. A Pareto improvement has thereby been achieved.

Two comments will help us to interpret this proposed way around the problem. (1) If costless transfers were indeed possible then every hypothetical improvement could indeed be converted into an actual Pareto improvement. Whenever the Pareto criterion were met then, costlessly, every one would actually be made better off, all the conventional paradoxes would vanish, nobody would have a legitimate grumble, and we should live happily in a "first best" world. Nobody takes this easy way out in allocative problems in the context of comparative statics, and there is no warrant for taking such an escape route from the problem when chronological time, particularly generational time, is introduced.

(2) Some economists might want to argue, however, that (in our example above) allowing these transfers as between individuals over time to be hypothetical, then a test of hypothetical compensation is met - which is to say one of potential Pareto improvement. In consequence, if the use of DPV results in a net benefit, a Pareto criterion is met. But this reasoning is facile and misleading for two reasons.

First, in our example, X, Y, and Z were persons, whereas they ought to be generations of persons, For example, the positive gain of 60 for the X generation in year 60 has now to be conceived as an algebraic total, the excess of gains over losses for the X generation in year 60. Within the X generation, that is, hypothetical costless redistribution has already to be invoked to warrant our use of the positive gain of 60. Secondly, the hypothetical transfers as between generations X, Y, and Z can no longer be

justified by reference to those considerations (i) to (iv) which were adduced for an existing generation in Section III. These four considerations, it was there argued, might reasonably be held to give rise to an ethical consensus in favour of adopting a potential Pareto improvement by the members of a given generation, or of a society at a point of time. Among these considerations were the activities of the welfare state, via progressive tax structures and other instruments of redistribution, which tend to diffuse the net gains from a public project which meets a Pareto criterion among the members of that society. However, it can not be taken for granted that these or other considerations would operate to secure a consensus among the members of all successive generations involved that a public project which, via hypothetical intergeneration transfers, could show a net gain ought to be adopted.

The above two reasons for rejecting the proposed argument can be cast in different forms.

If the transfers envisaged were not hypothetical but actually took place, then no generation would, on balance, be left worse off and one or more generations would, on balance, be left better off. In that event, a potential Pareto improvement would be possible among the members of the one, or more, generations that, on balance, were left better off. Thus, only when actual intergeneration transfers of this sort take place, is the conventional Pareto criterion met.

When we now face the fact that the possible transfers described do not actually take place, but are hypothetical only, this case A line of reasoning, by which the use of DPV is to be justified, can be seen to meet a hypothetical potential Pareto improvement - or potential potential Pareto improvement. In sum, this A operation advanced by economists for favouring the use of DPV transpires to be one that can be split into two hypothetical transfers; one

the familiar hypothetical redistribution among the members of an existing community or generation; the other, a hypothetical redistribution also as between the successive generations themselves.

B. The introduction of investment opportunities gives rise to much the same reasoning and reaches the same sort of conclusions. Adopting the rate r as reflecting also the rate of return on current investment, the sum 60 received by person X in year 60 could be invested at r for 20 years to compound to the sum 120. From the 120 so accumulated, person Z can be paid 100. Thus Z is left as well off as he was without the project (as is the case also with person X who dies 20 years earlier), while person Y is left with 80 in year 80. And this result is believed to meet a Pareto criterion.

The correct interpretation of the above simple example follows that of the preceding example. However, what is involved can be brought out more starkly yet by adopting the somewhat extreme example used by Freeman [1977] in order to illustrate his assertion that, in project evaluation, it makes economic sense to discount to the present the value of damages expected to be borne by generations who will be alive many thousands of years from today. Thus, a colossal amount of damage, equal in value to $D, to be experienced in 100,000 year's time should, according to Freeman, be discounted to the present to equal, say, $80 today. If the immediate benefits of such a project are equal to $100, then the benefit-cost ratio exceeds unity and the project is to be regarded as economically efficient.

Freeman goes on to argue that the justification for this conclusion resides in the fact that if the $80 were invested today, and continually reinvested at the discount rate for 100,000 years, it would compound exactly to this sum $D. The beneficiaries from this sum $D would then be able exactly to compensate those destined to suffer the loss of $D, leaving a

net gain of $20 for today's generation. According to Freeman, a potential Pareto improvement is thereby met, as required by economists.

Now with respect to the hypothetical time stream devised by Freeman, a potential Pareto improvement would indeed by met. But clearly this time stream is not the original stream that conferred a gain on the present generation and inflicted damages equal to $D on generations living 100,000 years from today. What his argument amounts to, therefore, is the sanctioning of an actual intergeneration project that, by recourse to investment opportunities, could be changed into a different intergeneration project, which different intergeneration project could then meet the conventional hypothetical compensation test. Since both a hypothetical project and a hypothetical compensation test are involved in his example, he also is, in effect, ascribing allocative virtue to an economic change that meets a potential potential Pareto improvement.

Extending the argument for illustrative purposes, if instead a colossal benefit equal to $B were to be conferred on some group that would be alive in 100,000 year's time by investing today the sum of $80, the project would also be approved on Freeman's logic if the discounted present value of this $B were equal, say, to $100. For although future generations cannot pass benefits backward in time to their predecessors, it is always possible for the existing generation to consume $100 of the existing capital stock which, were it not so consumed, could have compounded to $B in 100,000 years. Hence, if such action were taken, the generation alive in 100,000 years would also suffer a loss of potential value equal to $D, which loss would exactly offset the benefit of $B conferred on it by the project. Future gains and losses would thus cancel out, leaving only a loss to the present generation of $80 (equal to the outlay on the project) and a gain to it of $100 from consuming that much of the existing capital stock which

otherwise would have been passed on to the future. This contrived hypothetical time stream would, therefore, also meet a potential Pareto improvement.

In general, then, by appropriate intervention at points of time over the intergenerational period, an original investment project whose stream of benefits and outlays occurring over the distant future can be discounted to yield a positive net benefit today is one that can also be converted into a hypothetical project that - by using the rate r as a means also of compounding sums forward to the terminal date - would indeed meet a potential Pareto improvement.

Again, however, there are now, in these examples, two sorts of hypothetically costless transfers involved, not just one. The first has reference to the sums assumed to be taken from earlier generations which are invested for the time necessary to produce an algebraic sum of benefits that is positive at some future date, say, the terminal year. The second has reference to the assumed redistribution of this positive algebraic sum among members of the community at that time so as to make "every one" better off. Since the DPV method espoused by Freeman in this intergeneration context is not being regarded as contingent upon an agreement, between governments of all generations involved, actually to invest the receipts of earlier generations with the object of presenting later generations with sums calculated to offset the losses they are to suffer, this imaginary transfer between generations is clearly as hypothetical as the subsequent redistribution of net gains among members of the community at any point of time.

Once more then, Freeman's use of DPV in an intergeneration context would realise not a potential Pareto improvement, as he claims, but a potential potential Pareto improvement. A consensus on the acceptability of the ordinary potential Pareto improvement among members of a given generation may

be presumed to exist. Moreover, it can be assumed that at the time of completion of the change redistribution for actual Pareto improvement is feasible. In contrast, a consensus among members of all generations involved in the long-lived investment project may not be presumed inasmuch as there are no mechanisms which can be counted upon to diffuse the net benefits among this intergenerational community; nothing, in effect, to prevent later generations having to shoulder heavy burdens while earlier generations reap benefits. Moreover, the potential redistribution across generations becomes infeasible at the completion of the change if the compensating investment is not undertaken at the beginning of the change.

Bailey [1978] has suggested that the behavioral condition of hyper-rationality, along with normal market mechanisms, insure that a discounting approach leads to actual Pareto improvement across generations. This observation, depending on the plausibility of the behavioral condition, would tend, of course, to strengthen the ethical appeal of the discounting approach. We can illustrate the idea and our misgivings about it with a simple example.

Smith and d'Arge [1978] estimate the benefits associated with CFM's for the single use as a propellant for insect repellent sprays, for personal use in the U.S., to be $5 billion (p. 32). Suppose for the sake of illustration that these benefits are concentrated in the first year (the "present generation") and after this first year there will be a perfect substitute at no additional market cost and with no environmental hazard, so that future benefits of CFM's, as a propellant for insect repellents, are zero. Suppose further that these CFM's released to the atmosphere remain latent, in manifest effect, for one hundred years, but then in the hundredth hear there is a one percent chance of catastrophic effect in which the entire world population is destroyed. This last supposition is indeed somewhat extreme - it appears that scientists accept

non-negligible probabilities, of one percent or so, of enormous catastrophes associated with the continued growth, 10 percent or more worldwide, of CFM's - but no one is forecasting ultimate catastrophe from a single and minor use of CFM's over a limited period of production. Nonetheless, it sets out the decision problem more sharply to consider the illustrative case of an insect propellant which entails a one percent probability of ultimate catastrophy a century hence.

Under a discounting or type-(a) criterion, the first step is to calculate the expected value of the potential loss. Assuming that the world population a century hence would be about 10 billion, and taking a value of life of $500,000,[10] the expected value of the potential catastrophe is $(0.01)(10^{10})(5 \times 10^{5}) = \$5 \times 10^{13}$ or 50 trillion dollars, valued by those living in year one hundred.[11] Next this expected value is discounted back to the present at 11 percent, the rate recommended by Bailey [1978] for the ozone problem (p. 5), with the resulting present value of $\$1.5 \times 10^{9}$. This present value cost, one and a half billion dollars, is less than the present benefits of five billion, associated with the use of CFM spray repellants. In fact the benefit-cost ratio is 3.4 to one, in favor of the environmental gamble.

Some, including ourselves, will find this simple calculation and conclusion unsatisfactory, on the grounds that the advantage of a spray mosquito repellant over a lotion repellant is too trivial to justify the risk of an ultimate catastrophe. On the contrary, Bailey defends the methodology of this discount approach, on the grounds that the future would actually be better off under the gamble than without it. The idea is as follows. Suppose that CFM's were banned for the use of insect repellent spray. Present consumers would be faced with a decline of $5 billion in consumption. If they were hyperrational they would act to preserve their original consumption pattern, generating $5 billion worth of consumption through other consumption expenditures. With the aggregate

consumption stream maintained intact, the 5 billion comes out of natural savings (Bailey [1978] Appendix C, p. 9). Each year the consumption stream is maintained, so that this $5 billion is compounded forward as an investment foregone. Thus at the end of a century there would be, under the ban of CFM's, $(5 \times 10^9)(1.11)^{100}$ worth of less resource, compared with what there would have been without the ban. With the ban the future avoids the catastrophic risk, valued at 50 trillion dollars, but also is $(5 \times 10^9)(1.11)^{100} = 1.7 \times 10^{14}$ or 170 trillion dollars poorer in resources than it would have been without the ban. Thus, the argument goes, the future would actually be better off without the ban and with the ozone risk. For in the case of no ban in year zero, the future in year 100 could apply fifty trillion to life saving programs, reducing the aggregate risk of early death as much as the ozone depletion increases the risk. This risk of ozone depletion being offset, the future would still have 120 trillion left over, and thus would be better off than if the present had banned CFM's for insect sprays and correspondingly reduced its investment stream. Moreover, the present would also be better off without the ban. With respect to its own consumption it would be indifferent, for by the hyperrationality assumption it would act to maintain its consumption stream intact. But because the ban requires compulsion presumably the present is better off without the ban (Appendix C, p. 10). Thus the interests of the present and future harmonize. Both are better off without the ban than with it. And the decision not to ban is an actual Pareto improvement, compared with the alternative of the ban. If the discounted expected value of the risk had turned out to be more than the present benefits of the spray, and enough more to compensate the present for compulsive regulation, a similar argument could be constructed leading to actual Pareto superiority of the ban.

If hyperrationality (the assumption that the present acts to preserve its consumption stream intact) described the actual behavioral condition of the

economy, we would be prepared to accept the above analysis and we would find the ethical appeal of discounting, at a rate equal to the opportunity cost of capital, (criterion type-(a)(2)) greatly strengthened. Moreover, if hyperrationality were an immutable condition, there would be no conflict of interest between present and future. What is good for the present would also be good for the future and there would be no need to consider the problem of intertemporal equity. However, we find the condition of hyperrationality, which harmonizes the interests of present and future, to be implausible.

Consider that the U.S. GNP is growing at about 3 percent a year (without the ban). In a century we might expect it to increase about twenty fold (1.03^{100}) or to about 20 trillion. Thus it is not possible for the ban to reduce GNP by 170 trillion. The point is that it is possible for a marginal investment to grow at 11 percent for a few years, but it is not possible for it to grow at such a rate for many years if the entire economy is growing at a substantially lower rate. Over a long period, something must give and it appears that the assumption of hyperrationality must give. Otherwise it would lead us to believe that if hula hoops were banned in the 1950's the entire economy would be destroyed a century hence.

We can consider two other behavioral conditions which might be more plausible than hyperrationality, for the very long run. For the first, we assume that if CFM's for insect sprays were banned most of the reduction would come out of consumption and a little out of foregone investment. If foregone opportunities to consume and invest fall into the same pattern as consumer spending of income, we would expect about 90 percent to come out of present consumption and 10 percent out of investment (a "Keynesian savings rule"). Thus we take 10 percent of the $5 billion and compound that forward at 10 percent of 11 percent for a century. The resulting loss of investment resource a century hence is then $(5 \times 10^9)(.1)(1.011)^{100}$ or 1.5 billion. If the

"Keynesian savings rule" describes the actual behavioral condition of the economy, it is clear that the interests of the future lie with the ban. From the perspective of people in year 100, the ban prevents the catastrophic risk valued by them at 50 trillion at a modest cost, to them, of 1.5 billion. Of course this is not the whole story. The present is somewhat worse off with the ban, as its consumption is reduced by 4.5 billion, and each "generation," or year, between zero and 100 is worse off by a somewhat lesser amount, somewhere on to the order of about a billion. The two possible paths, under the assumption of a "Keynesian savings rule," are depicted in Figure 3. One entire path can be viewed as the intertemporal opportunity cost of the other. As can be seen Figure 3 indicates a conflict of interest between generations. The first generation is better off without the ban and the generation living in year 100 is better off with the ban.

The second behavioral condition is the polar opposite case of the condition of hyperrationality. For this condition we assume that the $5 billion comes entirely out of this year's consumption. Thus there is no effect of the ban except for reduced consumption the first year and reduced risk in the last year (Figure 4). While this assumption is no doubt unrealistic for major environmental regulations affecting consumer purchases, it has some plausibility for minor changes. For example, it would lead us to believe that if hula hoops were banned in the 1950's there would be no discernible effect on the economy a century hence. Similarly, if consumers were faced with the prospect of liquid insect sprays instead of aerosols it seems somewhat plausible that there would be no profound effect on the economy a century hence (except for the change in environmental risk). In fact it even appears conceivable that if consumers were faced with the slight extra exertion of liquid rather than spray insect repellents the economy, a hundred years hence, might actually be modestly stimulated. Thus, although this last behavioral condition is the polar opposite

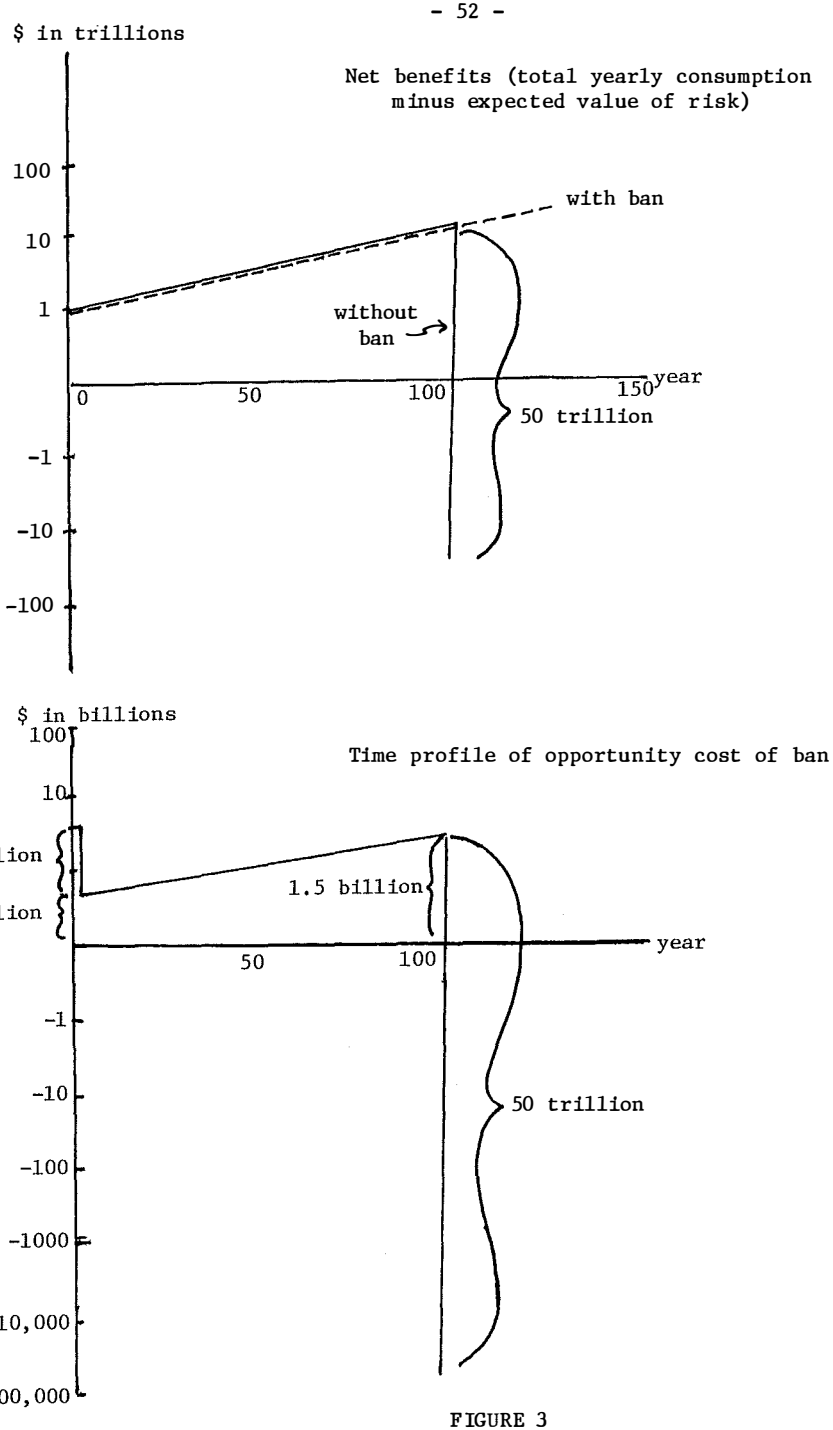
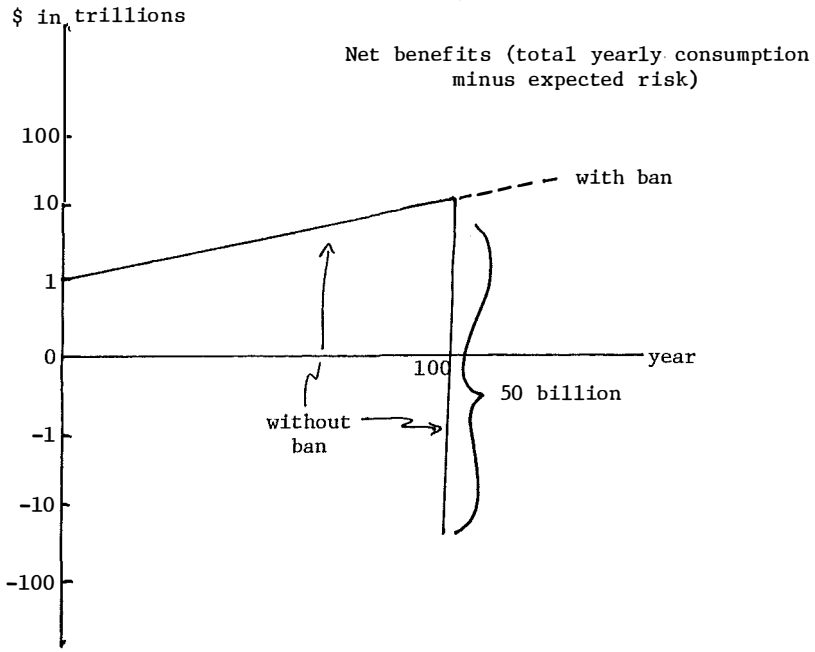


FIGURE 3

Keynesian Savings Rule Behavioral Assumption



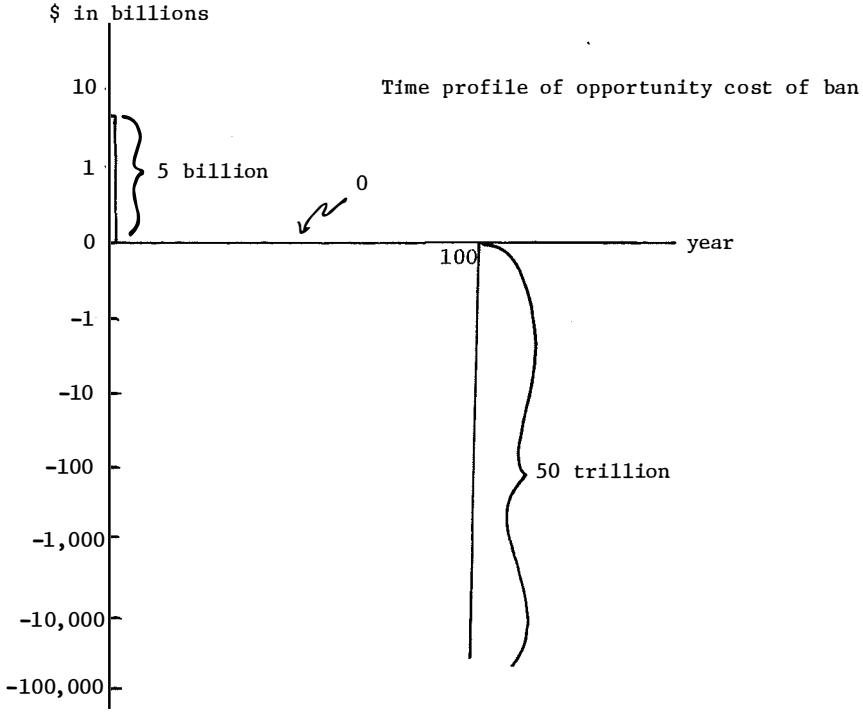
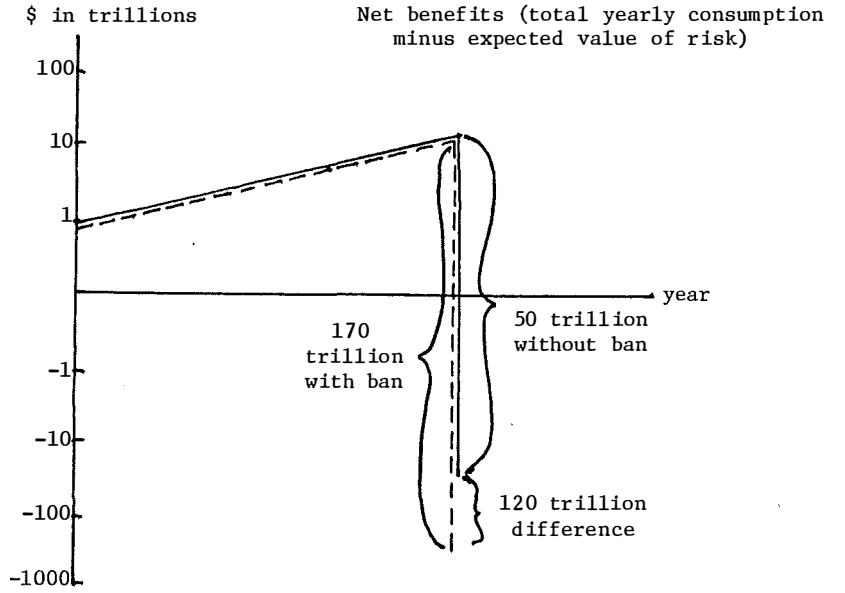


FIGURE 4

Behavioral Assumption that Cost of Regulation Diminishes First Period Consumption Only



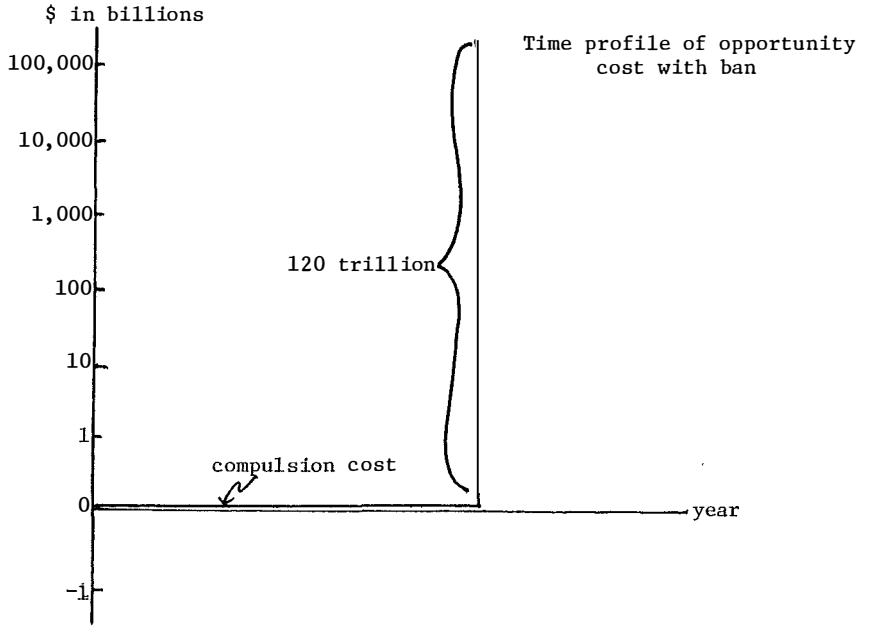


FIGURE 5

Hyperrationality Behavioral Assumption
(Note that this calculation implies that GNP in year 100 with the ban is less than zero.)

of hyperrationality, at least for minor environmental regulations it appears more plausible than hyperrationality, applied to the very long run.

The virtue of this last behavioral condition is its simplicity. It shows the conflict of interests between generations most starkly, and it may be the implicit assumption people have in mind when they reject discounting altogether and affirm that the present should not impose a one percent risk of ultimate catastrophe upon the future for a mere $5 billion benefit to the present.

However, this last behavioral condition appears to us to be less realistic than the "Keynesian saving" pattern, which is a mixed case lying between the two polar extremes. (As can be seen, the implications of the second two behavioral assumptions are not far different, as indicated in Figure 3 and 4, compared with Figure 5.) In the mixed case discounting still has an important role, in defining intertemporal opportunity costs of one whole path, or intertemporal distribution, of consumption and risk burden.[12/] In any case, once the behavioral assumptions are made explicit, it is useful to construct, as far as possible, the intertemporal distribution of costs and benefits with and without regulation. In doing so, infeasible implications, such as those derived by straightforward discounting at the short term marginal opportunity cost of capital, for a century or more, can be avoided. In dealing with long time horizons discounting exercises depend critically upon the underlying assumptions and empirical conditions and it is easy to be led to nonsensical results.

For the ozone case and many others like it, with immediate benefits and long delayed costs, we believe that intergenerational conflicts of interest are an inherent part of the decision problem. In these circumstances, the economist is impelled to face directly the intergenerational distributional implications of such projects.

VII. The Problem of Intergeneration Equity

Since it is unlikely that a stream of returns from a public project having significant welfare effects on future generations will, in fact, be transformed via institutional mechanisms into one that can meet a conventional Pareto criterion, the question of intergenerational equity has to be faced squarely. Certainly if an ethical consensus is the basis of any adopted economic criterion, an intergeneration consensus for the use of DPV (or CTV) is unlikely, as indicated in the preceding section, since it would entail acceptance by later generations of smaller weights being attached to their valuations - whether of benefits or losses - than to the valuations of earlier generations.

Thus, although the economist does, from time to time, extend his conventional maximisation techniques even so far as to resolve the problem of distribution over generational time, unless the results of his chosen set of assumptions - whenever the exercise is not merely taxonomic - yields a distributional pattern over time that accords with that to which our present society believes is just - for all the affected generations - his conclusions will, or should, go unheeded. However, one cannot suppose the economist to be wholly uninfluenced by what is held to be just and proper in this respect. For the results of much of the economic literature on the subject of an optimal distribution of the product over generational time conforms with the popular belief that a just distribution is one that yields constant per capita income over generational time - at least, whenever the populations of successive generations remains unchanged. A somewhat different version of this idea is that the means for future wellbeing be at least as good as our own, thus focusing our attention on the future condition of the resource base and its ultimate renewability, and the portfolio of catastrophic risks that are passed from one generation to another.[13/]

The appeal of an equal division among all members of a community of the fruits of their collective efforts rests ultimately on a philosophical view, or rather an interpretation of the world or, in the last resort, a factual judgement; namely that the material success of a person depends predominantly or entirely on factors outside his control - these being, primarily, his endowments of ability and character, the family that rears him, the social environment in which he grows, the people he happens to meet and the events that overtake him. A contrary interpretation of the world, one that regards such factors as minor influences, and believes that personal deficiencies are personally remediable, would explain differences in income between persons (within a unified economic area at least) as arising, in the main, from differences in personal decisions about the efforts and sacrifices to be made over the span of their lives.[14] Those who believe that differences in income arise chiefly from such causes are not likely to accept an equal sharing of the society's product as a just distribution. They would tend rather to support the dictum, "to each according to his work".

The observations in the preceding paragraph, however, are germane to the distribution of the product within an existing society at some point of time, or over some short period of time. The case is different when we are to consider distributions over generational time, comparing the average real income or consumption in one generation with that in another. For whatever be our view of the fundamental factors explaining differences in existing incomes, we are likely to agree that an equal per capita real consumption for all generations is an eminently fair arrangement. Even if we take what seems today to be the less popular view, that one's income is primarily the fruit of one's effort, it is the average income of each generation, not the distribution within it, that is at issue. For, making the minor assumption (which can always be modified) that the average effort of each generation is about the same, the reasonable supposition that the

distribution of relevant characteristics is much the same for one generation as for another impels us to the view that no generation deserves as of right to enjoy a higher standard than any other.[15]

Irrespective, therefore, of the way each generation chooses to distribute its own outputs among its members, and irrespective also of the way we think any generation ought to distribute it outputs among them, we can agree on each generation's right to a natural resource and capital endowment that, with the same average effort, will produce for it the same per capita real consumption as that of any other generation. In sum, the ethical appeal of equality of per capita consumption over generational time is independent of a belief in the justice of an equal division of the product in any existing society, and is far more compelling.

Other approaches to this problem tend to reinforce this conclusion. One of the interesting aspects of the Arrow axioms, when placed within an intergenerational context, is that they define the class of non-dictatorial social choice rules. All these rules have a common characteristic: if, in a finite number of generations all the others prefer option one to option two, then intergenerational social choice rules consistent with Arrow's axioms say that the first alternative should be chosen. As as abstract principle, this is not attractive. After all, the finite number of generations may be the next thousand generations, and an infinite majority may be all generations that follow. Yet the common sense of this idea may have appeal. Suppose this generation, the present, prefers A to B and, for the foreseeable future, every other generation prefers B to A, then consistent with the class of non-dictatorial choice rules, B should be chosen. Roughly speaking this is like majority voting among a succession of generations. A single generation which imposes its will irreversibly in disregard of the preferences of all generations to follow is clearly acting as a dictator.

In a trivial sense the DPV, as a rule of intertemporal choice, is a dictatorship of the present. The present, after all, must choose in the absence of the future. In this trivial sense every decision rule is a dictatorship of the present. But suppose the present wishes to be fair to the future's interests, which may differ from the interests of the present because of the difference in vantage points in time, among other things. The present can estimate the future's interests concerning a decision made in the present, such as the control or non-control of ozone depletion. Moreover, the present can try to build its ideas of intertemporal fairness into the aggregation rules which combine the present's preferences with those of the future into a single decision or ranking of alternatives. And in considering the fairness or unfairness of intertemporal aggregation rules, some things can be said without any knowledge of the future's actual preferences. Some aggregation rules are so time biased to be considered unfair no matter what the actual pattern of intertemporal preferences.

In this latter sense, which accords with Arrow's technical definition of a dictator, we have just seen an example of an (incomplete) intergenerational social choice rule which is not a dictatorship of the present. This rule, which says that infinite majorities should be decisive over finite minorities, is illustrated in Figure 6. In this case, the present generation prefers having project I to not having it, but every other generation prefers not having it. If the present abides by this rule, on the grounds that it values this version of intertemporal fairness more highly than the particular benefits associated with the project - convenience of freon hairsprays for example - the decision by the present - say to forgo from hairsprays - is clearly not a dictatorship of the present in the Arrow sense.

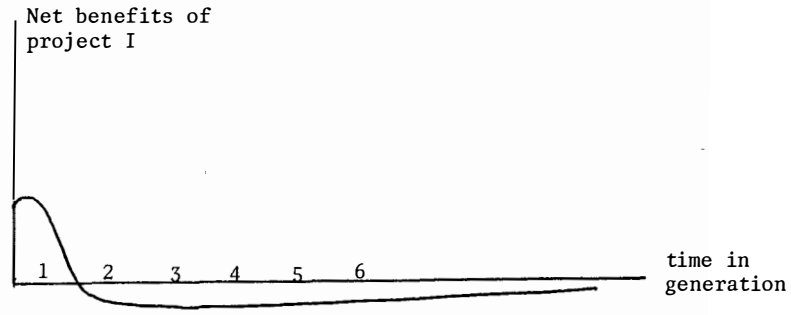


FIGURE 6

This aggregation rule may be called the "overtaking rule" because when it applies, eventually there comes a time when unaminously every later generation agrees on some course of action. The rule by itself is not time biased in the sense that a switch in time of one generation with another does not affect the outcome of any decision. However, the rule is clearly very future oriented. It is interesting to note that this rule follows from Arrow's axioms of transitivity, independence of irrelevant alternatives, and binary Pareto, none of which are future oriented in themselves; once these axioms are set in an intergenerational framework. The future orientation comes from the natural ordering of generations.

How, we may ask, does a discount rule (DPV) fit into this framework? In Figure 6 it would be easly to draw a stream of net benefits such that for a discount rate greater than 2 percent the discounted net benefits were positive. Then the DPV would indicate acceptance of the project, even though only the present generation prefers it to its absence. This indeed appears to be a dictatorship of the present. Is this just a happenstance of the way Figure 6 is drawn and the interpretation of "benefit"? Ferejohn and Page [1978] have shown that there is a close connection between a discount rule, with any interpretation and any non-zero discount rate, and dictatorship of the present in the Arrow sense. A necessary property of a discount rule is stationarity and this property added

to transivity, independence of irrelevant alternatives, and binary Pareto forces any resulting intertemporal social choice rule not only to be a dictatorship, but it picks out the present as the dictator. Further, a discount rule, through its property of stationarity, is not only time asymmetric; it is also time biased in the sense that switching one generation with another affects the outcome of the rule.

It appears that the proper procedure is to face the distributional problem directly. Only if the equity issue is to be otherwise ignored, does it make sense to consider a lower rate of discount as a kind of ad hoc palliative. One may surmise that some economists are a little uneasy about the possibility of intergenerational inequities resulting from the application of DPV to the time stream of a long-lived public project since, by way of apology to the future, so to speak, they sometimes propose a low rate of discount to be employed. But such a proposal is the sort of concession that springs from doubt. It does not rest on justifiable principle.

It seems to us that a proper and justifiable role for the discount rate is to help define the feasible set of intertemporal paths, from which one must choose an equitable resolution of intertemporal conflicts of interest. We have suggested that the simple procedure of discounting costs and benefits at the current opportunity cost of capital, about 11 percent, for long periods of a century or more, can lead to absurd results. Care must be taken to apply realistic behavioral assumptions when using a discount approach to defining the intertemporal opportunity set.

Once the intertemporal opportunity set is defined, an equitable intertemporal choice rule need not involve a further discounting procedure. For example, a promising procedure is to make a decision on the basis of net current benefits once a transition period is completed. This approach is virtually the same as following the overtaking principle and has been used

by the Council on Wage and Price Stability [Broder, 1978] for its analysis of drinking water regulations affecting cancer risk. The approach is particularly suited for cases where there are long term irreversibilities and long term latencies, and where there appears to be at most a single switch in current net benefits once the project start-up costs and latencies are passed in time. Both the problems of ozone depletion and carcinogens in drinking water appear to share these characteristics.

VIII. The Treatment of Risk and Uncertainty

The uncertainty of a future event may be split into two phases, that of assessing, where possible, the risk in terms of probability and severity of an event occurring - whether the probability is objective (based on a statistical sample) or subjective (based on personal estimates of likelihood) - and that of determining a method of evaluating the risk of the event in question. The latter phase may be extended to include the choice of an appropriate technique for decision-making when there is no known way of assessing the probability of the event occurring.

Wherever the statistics of a chance or risk of an event occurring are known, then in principle it is possible to place a value on the consequent increase or decrease in the welfare of each person subjected to that chance or risk, on an ex ante basis. Under these conditions, the Pareto criterion, where its application is justified, can be extended to cover changes in chance and risk.[16/] There will, of course, always be the problem not only of assessing the magnitude of the risk but that of ensuring that persons affected by it are aware of it also. Although this consideration raises the question of further investment in gathering and disseminating information, the recognition of possible net benefits of such investment has never prevented economists engaged in allocative techniques from accepting individual

valuations of goods or bads as the relevant data at the time of calculation notwithstanding the prevalence of imperfect knowledge.

Where, however, the risk in question is not known, and no agreement can be reached on the likelihood of its occurrence, techniques designed to deal with the resultant problem go beyond the bounds of allocative economics as described earlier. Such techniques, whatever their vitures, remain without social sanction unless they can be assumed to be understood and approved by society at large.

We may briefly describe some of the popular techniques proposed by economists and others for dealing with risk and uncertainty, bearing in mind the nature of the ozone problem.

1. Raising the discount rate. The notion of adding some arbitrary percentage points to the rate of discount may be defended as a crude way of coping with uncertainty, wherever the uncertainty refers to the magnitudes of the benefits over the future. It would be hard to justify for cases in which the events themselves, or the side effects of the projects in question, are as yet quite unknown.

Moreover, tampering with the discount rate is obviously an awkward form of recourse when employed simultaneously to cope with uncertainty (usually by raising the rate) and with the problem of intergenerational equity (usually by lowering the rate).

2. Building a probability distribution of net benefits from experts' guesses about future prices is an alternative way of dealing with the same kind of uncertainty. In an extremely simplified example in which there is uncertainty only about future input prices p_1 and p_2 and about output prices p_3 and p_4, experts confined to triple values for each price may agree that for each of these four prices the most likely price in the future has a 60% chance of occurring. As a result, the most likely estimate of the resulting

net benefit has only a $(0.6)^4$ or (roughly) a 13% chance of occurring. As for the most optimistic and the most pessimistic net benefit, they will obviously have a much smaller than a 13% chance of occurring. If, for example, experts agree that there is a 20% chance of each of the more optimistic prices occurring, there will be a $(0.2)^4$ or a 1.6% chance of the most optimistic net benefit outcome occurring. Similarly for the most pessimistic net benefit in this case.

For a triple value of each of the 4 future prices, there is as many as 3^4 or 81 possible net benefit outcomes, each with its own subjective probability. Such a distribution is likely to have a normal shape, but it cannot be more accurate than the guesses made by the experts.

In general, there will be far more than four uncertain prices over the future and, sometimes, more than three estimates for each price. Possible net benefit outcomes can then run into many millions. Nevertheless, a sample distribution can be simulated with the aid of a computer set to select at random a number of combinations consisting of each of the prices along with one of the prices subjective probabilities, each such combination corresponding with a net benefit figure. A sample of some 200 or 300 combinations usually suffice to produce a reliable enough distribution to work with.

Such a technique might usefully be employed in evaluating the opportunity cost involved in controlling output of products believed to damage the ozone layer. In other words, it might be useful for estimating a distribution of net benefits forgone for each of a number of proposals for reducing the outputs of the suspect activities. No comparable calculations, however, can be made for the value of the benefits arising from a reduction of outputs of such activities inasmuch as existing knowledge of the effects of such activities on the ozone layer, and of the ecological and other consequences of its depletion over time, is too meagre to permit of intelligent guesses.

3. The uses of game theory. Game theory is a technique applicable to cases in which there is complete ignorance about the probability of each of the possible outcomes of an uncertain event or combination of events. As such, it might seem to lend itself to decision making in this instance.

Restricting ourselves to a two-person zero-sum game (in which one person is "nature") and in which the game can be played but once, allows a choice of a single strategy among a given number, say n, where each strategy is deemed to produce a known result for each of the possible m outcomes. In consequence, there is an n × m matrix of possible results, each element having a value corresponding to the combination of one possible strategy and one possible outcome of the uncertain event.

The choice of the strategy to adopt, which is the object of the exercise, depends upon the rules or method adopted in the first place, the more popular being the "maximin" method, associated with a prudent decision-maker and the "minimax regret" method, associated with a more enterprising decision-maker. The maximin method selects a strategy thatforgoes possibilities of greater gains in order to ensure that the resulting value, whatever it is, does not fall below some minimum, which value, however, cannot be made larger by the choice of any alternative strategy. A general criticism of this method is that, by so restricting itself, it can sometimes forgo the possibility of substantially greater gains.

The minimax method meets this criticism by estimating the potential loss from choosing every strategy other than the best for each of the possible outcomes. The original matrix of resultant values is thereby transformed into one of potential losses from not choosing a best strategy. In the event, the strategy that is chosen is that which, whatever the outcome happens to be, minimises the potential loss as compared with the choice of any other strategy. The defect of the minimax method is, not surprising, the opposite of the more

prudent maximin method. It is the risk of losing the certainty of a good gain for the chance of making just a little more.

There can be other criticisms of game theory and, indeed, the arbitrariness of the decision whether to adopt maximin or minimax (or some other rules) is itself a weakness of the technique. The chief factor in our rejection of game theory as a decision technique for the case under consideration, however, is the extent of our current ignorance of the ozone problem. The number of alternative strategies that may be adopted is, of course, unlimited although, as a practical matter, it can be reduced to a limited number. But, since we are almost wholly ignorant of the phenomenon, there can be no limit to the number of possible outcomes. Even were we able to guess at the nature of some of the results from adopting strategies involving little reduction of current activities, the placing of monetary values at various points of time on a number of the more disastrous of them would be arbitrary and highly controversial.

4. Other techniques such as risk-benefit analysis (which is, in fact, no more than a variant of cost-benefit analysis where the risk entailed is part of the cost), and the use of strategies based upon conditional probability (in which prior events associated from experience with the likelihood of specific outcomes occurring) have also to be precluded since they, too, depend upon some knowledge of the nature of the risk and upon the social value or cost of the event should it occur.

The ozone problem in fact falls into the category of externalities or spillover effects that has grown rapidly since World War II, being the product of recent technical innovation, and having in common certain features that separate them from the more conventional spillover effects - effluent, noise, fume, congestion, and the like - which feature so large in the economic literature.[17/] The chief distinguishing features of this new category

of spillovers that appear to render them untractable to familiar economic methods are as follows:

First, since the industrial processes and/or products are novel to this planet, there is very limited experience of the nature or incidence of their side effects. The consequences for humanity of the continuance and spread of these new activities and/or products are, therefore, as yet under a gigantic question mark. Specific effects are sometimes suspect and give rise to controversy and speculation. For the rest, it is expected, and feared, that other side-effects will emerge over time.

Secondly, there is in such cases an intelligent apprehension that the spillovers associated with these new activities may well take the form of large-scale disasters, possibly having global dimensions. In particular, the damage caused may be irreversible, and possibly fatal, to humanity or to all forms of life on earth.

Thirdly, some part or all of the as-yet imperfectly understood damage or hazard of pursuing these new activities may fall on future generations. And there can be general presumption that safe technological methods for dealing with them will be discovered in time.

The question, then, is whether the economist or any kind of scientist can produce meaningful figures purporting to be an economic contribution to the decision-making process when the problem under consideration involves spillovers having the singular features mentioned above.

Thus, in the particular problem under consideration, of ozone depletion, the possibility of a number of catastrophic outcomes cannot, at present, be dismissed as being beyond the pale of likelihood. One such outcome is that of so much additional ultra-violet light reaching the earth as significantly to increase the incidence of melanoma and other skin cancers. Alternatively, or simultaneously, temperature and rainfall patterns over the earth may

become so altered as to produce disastrous effects on agricultural output. At least as great a disaster could arise from a critical change in the amount of ultra-violet light reaching the ocean surface so as to interfere with the plankton photosynthesis cycle which both absorbs carbon dioxide and releases oxygen. This latter possibility deserves far more attention than it receives, for the oceans are the largest sinks for carbon dioxide. In general, it is important to take account not only of what are currently believed to be the more likely effects of ozone depletion but also of the potentially worst effects; and to try to estimate not only the probabilities of these worst effects but also to measure the degree of confidence with which they are held.

IX. Conclusions and Recommendations

In the circumstances surrounding the ozone problem, the conscientious economist has to recognize that the conventional tools may be only of limited service. Nonetheless, some proposals can be made by economists and others for coping with products or processes, the introduction of which involves the local or global community in some, as yet, unknown degree of hazard. The following are illustrative:

(1) Thinking in terms, not of the prohibition of a project, but of its public regulation, a prudent maxim would have it that the larger the possible catastrophe and the higher the probability of its occurrence the stricter should be the details of its regulation. Such a maxim, however, is not very useful where the conditions are so novel that we virtually know nothing of the nature of the catastrophes and/or of the probability of their occurrence.

(2) Still thinking in terms of government regulation, it might seem reasonable to suppose that the burden should be placed on the regulatory agency to show - in the words of the Toxic Substances Control Act - that

there is a "reasonable basis for concluding that there may be an unreasonable risk". The regulatory agency would then have to demonstrate that something like a large scale catastrophe is a possibility that cannot be lightly dismissed.

The trouble with this seemingly reasonable proposal, however, is that there may be no way of demonstrating the credibility of one or more possible large scale catastrophes and, in default of such demonstration, the project in question would be adopted with the possible result that the suspicion of some dreadful calamity would, alas, be vindicated within the lifetime of the existing generation or of some future generation. Thus, while such a rule of procedure might be acceptable enough for a spectrum of limited risks, it is manifestly unacceptable wherever there is a risk of a major and irreversible disaster, even where the degree of risk cannot be calculated and even where there is reason to believe it is small.

(3) Arrow and Fisher [1974] have discussed the problem of irreversibility in terms of the growth of information over time. On the supposition that information improves continuously with time, they introduce a simple model designed to indicate the conditions under which there is a balance of advantage in not foreclosing irreversible options. Although their paper is indeed a contribution to the subject within their chosen context, and their conclusion that caution should be exercised in the presence of irreversibility is entirely acceptable, the extent of the caution envisaged has to be increased substantially when the problem is placed within an intergeneration context (one in which their conventional procedure of using a discount rate to maximise present value is no longer valid) and when the problem is raised in a situation in which the irreversibility contemplated has reference not so much to the loss, say, of some unique wilderness area but rather to the ecological viability of the planet earth.

(4) Another possible way of proceeding in the face of uncertainty with respect both to the range of outcomes and to their associated probabilities is to compare, for each possible or credible outcome, the consequences on the one hand, of acting on the basis of what, in the event, turns out to be unwarranted alarm with the consequences, on the other hand, of acting on the basis of what turns out to be unwarranted complacency. For there may well be close agreement among scientists that for each credible outcome, or for most of them, or a least for all the worst outcomes, the damaging consequences for humankind of adopting policies based on unwarranted complacency far exceed in magnitude the consequences, in terms of loss of social gain, of adopting policies based on unwarranted alarm.

Should this agreement exist, it might seem to follow that strict regulation of all suspect activities and products (which regulation may include a ban on the activities or products) should be enforced until our knowledge of their range of effects on the planet has increased to the point of consensus in detail and a high degree of confidence. Only in the fullness of time, then, should it become evident whether our apprehensions of possible disasters were justified, more than justified, or less than justified.

At this point, however, a caveat should be entered. However it is measured, the growth of knowledge, like any other index, is not likely to take the form of a smooth upward trend. Within short periods of time, say decades, we can now recognize with the benefit of hindsight that what was once believed to be new knowledge, or an advance in our understanding, turned out to be erroneous or misleading. Thus, in the near future, we may come to believe the action of certain items on the biosphere to be less dangerous than we originally thought it was, only to discover later that it was more dangerous. What is more, persistent research may eventually bring to light hitherto unsuspected consequences of these same items that may be potentially more dangerous than those currently suspected.

Issues touched upon in the above proposals combine to raise a crucial question. For the problems of the sort the economist has recently had to face are distinguished by three features: (a) although there are grounds for suspicion of a possible major disaster, there is an absence of dependable knowledge with respect both to the nature of, and the probability of, the worst outcomes. (b) Credible worst outcomes are marked by global irreversibility. (c) Recognition that such worst outcomes are as likely, or are more likely, to fall on some future generation as on the present.

The crucial question referred to, then, is that of the policy to be pursued during the period necessary for knowledge to accumulate to the extent needed for a decision with respect to the project to be taken with confidence. This question is clearly related to that which faces the pure scientist whenever he is presented with a new hypothesis. His traditional response in these circumstances can be interpreted as one of methodological conservatism: of resisting novelty until it has survived a long gauntlet of attack and opposition.

At all events, for the economist faced with problems having the aforementioned features it is appropriate to consider, first, two alternative and diametrically opposed social responses, or rules of action, wherever an existing or proposed economic activity may legitimately be suspected of generating dangerous and incalculable spillover effects.

Rule A would countenance the initiation or continuance of an economic activity until the evidence that it is harmful or risky has been established beyond reasonable doubt. Rule B, in contrast, would debar the economic activity in question until evidence that it is safe has been established beyond reasonable doubt. The phrase "beyond reasonable doubt" can excite much controversy, but whatever the interpretation agreed upon, the distinction between the two rules is of the essence.

Which rule tends to prevail depends upon the institutions and attitudes which reflect the ethos of a particular society. Which rule ought to prevail, however, depends upon the state of material well-being and inter alia upon a recognition of features of the spillover effects associated with the activities in question.

Concerning the existing tendency, the A rule has generally prevailed with respect to commercial enterprise in the West, at least since the industrial revolution, in the belief that the progress of industry, although it inevitably occasions inconvenience, eventually promotes the welfare of society as a whole. Whether or not this presumption could be justified by a sophisticated examination of the evidence is a matter of conjecture. However, it must be conceded that the spillovers which most concerned the public in earlier days were of the more conventional kind and, therefore, in a crude way at least, subject to economic calculation.

Since World War II, many authoritative voices have challenged this general presumption of economic progress though without making much impression on the mind of public until the last few years. For the seeming success, scientific and industrial, of the past 200 years has given rise to an establishment of technocrats, bureaucrats, and enterprises, steeped in the belief that science and technology, given the freedom and the funds, will eventually solve all the problems that have been and are being created by science and technology. Yet that immaculate faith in the omnipotence of the scientific method to overcome all obstacles has begun, slightly but discernibly, to waver. The subsequent history of acclaimed scientific discoveries or technological feats over the last thirty years do not read off like a success story. In recognition of the new type of spillovers referred to, the wisdom of being guided by the A rule is no longer self-evident.

If spillovers were such as to be restricted to a single country, and that country, perilously poor, could not depend on outside aid to mitigate the poverty and malnutrition of the bulk of its population, a case could be made for the adoption of the A rule wherever the benefits of introducing an innovation were expected to be substantial. After all, the incurring of some risk of uncertain and possibly irreversible damage to existing and future generations could arguably be justified if, in the absence of the new process and the dissemination of its products, millions of people would be almost certain to die of malnutrition or exposure.

The position is quite different, however, for a country such as the U.S. which, in comparison with a country such as India, is a goods-saturated economy. The continued use of freon and other gases is far from urgent in terms of the saving of life. The present value of the net benefits to be sacrificed from dispensing altogether with such luxuries can hardly be an impressive magnitude. And even it it were reckoned at some outlandish figure, say $100 billion or more, application of the A rule to the case in issue would be difficult to support in view of the possible danger and the possible irreversibility of the ecological disaster envisaged. We might well ask, just how large the value of the net benefits to be foregone has to be in order to warrant the incurring of a risk of that order. If there were some finite figure for these foregone benefits that would indeed warrant exposing the country's population to such a risk, it is virtually certain to be many times any plausible estimate of the present value of such benefits.

The above methodological maxim, if adopted, is sure to offend some commercial and consumer interests. But political sensitivity to these immediate interests on so momentous an issue for the future of mankind would be unforgivable and would amount, in effect, to clear proof of the utter inadequacy of our system of democratic government in the face of crisis.

In the circumstances surrounding the ozone problem, however, the commercial and consumer interests can hardly be very strong. Regulation or prohibition of the items in question would surely be more acceptable even to the less environmentally concerned or less informed segment of the public if they were to be replaced by substitutes that could not seriously be held to occasion much loss of welfare. A policy of replacing push-button aerosols by hand sprays, for instance, can hardly be described as one causing hardship or discomfort. Neither, for that matter, would increased regulation of refrigerant units or control of their disposal be regarded as imposing much of a sacrifice on the consuming public.

The response in the United States to the potential risks of supersonic transport and recombinant DNA suggest a shift toward the B rule. Development of the U.S. SST was suspended in part because the burden of proof that the SST would not deplete the ozone shield was shifted, in the public mind, toward the proponents of the SST. In subsequent years the extent of the risk has not been fully resolved, but it now appears that the risk is considered by scientists to be somewhat lower than first estimated. Some might argue that the later turn of events showed that the SST development should not have been slowed down because the risk proved smaller than originally thought. But even if it were known for sure that the risk of supersonic transport is less than originally estimated it would appear to us that the partial reliance on the B rule was the correct decision. Subsequent events have shown that the costs of delay are not nearly as high as proponents of the SST claimed. More important, some false positives are the price to be paid for controlling false negatives. Similarly it now appears that the risks of recombinant DNA are more manageable than originally thought. Application of the B rule at the Asimilar Conference led to a few years' delay of research development, but with the benefits of a greater understanding of the risks and institution of better laboratory controls.

In this case as well, the costs of the B rule, in terms of delay, have been small in comparison with the benefits, in terms of precautionary management of potentially irreversible and catastrophic risk. On the other side, where the B rule has not been applied and where later estimates of risk have proved higher than earlier estimates there is likely to be an enormous amount of unnecessary suffering, as in the cases of Tris and PPBs. Tris is now known to be one of the most potent carcinogens the National Cancer Institute ever tested, yet it was used for several years as a flame retardant for children's sleepwear, with exposure to millions. During the period of regulation, burden of proof as to the potential toxicity was not shifted to the proponents of Tris, even though there was information existing as to the long term toxicity of related chemicals. Similarly the tragedy of PPB contamination in Michigan could perhaps have been prevented or reduced with application of the B rule, at the beginning and throughout the legal and regulatory process.

X. Final Reflections

We are impelled to conclude that a valid cost-benefit calculation of actions to protect the earth's ozone shield cannot be undertaken in the present state of our ignorance concerning the relevant physical relationships and, therefore, in the present state of any ignorance concerning the nature and magnitude of the risks posed by existing economic activities. Nor can the decision-techniques devised by economists and others for problems involving future uncertainty shed much light on the issue. It is, of course, proper that continued research into all aspects of the ozone problem should continue. But until such time as there is basic agreement on the range of consequences flowing from the use of all suspects goods and activities, or until such time as processes for recycling all substances suspected of affecting, directly or indirectly, the stratospheric ozone have been perfected, any society having a sense of obligation toward its citizens,

and a sense of responsibility for generations yet to come, should adopt the prudent course entailed by the B rule.

The question of the instruments by which to implement action in constraint of such suspect activities is a secondary matter and one open to debate. Although economists by training tend to favour taxes rather than blanket prohibitions, there are political advantages in having recourse, in circumstances of such gravity, to the latter and more dramatic instrument and, indeed, for making the period of adjustment as short as possible. Public support tends to rally to a government that is manifestly in earnest about a declared clear and present danger. In contrast, prolonged debates about taxes and subsidies, about possible exemptions and extensions of the status quo, are apt to weaken the resolve both of governments and citizens, and to detract from the gravity of the situation.

Finally, although the problem is clearly an international one and the U.S. should seek ways of persuading other countries to act in concert in the interests of mankind as a whole, any initial failure to achieve international or multinational agreement ought not to deter her from taking unilateral action in an endeavour to diminish the existing risks being run. The U.S. is, in any case, by far the greatest user of spray cans, accounting for about half the world's total. Her unilateral action in this respect would therefore make a substantial difference to the global risk while serving also to enhance her moral influence in the world and, thereby to encourage other countries to follow her example.

FOOTNOTES

1/ See Mishan [1969].

2/ See Mishan [1976A], Meade [1972], and Mishan [1976B] for futher discussion.

3/ See Dasgupta, Marglin, and Sen [1972], p. 5.

4/ See Georgescu-Roegen [1975], Daly [1977], Solow [1974B], Page [1977A], Sen [1977], Price [1973], Neher [1976], and Burness and Lewis [1977].

5/ More precisely, the value "grows" in the sense that an individual in time zero is indifferent between B now and the anticipation of $B(1+r)^t$ t years from now.

6/ See Marglin [1963].

7/ For further discussion see the investment section of Mishan [1976A].

8/ See Mishan [1976A].

9/ From what vantage point in time is this indifference relation to be defined? Presumably for A the vantage point is at time zero, at which time it is plausible that the future is valued less highly than the present. At a vantage point of year 20, Figure 1 suggests that A values the past (years 0-19) more than the present (year 20), which is hardly plausible. For a discussion of intertemporal decision problems where vantage points shift and the present is more highly valued than either the past or the future, see Page [1977B] and for related discussion see Solow [1974] and Strotz [1955]. In this section we consider some of the implications of the implicit assumption most commonly found in the literature, that time preference relationships do not change with changes in the vantage point of time. We find this assumption unrealistic, but to relax it would lead to questions of inconsistent planning and intertemporal equity, for the individual planner. As the issue of intertemporal equity can be understood most clearly across generations, rather than for a single individual,

discussion of the equity issue is postponed until the following section. The implicit assumption that there is no intertemporal equity problem for this individual - that Figure 1 describes A's time preference structure for any time in A's life - can be viewed as an intertemporal version of "conflation" in the utilitarian tradition. See John Rawls [1972], for further discussion of conflation.

10/ Under the willingness-to-pay approach it has been estimated that workers are willing to accept a 1/1000 increase in the annual probability of death by accident for about $200 annual wage premium which translates to $200,000 per life, in actuarial terms, per life. This empirical estimate does not by itself imply that individuals would be willing to accept a 1/100 increase in the chance of death per year for a compensation of $2000, which would also translate into $200,000 per life. However, the time dimension of the empirical study is not clearly focused on risks of one year duration. If workers viewed the decision to work in a mine as a decision to work for 10 years with a total risk of early accidental death of 1/100 and total premium of $2000, then the figure of $200,000 per life would be appropriate as the actuarial equivalent of the "value of life" for risks in the range of one percent. We will not go into the important qualifications here of this approach, but simply offer the figure of $500,000 as a "generous" estimate of what might be found in the risk-benefit literature using a discounting approach. See Linerooth (1975) and Bailey (1978) for further discussion. Some estimates of the value of life are a good deal higher; see also Page, Harris, and Bruser [1979], Appendix D.

11/ There is the valid question of whether a collective risk involving the entire world population should be treated as equivalent to 20 billion times the individual risk, where 20 billion is the assumed population. But resolution of this question is not essential for the observation made below.

12/ For further discussion see Dasgupta [1977].

13/ See Page [1977A].

14/ See Mishan [1977].

15/ These remarks define a base case in which secular declines are ruled out as long as steady states are feasible. They do not rule out advances, if the present is altruistic toward the future, or if some criterion like Rawls' "golden rule of saving effort" is adopted. Rawls' golden rule requires a saving effort of the present equal to what it would have liked its immediate predecessor to have made.

16/ But see footnote 9 concerning intertemporal conflicts of interest for the individual. Society does not allow voluntary contracts made in the present leading to slavery at a future date, thus protecting the future interests of the individual against present interests. The same ethical concern applies to lotteries for future slavery such as the exposure to carcinogens or other irreversible environmental risks. This ethical concern must be balanced against the supposition underlying methodological individualism, that the individual is better able to look out for his future interests than the government.

17/ See Page [1978] for a more complete discussion of these differences and some of the implications of these differences.

REFERENCES

Arrow, K.J. and Fisher, A.C. (1974) "Environmental Preservation, Uncertainty, and Irreversibility," Quarterly Journal of Economics, V. 88, May 1974.

Arrow, K.J. and Lind, R.C. (1970) "Uncertainty and the Evaluation of Public Investment Decisions," American Economic Review, June 1970.

Arrow, K.J. and Lind, R.C. (1972) "Reply," American Economic Review, March 1972.

Bailey, Martin (1978) "The Discount Rate for Environmental Programs," Appendix C of "Costs and Benefits of CFM Control," University of Maryland Conference on Ozone Management, John Cumberland, director, July 1978.

Baumol, W.J. (1969) "On the Social Rate for Public Projects" in The Analysis and Evaluation of Public Expenditures: The PBB System, Vol. I, Joint Economic Committee. Washington, D.C.

Baumol, W.J. (1968) "On the Social Discount Rate," American Economic Review, September 1968.

Broder, Ivy (1978) "Analysis of Proposed EPA Drinking Water Regulations," Washington, D.C., September 1978.

Burness, H.S. and Lewis, T.R. (1977) "Democratic Exploitation of a Non-Replenishable Resource," Social Science Working Paper No. 161, California Institute of Technology, Pasadena, CA.

Choi, K. (1978) "Summary of Technical Information on Sources and Effects of Ozone Depletion," Univ. of Maryland Conference on Ozone Management, John Cumberland, director. July 1978.

Daly, H. (1977) Steady State Economics, W.H. Freeman and Co., San Francisco.

Dasgupta, P. (1977) "Resource Depletion, Research and Development and the Social Rate of Discount," Conference paper, Resources for the Future, Washington, D.C..

Dasgupta, A.K. and Pearce, D.W. (1972) Cost Benefit Analysis, Theory and Practice. London: Macmillan.

Dasgupta, P., Marglin, S., and Sen, A. (1972) Guidelines for Project Evaluation. New York: United Nations.

Eckstein, O. (1957) "Investment Criteria for Economic Development," Quarterly Journal of Economics, June 1957.

Ferejohn, J. and Page, T. (1978) "On the Foundations of Intertemporal Choice," American Journal of Agricultural Economics, V. 60, No. 2, May 1978.

Freeman, M. (1977) "Why We Should Discount Intergenerational Effects," Futures, V. 9, No. 5, Oct. 1977, p. 375-376.

Georgescu-Roegen, N. (1975) "Energy and Economic Myths," Southern Economic Journal, V. 41.

Harberger, A.C. (1972) "The Opportunity Costs of Public Investment Financed by Borrowing," (1966) in R. Layard, ed., Cost-Benefit Analysis. London: Penguin Books Ltd.

Haveman, R.H. and Krutilla, J.V. (1968) Unemployment, Idle Capacity and the Evaluation of Public Expenditures, Washington, D.C. Ref.

Hirshleifer, J., et al. (1961) Water Supply: Economics, Technology and Policy, Princeton, Princeton University.

Kaldor, N. (1939) "Welfare Propositions of Economics and Interpersonal Comparisons of Utility," Economics Journal.

Krutilla, J. and Eckstein, O. (1958) Multiple Purpose River Development, Baltimore: The Johns Hopkins Press.

Linerooth, J. (1975) "The Evaluation of Life-Saving: A Survey," International Institute for Applied Systems Analysis, Laxonburg, Austria.

Marglin, S. (1963) The Opportunity Cost of Public Investment," Quarterly Journal of Economics, V. 77, p. 274-289.

Meade, J.E. (1972) Review of Cost-Benefit Analysis by E.J. Mishan, Economic Journal, V. 82, 244-246.

Mishan, E.J. (1977) "Economic Criteria for Intergenerational Comparisons," Futures, V. 9, No. 5, p. 383-403.

Mishan, E.J. (1976A) Cost-Benefit Analysis (2nd Edition). New York: Praeger.

Mishan, E.J. (1976B) "The Use of CV and EV in CBA," Economica, May 1976.

Mishan, E.J. (1974) "Consistency and Flexibility in Cost-Benefit Analysis," Economica, February 1974.

Mishan, E.J. (1969) "Welfare Economics," deVries Memorial Lectures, Nath Holland.

Mishan, E.J. (1967A) "Criteria for Public Investment: Some Simplifying Suggestions," Journal of Political Economy, September 1967.

Mishan, E.J. (1967B) "A Proposed Normalization Procedure for Public Investment Criteria," Economic Journal, V. 77, 777-796.

Nath, S.K. (1969) A Reappraisal of Welfare Economics, London, Routledge and Kegan Paul.

Neher, P. (1976) "Democratic Exploitation of a Replenishable Resource," Journal of Public Economics, V. 5, 361-371.

Page, T. (1978) "A Generic View of Toxic Chemicals and Similar Risks," Ecology Law Quarterly, V. 7, No. 2, 207-244.

Page, T. (1977A) Conservation and Economic Efficiency, Baltimore: Johns Hopkins Press.

Page, T. (1977B) "Equitable Use of the Resource Base," Environment and Planning, V. 9, 15-22.

Page, T., Harris, R., and Bruser, J. (1979) "Removal of Carcinogens from Drinking Water: A Cost-Benefit Analysis," Social Science Working Paper No. 230, California Institute of Technology, Pasadena, CA.

Price, C. (1973) "To the Future: With Indifference or Concern? -- The Social Discount Rate and Its Implications for Land Use," Journal of Agricultural Economics, V. 24, No. 2.

Rawls, J. (1972) A Theory of Justice, Cambridge, Mass.: Harvard Univ. Press.

Sen, A. (1977) "Approaches to the Choice of Discount Rates for Social Cost-Benefit Analysis," Conference paper, Resources for the Future, Washington, D.C.

Smith, K. and d'Arge, R. (1978) "Managing an Uncertain Natural Environment: The Stratosphere," Univ. of Maryland Conference on Ozone Management, John Cumberland, director. July 1978.

Solow, R.H. (1974A) "Intergenerational Equity," Review of Economic Studies, V. 41, Supplement, 29-45.

Solow, R. (1974B) "The Economics of Resources or the Resources of Economics," American Economic Review, V. 64, May 1974.

Strotz, R.H. (1955) "Myopia and Inconsistency in Dynamic Utility Maximization," Review of Economic Studies, V. 23, 165-180.

Weisbrod, B. (1968) "Income Redistributive Effects and Benefit-Cost Analysis," in Problems in Public Expenditure Analysis (S.B. Chase, ed.), p. 177-208. Washington, D.C.: Brookings Institution.