INTERTEMPORAL INDICATOR EVALUATION: A PRELIMINARY NOTE ON PROBLEMS OF EVALUATING TIME STREAM DATA FOR ENVIRONMENTAL POLICY ANALYSIS

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I. The Time Aggregation Problem in Applied Systems Analysis

A. Introduction

Assumptions regarding the aggregation of time stream data (e.g. "discounting") are crucial in the evaluation of regional development proposals and the assessment of environmental impacts. Nonetheless, present practice reflects a great deal of confusion, ambiguity, caprice, and downright error in the calculation and implementation of such assumptions. We present in this paper the outlines of an approach to inter-temporal indicator evaluation for use in the analysis of regional development alternatives. Our ultimate objective is pragmatic: We wish to develop a practical framework for the reduction and comparison of time stream data for evaluation of public programs and policies. As a foundation for this approach, however, it has been necessary critically to review the existing controversy on intertemporal aggregation in a public policy context, and to clarify the practical implications of the points at issue. Three interrelated themes pervade this review and provide a conceptual focus for the work.

1) *The determination of rules for intertemporal indicator evaluation properly constitutes a public policy question.* Market behavior is one source of public opinion on which such decisions should be based, but only one. The ballot box and the publicly responsible administrative body constitute similarly legitimate channels for the expression and articulation of relevant opinion. The "sensibility" of such opinion should doubtlessly be considered through evaluation of their implications but it is ultimately the opinions, not the sensibility, upon which time aggregation rules are to be founded.

2) *The time stream aggregation problem is essentially a distributional problem.* The impossibility of intergenerational transfer payments obviates all solutions based on Hicks-Kaldor or less restrictive welfare criteria, and calls into questions the applicability of the entire Ramsey-cum-von Neumann utilitarian

outlook for matters of time aggregation. Related considerations are introduced through recognizing the inability of future generations to express themselves through either today's market or ballot box.

3) *The unknown is the dominant factor of the intertemporal evaluation equation.* Given the inherent unpredictability of the future, time stream aggregation procedures must address explicitly the uncertainties in both project impact projections and future preference assumptions. The fact of irreversability and the concept of option value are central in this context, and must likewise be addressed effectively.

B. The Importance of Time Stream Aggregation Assumptions in Project Evaluation

The treatment of intertemporal indicator aggregation problems is a dominant factor in the evaluation of alternative public policy programs. At stake in these assumptions is nothing less than the distribution of economic activity between the private and public sectors and, less directly, the allocation of consumption and choice opportunities among present and future generations.

The stream aggregation assumptions, usually though not necessarily embodied as a compounding percentage discount rate, are often the most sensitive aspect of the entire evaluation analysis. In one study, Fox and Herfindahl (1964) reevaluated 178 water resource development projects undertaken in 1962 by the U.S. Army Corps of Engineers. These projects represented a combined initial investment of over 3 billion dollars, and were all characterized by benefit/cost ratios greater than or equal to 1. when evaluated at the prevailing prescribed discount rate for federal project costs of 2 5/8%. Fox and Herfindahl reevaluated the projects at discount rates of 4, 6, and 8% and found that the project adoption decision was reversed (i.e. the newB/C ratio dropped below 1.) for 9, 64, and 80% of the investment, respectively. Similarly powerful cases for the dominating influence time stream aggregation assumptions may

be found in Baumol (1968), Krutilla (1969) and Koopmans (1974). Furthermore, conservationists and environmental protection advocates have frequently called for lower social discount rates as a means of reducing rates of resource exploitation. The likelihood of counterproductive results of such a proposal (see Scott 1955, and below) in no way lessen its significance as an indication of the perceived relevance of time aggregation rules in project evaluation and analysis.

C. The Present Lack of a Defensible Rationale For Time Stream Aggregation

Given the importance of time stream aggregation assumptions, it is alarming to find that no reasonably defensible rationale presently exists for the discussion and specification of such assumptions. The most obvious symptom of this lamentable state of affairs is the extreme spread in published recommendations for the "social" discount rate to be used in evaluating public projects. Baumol for instance, cites a range of 4 1/2 to 9% (Baumol 1968), and Hirshleifer and Shapiro (1969) document seven different studies suggesting rates from 2 1/2% to 13 1/2%. In light of the sensitive relationship between discount rates and benefit/cost ratios in the Fox and Herfindahl analysis, this sort of variation is all the more alarming.

But if a wide spread of published time aggregation factors is disturbing, it is not particularly surprising. For although most economists agree that a proper representation of the "opportunity cost of postponement of receipt of any benefit yielded by a public investment" (Baumol 1968, pg.788) is central to the time aggregation issue, there is great disagreement as to just what this means in practice. In particular, various arguments flourish as to the relevance of market indicators and imperfections; bank and government interest rates; the degree of project riskiness; private versus "public" goods (sensu Samuelson 1954); and assumptions concerning future population growth, technological capabilities, and preferences. Different estimates of opportunity costs and time preference rates emerge,

depending upon the particular treatment of these matters adapted in a given analysis. Furthermore, underlying the technical debate there exists a radical disagreement regarding the normative social welfare models most appropriate for use in intertemporal allocation problems. These various normative assumptions again tend further to promote differences in time aggregation recommendations. We shall discuss detailed aspects of both the technical and ethical issues subsequently, but the thrust of our argument may be usefully summarized at the ouset.

D. The Need For a New Approach to the Time Problem

Intertemporal social welfare decisions are too important to be left to the economists. States have been founded "to secure the blessings of liberty to ourselves, and our posterity", by explicitly participatory political means. Ethical and religious systems provide a variety of strong precepts regarding our responsibilities and prerogatives to time future and generations unborn. Optimal market models governed by efficiency criteria also have implications for these matters, but they have no preordained right to monopolize the field.

Particularly unjustifiable in this respect is the seemingly ubiquitous, slavish, and uncritical adherance to a Fisherian interest rate model as the ultimate arbitrator of social time preference decisions (see Fisher 1930, and a critique by Feldstein 1964). Even if this model's assumptions of perfect markets and perfect competition could be met in practice, its social acceptability would be questionable because of its failure to address distributional equity questions. But the market seg-

mentations, imperfections, and uncertainties characterizing the present economy leave the model badly crippled in any case, as the frantic patching and shoring activity of its own advocates so clearly demonstrates.

A dispassionate review of the present literature can only lead one to conclude that time aggregation assumptions - again, most often embodied as a compounding percentage "social" discount rate - have become little more than a free parameter in the project evaluation equation: a parameter uncritically adjusted to accomodate worries about anything from risk (Frost 1971) to bias (Bain et al. 1966), to option values (Fisher and Krutilla 1974), to growth projections. The real criteria for the form and magnitude adjustments seems to be little more than one of plausibility of the evaluation results. Implicitly saddled with an inappropriate evaluation model we seem unable to reject, and convinced on intuitive or experiential grounds of the plausibility of certain evaluation outcomes, we are treated to the sorry spectacle of professional economists indiscriminately loading the discount term with sundry paraphernalia until the evaluation answer comes out "right". The correctness of the answer is then - mirabile dictu - passionately and seriously defended with the irrefutable but irrelevant argument that nonoptimal discount rates result in inefficient resource allocation in optimal growth market models. John Rawls summarized the case with an appropriate air of bemusement:

> "Having started with the idea that the appropriate rate of saving is the one which maximizes social utility over

> time, we may obtain a more plausible result if the welfare of future generations is weighted less heavily. What we are doing is adjusting certain parameters so as to reach a conclusion more in line with our intuitive judgements" (Rawls 1971).

But it is precisely this sort of "intuitive" tinkering with the time stream evaluation assumptions which we cannot afford. The practice cloaks vital social issues in a cloud of empty and unnecessary rhetoric, allowing opinion to pass for expertise and forcing expertise to pass as opinion. Selfserving biases find ample latitude to creep into discount rate recommendations, and once there are uncritically accorded the sanction of scientific and economic respectability (c.f. the documentation of of such occurences in the water resources field given by Haveman, 1969). Pressing and relevant theoretical questions fail to receive the attention they deserve, and grave misallocations of resources - the one condition which the economic rationale is designed to prevent - accrue unremarked and persist unappreciated amidst the general confusion. Finally, the apparent and in many cases real caprice of the resulting "social" discount rate decisions robs the entire project evaluation exercise of much of its scientific and political legitimacy (Lipset 1963). Alienated constituencies, rightly distressed at what appears to be the undebatable but arbitrary interjection of unsupported technical opinion into decisions of great moral and political import, find little credibility in the resulting project evaluations and recommendations. More

often than not, the critical decisions regarding appropriate time-stream aggregation assumptions are ultimately reduced to exercises in rhetoric and political power: devoid of knowledgeable content, inefficient in the extreme, and satisfying to no one but the winners of the battle. [see, e.g. the controversy over the third London airport (Mishan 1970), the U.S. Congress Hearings on the PPBS system (U.S. Congress 1969), etc.]

We suspect that there are practical, defensible alternatives to the present social time preference debacle. But these can only be articulated through a critical examination of present difficulties and questions, and a conscientious questioning of even the most time- and tradition-honored presumptions when these are found to be at variance with the realities and ethical precepts of the day.

We turn now to a manifestly incomplete and sketchy review of some of the particular issues which it seems necessary to address with regard to the time aggregation question.

II. Constraints and Structure of the Social Time Preference Problem

[This section as yet unwritten; see Feldstein 1964, Koopmans 1967, and Keeney and Raiffa (Ch.9) 1975 for the formal structure and constraints of the time preference problem].

III. Uncertainty and Time Stream Evaluation

E. An Overview of Opinions

As noted at the outset, the essential unpredictability of the future means that considerations of uncertainty (more precisely, risk, uncertainty, and surprise; see Clark and Swain 1975) are central to the time stream evaluation problem. All of attitudes towards uncertainty can be found in the theoretical and empirical literature. A brief sampling should suffice to convey the disparity of outlooks.

In an early work McKean (1958, pg.64) held risk to be an intangible, the resolution of which was best left to the "sphere of judgement". Dorfman (1962), discussing just this matter, found statistical decision theory not particularly applicable to treatment of risk in a time stream evaluation context, but nevertheless went on to describe several ways in which risks might be evaluated.

In any event the notion of a "risk premium", drawn from business decision making jargon, emerged in the late 1950s and 1960s. Its evolution in the U.S. federal bureaucracy is nicely documented by Haveman (1969). Frost (1971) summarizes a common attitude: "In practice, it is usually appropriate to adopt approximately the bank rate for low discount projects and a rather higher rate if the element of uncertainty is greater". Just why this is appropriate and how high is "rather high" is passed over with marked silence.

The "risk premium" concept became a catch-all for several proposed "adjustments" to time streams of data almost as soon as it was introduced. Havemann (1965, App. B) suggested that

on a presumption of risk aversion, present values of future benefits should be adjusted down, but those of future costs up. Further, the benefit adjustment should be greater than the cost adjustment because of the presumed greater uncertainties in the former.

Bain, Caves, and Margolis (1966), were not of this opinion, arguing instead that

> "the only general justification for introducing a 'risk allowance' of one sort or another into investment calculations would be that some or all water agencies seem to have shown a propensity to make unjustifiably optimistic estimates of future benefits of projects; thus reducing their estimates by such a means as increasing the rate of discount by 2 or 3 percentage points would compensate for their bias in estimating" (pg. 272).

More recently, Fisher and Krutilla (1974) have suggested other modifications of the discount rate, viz. to account for option-value risk costs (1974 pg. 104ff) and even to balance out predicted trends in costs and demands (1975 pg. 360ff).

Finally, Hirshleifer and Shapiro (1969) preface an excellent discussion and summary of existing quantitative recommendations for federal investment discount rates with the following revealing reservations:

> "The figures are not fully comparable, since they were made at varying dates in a period of changing conditions in financial markets. Also, in some cases different types of government decisions were under consideration, so that the comparable private rates would not be expected to be the same. Against all these should be kept in mind the recommendation of some authors that the riskless rate be used... However, it is clear that the figures here include an adjustment for inflationary expectations; the anticipated real riskless rate has probably been rather steady..." (pg. 517).

In light of all this, recall the rationalization upon which a recommendation for market determination of time stream

aggregations must be justified. From Fisher's 1930 Theory of Interest:

> "In such an ideal loan market, therefore, where every individual could freely borrow or lend, the rates of preference or impatience for present over future income for all the different individuals would become, at the margin, exactly equal to each other and to the rate of interest" (Fisher 1930; pg. 106).

The uncertainty issue has clearly wrought havoc with this attractive and elegant view of time preference determination. To find out how and to what effect, it will be useful to explore the various aspects of the uncertainty question in a bit more detail.

F. States, Preferences, and Attitudes: Some Distinctions

Two sorts of basic uncertainty questions are particularly relevant to the discussion of time stream problems. The first concerns that a decision adopted to achieve some specified result will not in fact do so. If I order my roast beef rare in some of the nation's restaurants, there is a fair likelihood it will arrive well-done. At issue is a question of what state or states of the world will in fact result from my decision to specify rare roast. But there is a second sort of uncertainty here as well, reflecting the fact that I'm not really sure that its rare roast I'll want by the time my original decision has taken effect and the roast arrived. I may, by then, want the roast well done instead, or have seen the lobster ordered by my colleague and want that rather than any sort of roast at all. This is not a question of the physical effects of my decision, but rather reflects the possible uncertainty of my preferences at some future time effected by the decision. These two issues of uncertain states of the world and uncertain preferences among those states are discussed in turn in the following sections. Regardless of which sort of uncertainty problem is under consideration, however, an obvious but oft-ignored distinction must be made between the fact of uncertainty per se,

and our attiudes towards that uncertainty (Hirshliefer and Shapiro 1969).

This point is central to the modern view of utility theory, and would not be worth making were it not so often missed in applied evaluation studies. Uncertainty itself, most would agree, is a fact of life. Thus we may be willing to quote the chances that a given event will occur, when a statement that it would (or would not) occur for certain would make no sense. The "chance" estimates may be objectively determined or unabashedly subjective in nature. In either event, the expected value notion lets us in some sense "aggregate" these uncertainties, telling (for instance) the most likely mean result of taking the same gamble repeatedly.

But given any estimate of the physical probabilities of a set of outcomes, our attitudes towards those probabilities are another matter altogether. Thus, given an offer of winning $1000 for sure or taking a 50/50 gamble between $5000 won or $2000 lost, it is perfectly plausible that I would take the sure thing even though its expected value is $500 less than that of the gamble. In such a case, I would be described as "risk-averse", and the $500 differential would in some sense represent the magnitude of my distaste for gambling: for me, "certain" projects may be adopted over uncertain ones even when the latter have expected values equivalent to the former.

The important point here is that attitudes towards uncertainty - in the form of risk averse, risk prone, risk neutral, or other more complex forms of decision rules (Dorfman 1962, Chernoff 1954)- are potentially of the utmost importance in project evaluation. Such attitudes must be explicitly assessed or defined and reflect altogether different characteristics of the evaluation problem than those relating to the assessment of outcome state or preference probabilities per se. It is plausible, for instance, that serious reflection might lead us to conclude that the estimation of uncertainties states resulting from a decision is largely a matter for the relevant experts; that assumptions about future preferences should be approached with

some fair humility, a fair amount of guidance from ethical/ political precepts, and due attention to poets, artists, and sundry other future-perceptive neurotics (May); and that attitudes towards these respective uncertainties are empirical issues to be determined through open and informed soci-political dialog. We do not argue for or against these positions for the moment, but raise them as illustrative of the sorts of distinctions which must be made for a useful consideration of the time problem. In any event, it should be clear that confounding the estimation of uncertainty per se with the assessment of attitudes towards uncertainty and risk taking is entirely without theoretical or logical justification, and can only serve to further confuse an already difficult issue.

G. Uncertainty in Time Stream Projections (Working Notes)

Most of the literature on "risk" in time stream evaluation problems concerns treatment of uncertainties in the "states of nature" likely to result from a specified decision. The relevant arguments are noted here, with the less well developed issue of uncertain preferences reserved for the following section.

1) Uncertainties regarding project outcomes exist and should be dealt with in the evaluation process (Samuelson 1964). Project promoters tend to equate target estimates with actual expected performance values. (Bain, Caves, and Margolis 1966, quoted here on pg. 9). This practice is obviously wrong and should be guarded against. The appropriate response requires explicit estimation of outcome probabilities, not inclusion of a "general", "average", and meaningless correction factor (Bain, Caves and Margolis 1966).

2) Uncertainties regarding project outcomes should be represented as probability distributions of particular outcomes, given alternative decisions. If these distributions are functions of time, they should be stated as such. Although such time functions will occasionally be of a constant compounding form (and thus look similar to a discount rate) this will not

generally be the case. Fixed "risk-premium" additions to base level discount rates are therefore generally inapplicable to even single project evaluations. Because of the project - or decision - specific nature of outcome probability distributions across-the-board treatments of risk education are also inappropriate. Counter arguments (McKean 1958, Hirshleifer et al. 1960, Joint Economic Committee 1968), are all based on a demonstrably false contention that market behaviour is an adequate register of social time preference opinions (Marglin 1963, Feldstein 1964).

3) It follows that uncertainty in project outcomes, and attitudes towards these uncertainties, should not be expressed implicitly in the discount parameter, common practice to the contrary (cf. Hirshleifer and Shapiro 1959 pg. 515). One affirmitive voice is that of Fred Hoffman as Asst. Director, BOB: "While I certainly do not wish to argue that government programs are riskless - on the contrary, they are often subject to considerable risk. I believe that better decisions are likely to result from considering risks explicitly by adjusting the expected costs and benefits than by attempting to relate the average risk of public programs and 'similarly risky' investments in the private sector". (in Hirshleifer and Shapiro 1969).

4. A more serious argument questions the relevance of private attitudes towards uncertainty, to the treatment of uncertainty in evaluating public projects. This is generally posed in the context of whether (individual) risk aversion represents a public cost, but corresponding reasoning can be used for the analysis of a more generally class of uncertainty attitudes. Samuelson and Vickery (1964) crystalized the debate by suggesting that since the governemnt invested in a large number of projects, by the law of large numbers the expected outcome was virtually certain. The government should therefore evaluate projects on an expected value basis, ignoring the potential risk-bearing cost of each individual project as socially irrelevant. Arrow and Lind (1970) develop similar arguments for a perfect market model. But they alter their conclusions dramatically for actual practice. They invoke the government as

risk-spreader showing that [if the returns of any given investment are independent of other investments then] public project risks become insignificant if borne by a large enough public. But if the risk-bearing in fact falls on private individuals, then their risk attitudes should be taken into account in evaluation. It would seem that many environmental impact and regional development proposals might reasonably be viewed as impinging risky time streams on just such private groups, even when the risky costs of the project could be treated as publicly borne. Finally, Fisher and Krutilla (1974) note that when Samuelson's (1954) "public goods" are involved in the decision [i.e. goods for which consumption by one individual does not change amount available for the next], then the "pooling" or "spreading" arguments fail and make sense: for "public goods" (i.e. many environmental attributes), risk-bearing cost of individuals should enter into the evaluation process. This issue seems to stand in need of review with specific respect to its bearing on environmental and amenity impact problems. (sa. references in works cited, plus review in Baumol 1969 pg. 794).

H. Uncertainty in Future Preferences (Working Notes)

1) We cannot know for certain what our state-of-nature preferences or attitudes towards risk will be in the future. This presents an obvious problem for the evaluation of time streams, even if the physical outcomes of project alternatives are known for certain.

2) This uncertainty becomes relevant to the extent that decisions taken now are reflected in time stream values in later periods. To the extent that present decisions have low futurities and/or are easily reversible, the uncertainties regarding future preferences will become less significant.

3) At one level, the uncertain preferences problem can be dealt with via a probability distribution of future utilities. This should be relatively straightforward conceptually if difficult to assess in practice.

4) Under conditions of risk aversion, uncertainties of future preferences will lead to a sort of "risk bearing cost" for the present decision maker.

5) A very important additional consideration concerns the notion of "option value". It is a central postulate of welfare economics that an expansion of choice represents a welfare gain, whereas a reduction represents a welfare loss. Irreversible decisions, or those exceedingly difficult or costly to reverse, will entail a loss of "option value" (Weisbrod 1964) and consequently of welfare. The magnitude of this option value will depend upon the value of resources necessary to restore the opportunity, and the duration of time over which the opportunity is foregone. It is not clear at present whether the option value loss is also dependent on the likelihood of the option being desired, or whether the loss of options should be counted a welfare cost even if no one wants to use the option. Finally, it should be noted that decisions which enrich opportunities should be assigned positive option values.

6) The irreversibility - option value - preference uncertainty relationships seem likely to be exceedingly important in evaluating alternative development proposals, and have received exceedingly little attention in the literature. This disparity should be addressed. Relevant comments are provided by Weisbrod (1964), Koopmans (1964), Arrow and Fisher (1974), Fisher and Krutilla (1974, 1975).

IV. A Methodology for Intertemporal Indicator Evaluation

I.

Here we attempt to give a framework by which the problems of tradeoffs over time may be handled. In this working paper our aim is to get the general ideas down on paper, so much of the background and details are left to the reader's imagination.

First, a brief review of current methods which involve multiattribute analysis. We are aiming at a fairly high level of sophistication and we feel that cost-benefit type analyses which rely heavily on discounting and mysterious factors can be omitted here. There are evidently tradeoffs to be made in which analytical procedure to adopt for any given problem and often a simple technique not only gets quicker results but there is a smaller chance of making a fundamental error. Recognising this but believing that there is a place for more detailed analysis (see for example that by Bell (1975)), we adopt this more detailed approach.

Next we propose modifications of existing procedures to handle uncertainty of future preferences. There are at least three different ways in which this uncertainty can arise, due to uncertainty with respect to how the physical situation (of the world) will develop, due to a natural, but unknown, gradual change in outlook of the individual with respect to those things that concern him now, and thirdly due to new objectives and considerations that were not known at the time (now) that the analysis was performed. We leave out of this discussion the question of new physical factors arising that change the real world surroundings. There is a growing literature on modelling to take account of "surprises", see for example Holling (1973) and Haefele (1975).

Then we discuss the questions of option foreclosure, intergenerational tradeoffs and the general problems associated with decisions in the public rather than private domain. We have less to offer here in concrete terms but suggestions are made.

Finally we examine the question of resolving inconsistencies

that arise by considering separately long term and short term issues.

J. The Current State of the Art

Given a set of objectives or attributes, $x_1,\ldots,x_n$ a utility function $u(x_1,\ldots,x_n)$ possesses the property that for two uncertain consequences $\tilde{\underline{x}}$ and $\tilde{\underline{y}}$, the decision maker prefers $\tilde{\underline{x}}$ to $\tilde{\underline{y}}$ if $[E\{u(\tilde{\underline{x}})\} > E\{u(\tilde{\underline{y}})\}]$. We will not go into it here but there are independence assumptions which allow this utility function to be assessed using only one or two dimensional marginal utility functions, for details see Keeney and Raiffa (1976).

In particular, with respect to time streams Fishburn (1965), Meyer (1970, 1976) and Bell (1975 a) have given assumptions which allow simplified forms of the utility function, the simplest expressing $u(\underline{x})$ as a sum or product of one period utility functions:

$$u(\underline{x}) = \sum_{t=1}^{T} k_t u_t(x_t) \qquad \text{(i)}$$

or

$$1 + ku(\underline{x}) = \prod_{t=1}^{T} (1 + kk_t u_t(x_t)) \qquad \text{(ii)}$$

where the k, k_t's are constants. See Meyer (1969) or Keeney (1975a) for details.

It is worth mentioning how these k_t's are assessed since we will use it later. The procedure is virtually identical for (i) and (ii) but we will show the harder case (ii). Utility functions may be scaled with the worst possible outcome of period t at 0 and the best at 1. Note the underline which emphasizes that this best/worst consequence need not be constant over time. Consider the question - "Suppose you are faced with a time stream in which every consequence is at its worst level, but that you could raise precisely one of these from worst to best, which would you choose"?
Whatever the answer j_1 say, we then find the second best, j_2 and so on. This shows that $k_{j1} \geq k_{j2} \geq k_{j3}\ldots\ldots$

Now we ask if you must choose between a stream with all at their worst except j_1 which is at its best, or a lottery giving a probability p at a stream with all at their best and 1-p at all their worst which would you choose? Which value of p would make you indifferent? The value of p, p_{j1} say, is the value of k_{j1} This may be repeated for each index to obtain all the k_i's (though there are better ways). Now to find the remaining constant k, solve

$$1 + k = \prod_{t=1}^{T} (1 + kk_t)$$

which is the situation that (ii) gives if all consequences are set at their best values.

Interpret the k_t's as the relative value of the tth attribute. Note that u_t does change if the range changes. If we make the worst consequence in the tth period much worse then k_t should rise.

K. Uncertainty of Future Preferences

One of the difficulties inherent with doing anything analytical with time stream preferences is that all of utility theory is based on a single decision maker who knows his own mind. The problem of establishing utility functions for groups of people is largely unsolved precis because there is no single decision maker (see Kirkwood (1972), Keeney (1975b)). In our case our single decision maker does not know for sure what will be his preferences next year, and occasionally even tomorrow.

This uncertainty stems from three circumstances apart from the short term reversibility of preference in the brain These we will discuss in turn.

a) It depends what happens

For a time stream $x_1, x_2, x_3, \ldots, x_{10} \ldots\ldots$ our preferences for events in period 10 may depend on what happens in periods 1 - 9. An Englishman who has never been to the U.S. will not care less who wins the World Series in period 0 but perhaps if

he lives there during periods 1 - 9 he might care by period 10. Of course he still may not, and it is this assumption that preferences for what happens in a given year do not depend on the particular set of circumstances that preceded it, that is incorporated in models (i) and (ii). We allow that there is considerable interest in the World Series in period 10 but none in period 0 so long as that interest is independent of the circumstances in periods 1 - 9. Thus models (i) and (ii) would not be suitable for our example.

These extra complications can be handled by assessing larger dimensional utility functions but this is undesirable if the dimensions get above 2. Bell's formulation allows explicit dependency up to k periods back and requires assessing k+1 dimensional functions, so that k = 1 (or a sort of Markov property) is the most that should be attempted unless other assumptions can be found. Meyer (1976) has a promising idea of using "state descriptors" an idea similar to that of sufficient statistics, to describe the salient features of the events in the past. One such state descriptor for our example might be SD = Number of years spent in the U.S.

b) One's views might change

As time goes by it may be that although our views concerning the relative merits of our objectives do change according to how things develop, they may also change due to external factors, incidents that weren't anticipated and so on. We can anticipate now that that will happen, but what should we do about it? Consider model (ii) and suppose that $u_1(x_1)$ the utility for the first period is a function of s attributes $x_1 = (x_{11},\ldots,x_{1s})$, and that $u_T(x_T)$ is also a function of the same attributes $x_T = (x_{T1},\ldots,x_{Ts})$. For simplicity suppose that $u_T(x_T)$ is independent of the preceding history $x_1,\ldots,x_{T-1}$.

The function u_T is uncertain, so suppose we assess a probability distribution over all possible u_T's perhaps indexed by a parameter θ say. So $u_T(\theta,x_T)$ is the utility function with probability density $p(\theta)$ (see Kirkwood (1974)). Suppose that, given θ, the worst consequence is $x_T^0(\theta)$ and the best $x_T^*(\theta)$ and that

$$u_T(\theta,x_T^0(\theta)) = 0 \quad , \quad u_T(\theta,x_T^*(\theta)) = 1 \quad .$$

Interpret the situation as follows. Suppose the probability density is discrete with two non-zero points θ_0 and θ_1. With probability $p(\theta_0)$ at time T you will be in mind $u_T(\theta_0,x_T)$ and with probability $p(\theta_1) = 1 - p(\theta_0)$ you will be in mind $u_T(\theta_1,x_T)$. Suppose further that $p(\theta_0) = p(\theta_1) = 1/2$.

At time zero (now) you may choose between two options either

$$x_T^0(\theta_0) \quad \text{if} \quad \theta = \theta_0 \quad \text{and} \quad x_T^*(\theta_1) \quad \text{if} \quad \theta = \theta_1 \qquad \text{(iii)}$$

or

$$x_T^*(\theta_0) \quad \text{if} \quad \theta = \theta_0 \quad \text{and} \quad x_T^0(\theta_1) \quad \text{if} \quad \theta = \theta_1 \quad . \qquad \text{(iv)}$$

Which do you prefer? Say the former for example. Now we ask, given the second alternative (iv) for sure or a (p,1-p) lottery between (iii) and

$x_T^0(\theta_0)$ if $\theta = \theta_0$ and $x_T^0(\theta_1)$ if $\theta = \theta_1$. (v)

What value of p would make you indifferent? Call it p_0. Now suppose $p(\theta_0) \neq p(\theta_1)$, in particular suppose that $p(\theta_0) = 2/3$ and $p(\theta_1) = 1/3$, and that $p_0 = 1/2$. Given these new circumstances, what should be the preferred option between (iii) and (iv)?

Each represents, effectively, a 1/3 chance at the option $\{x_T^0(\theta_0), x_T^*(\theta_1)\}$ and a 2/3 chance at $\{x_T^0(\theta_0), x_T^0(\theta_1)\}$, and so indifference should hold.

If the relevant independence properties hold regarding preferences for x_T given θ_0 with respect to values of x_T given θ_1 and vice versa we may assume one of the model

$$u_T(x_T) = \int_\theta k(\theta)p(\theta)u_T(\theta,x_T)d\theta \qquad \text{(viii)}$$

$$(1+k^*u_T(x_T)) = \prod_\theta (1+k^*K(\theta)p(\theta)u_T(\theta,x_T)) \qquad \text{(ix)}$$

where $k(\theta)$ are the weights obtained in the fashion of p_0, $p(\theta)$ is the probability distribution of θ and

$$1 + k^* = \prod_\theta (1+k^*K(\theta)p(\theta)) \quad .$$

As a simple example suppose that x_T is a scalar and

$$u_T(\theta,x_T) = -e^{-\theta x_T}$$

and that $p(\theta) = r\, e^{-r\theta}$, $0 \leq \theta < \infty$

$k(\theta) = 1$ and we use model (viii). Then straightforwardly we get

$$u_T(x_T) = -\int_0^\infty r\, e^{-r\theta} e^{-\theta x_T} d\theta$$

$$= -\frac{r}{r + x_T} \quad .$$

c) A new objective may arise

In the process of creating a utility function one goes through the identification of objectives and creates a number attributes $x_1,\ldots,x_s$ accordingly. But suppose by the time period T comes around there are new objectives $x_{s+1},\ldots,x_S^*$. What then? (We need not worry about objectives which lose their importance, that is covered in section b) above).

For simplicity suppose that $u_T(x,y)$ has only two attributes only one of which, x, is explicitly recognised at time zero. Suppose that, had we known of y we could have established that one of the forms

$$u_T(x,y) = k_1u^1(x) + k_2u^2(y)$$

or

$$1 + ku_T(x,y) = (1 + kk_1u^1(x))(1 + kk_2u^2(y))$$

was appropriate. Suppose also that the probability density function $p(x,y)$ of an occourence (x,y) (taken from the physical model) is separable i.e. $p(x,y) = p_1(x)p_2(y)$, then the criterion by which we judge events, namely the expected utility is

$$\int u_T(x,y)p(x,y)dxdy = \int k_1u^1(x)p_1(x)dx + \int k_2u^2(y)p_2(y)dy$$

$$= \int k_1u^1(x)p_1(x)dx + k_2c \qquad (x)$$

The other case is

$$\int (1 + ku_T(x,y))p(x,y)dxdy = (1 + kk_2c)\int (1 + kk_1u^1(x))p_1(x)dx \qquad (xi)$$

where $c = E\{u^2(y)\} \leq 1$.

From these we can see that a useful approximation to $u_T(x,y)$ is given in each case by a functional form $\alpha u^1(x) + \beta$ where in case (x)

$$\alpha = 1 \qquad \beta = \frac{k_2c}{k_1}$$

and in case (xi)

$$\alpha = k_1(1 + kk_2) \qquad \beta = k_2 c$$

Notice that if models (i) and (x) are used together or if (ii) and (xi) are used together (both additive and both multiplicative) then this missing objective aspect can be ignored. Otherwise this effect acts as a weighting factor which reduces the importance of x. We have ignored in this draft the question of how the estimate k_T in (i) or (ii) is affected by the presence or absence of y.

L. Option Foreclosure

A concern with regard to decision making which has impacts over time is that future circumstances, or preferences may determine that the current decision was not only "wrong" but also has prevented anything being done to correct things. Building a dam on a site of historical interest and beauty may be "correct" now with today's concerns and preferences, but in 10 years time all may be changed and there is no reversibility. (For further examples see Walters (1975)).

If the methods of the last section on "Uncertainty of Preferences" is applicable then the question of option foreclosure can be handled. The difficulty of course lies in getting a satisfactory priori over future preferences and from a modelling point of view, for events. There seems no way of planning for completely unexpected events, (cf. Bell and Clark (1976)), other than by having a very diffuse prior.

M. Integenerational Tradeoffs

Throughout this discussion of methodological techniques we have referred to period T in the future, and impliciately assumed that the concerns of that time were with respect to the same individual who now considers them. Suppose that T is expressed in terms of generations, or centuries or millenia Using the techniques of uncertain preferences we can see that the tendency would be for us to exercise extreme caution -

unless we weigh their preferences quite lowly, that is, have k_T very small.

This is done in practice for the pragmatic reason that we would never use another sack of coal or barrel of oil again, and this is not only intolerable but evidently not the way things need to be. We are trying here however to establish a methodology by constructive means rather than by empiricism.

There is certainly an argument on moral grounds to have $k_T = k_1$ and if we think in terms of per capita value perhaps k_T should be related to the population, in which case we would eventually have k_T much larger.

Though our analysis has not been detailed (or careful!) we feel that the last paragraph is sound and practical. We still arrive at the same conclusions but through section b) in the "Uncertainty of Preferences" section, that we weigh future generations less because of the uncertainty we have concerning their likes and dislikes, however because we include a wide range of utility functions as possibilities, decisions now that have an extreme effect on the future will be weighted negatively and heavily.

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