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The Precautionary Principle for Environmental Management: A Defensive-expenditure Application

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The Precautionary Principle has emerged in response to the need for an effective method for dealing with risks and uncertainties in environmental management. In essence, the Principle requires action to prevent serious and irreversible damage even before harm can be scientifically demonstrated or economically assessed. Proponents argue that the Principle should be applied in situations where both the probability and value of irreversible damage are unknown. The lack of these particular data prevent a full cost–benefit analysis, but permit application of the Principle through the defensive-expenditure approach. How much would the community be required to pay to fund alternatives to maintain the environment and so defend existing levels of utility? Through the application of risk analysis and the stochastic dominance technique, a range of options and outcomes can be examined incorporating the using available information within a framework consistent with economic rationality. An extended risk simulation is applied to an environmental issue where there is a risk of serious and irreversible damage to the environment, namely, protection of the Barmah-Millewa forest-wetland in Australia.

Keywords: Precautionary Principle, stochastic dominance, risk and uncertainty, defensive expenditures.

1. The Principle

The issues of risk and uncertainty have long been a concern for society, with natural hazards to human health and safety providing the impetus for many welfare improvements. The Precautionary Principle has however, evolved in response to an alarming increase in human induced environmental hazards arising from many technical developments. The Precautionary Principle focuses attention on issues where the cause and effect relationships are uncertain or indeterminate, and where the likelihood of outcomes is also uncertain, if not unknown. In essence, the Precautionary Principle

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requires action to be taken to prevent serious and irreversible damage even before harm can be scientifically demonstrated or economically assessed. This means that environmental management decisions are to be made in the absence of primary empirical data, whenever scientists suspect a serious and irreversible outcome.

Since the framing of the term "Precautionary Principle", there have been various versions of the terminology used to describe it. The definition adopted in Australia is broadly consistent with others, at least in the initial sentence, stating that:

> where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the Precautionary Principle, public and private decisions should be guided by:
> (a) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment, and
> (b) an assessment of the risk-weighted consequences of various options.
>
> Intergovernmental Agreement on the Environment, May 1992, para 3.5.1.

The generally accepted aims of the Precautionary Principle include shifting the burden of proof, making the inherent uncertainties explicit, and the encouragement of greater social debate about acceptable levels of environmental risk.

Our inability to know "all", combined with our overweening desire to ignore uncertain hazards that threaten to restrict economic activity, is the prime motivation behind the development of the Precautionary Principle. If we did know "all" the relevant pieces of information, and assuming each component could be attributed with an economic value, then the choice between options could be weighed up in terms of the costs and benefits. In reality, of course, this is not so. However, from an economic analysis point of view, the best way to begin to appreciate the gaps in information is to identify all that is known and can be valued. Then the areas of limited understanding and areas of great uncertainty can be brought into focus and subsequently incorporated in the analysis through various decision-making techniques. This way the basic cost-benefit analysis can be substantially broadened to function more as a questioning tool rather than a provider of utility maximizing solutions. While the goal of utility maximization remains important, other objectives such as the maintenance of ecological integrity and social equity can be attributed with at least equal importance, with net present values being only one informative component.

The extension of cost-benefit analysis through risk simulation and the application of the stochastic dominance criteria enables the incorporation of ecological probability data and environmental benefits data in a manner that highlights the inherent uncertainties. It also provides a powerful tool for comparing the net present value outcomes derived for a wide range of contingencies in the available data. As George and Shorey (1978) acknowledge some 20 years ago, no account of clever statistical [or computational] manipulation should aim to conceal the fact that there are no tidy solutions to dealing with risk and uncertainty. This extended analysis serves to indicate its own limitations in situations where methodological and epistemological uncertainty begins to dominate. It is at this point that social debate and input becomes more critical, requiring alternative decision criteria.

The Precautionary Principle does not offer direct insights into how precaution is to be applied. Rather it raises important questions, such as: what constitutes a serious and irreversible threat; at what level of risk and uncertainty should strict precautionary measures be adopted; how much is society required to pay to reduce the risk of serious or irreversible damage; and how much environmental risk is society prepared to accept.

As Suter (1995) suggests, new ways of thinking need to be developed whereby economists and ecologists work together to identify the problems and their solutions. If ecologists can define the ecological functions that need to be maintained, economists can set about finding ways to influence human behaviour. In this context, and through the analysis of an environmental problem that poses a threat of serious and irreversible damage, this paper aims to explore the application of precaution. By drawing on ecological expertise to define the general likelihood of irreversible damage, the Principle can then be set in the context of economic analysis and risk simulation.

Individuals and communities are often willing to spend money to defend their environment from damage because they believe the benefits they receive are greater than the cost of defence. In other words they are willing to pay to defend their existing levels of utility derived from those environments. These sums of money are, in fact, minimum levels of the net-benefit from maintaining the environment. This defensive-expenditure approach to the valuation of unpriced benefits is now applied as a framework to estimate the expenditures that the community would be required to make to maintain an environment. These expenditures provide useful information about the community's desire for environmental precaution.

The objectives of the paper are therefore: (a) to estimate the amount that a community would be required to pay, or opportunity costs that a community would be required to bear, to defend a particular environment in a range of circumstances; and (b) to explore the application of the Precautionary Principle as a guideline for environmental management. Application of the stochastic dominance technique, in the risk simulation, provides a substantial extension to cost-benefit analysis, whereby the many contingencies of complex environmental problems can be explored.

The case study concerns water allocations for the environment to maintain vegetation associations of the Barmah-Millewa forest-wetland, and thereby contribute to the maintenance of the Murray River system. In this case, scientists agree that there is a very high likelihood of serious and irreversible damage to the river system if the riparian wetlands are not maintained in a healthy state. Yet, they don't know much about the type, extent and time frame of such damage.

2. Current status of the Principle

The Principle has already been incorporated into many international agreements and into environmental legislation by more than 40 countries. In Australia, the Precautionary Principle has been incorporated into the Inter-Government Agreement on the Environment (IGAE), and is one of the five guiding principles of the National Strategy for Ecologically Sustainable Development (ESD) (Commonwealth of Australia, 1992). Most states in Australia are yet to directly incorporate it in either policy or legislation. However, reference to ESD in legislation is now common place, even at local government level, and therefore inclusion of the Principle is implied.

The influence of the Precautionary Principle on environmental management remains to be seen, but according to Harding and Fisher (1994), it has captured power politics and should not be underestimated. Thus far we know it has been explicitly included in the following Acts, policies and strategies for environmental management:

- *NSW Protection of the Environment Administration Act* 1991 s6.2a;

- *Water Board (Corporatization) Act* 1994 s21.1b; and
- *SA Environmental Protection Act* 1993 s10.1b(iv).

The degree of precaution that the community should adopt is clearly a central ecological, social and economic issue that may well be interpreted through the judiciary. Several cases have already come before the courts where the Precautionary Principle has been a central factor in the deliberations—such as, *Leatch*, 1993 LGERA 271 and *Nicholls,* 1994 LGERA 397. O'Riordan and Cameron (1994) believe the Principle should enter voluntarily, and not by force or magisterial command. However, Bates (1995) pointed out that the legal profession would, given the opportunity, push the boundaries of its interpretation. Regardless of ones view of the usefulness of the Precautionary Principle in environmental decision making, it therefore must be taken seriously.

3. The treatment of uncertainty

Does uncertainty really matter in terms of choice, analysis, and the reliability of an analysis? It does when future outcomes are perceived to pose a serious and irreversible threat, where the choice of policy or option turns on the uncertainties, and where the community's aversion to environmental risk and uncertainty is an important component in the decision-making process.

Uncertainty is not limited to the realms of scientific knowledge and information. The application of cost-benefit analysis, with its standard economic criterion of net present value, is equally fraught with uncertainty. This technique requires dollar values for each cost and benefit, and requires that money values reflect true social values. Market prices may not reflect social values because: (a) not all costs and benefits have a market, or exchange value; (b) not all market-based variables are subject to the forces of supply and demand or free of market failings; and (c) not all the costs and benefits can be identified and included, particularly when the outcomes of alternative actions are unknown.

These difficulties have led some economic analyses to be undertaken without the values of environmental benefits—or without reference to their likely impacts. Nevertheless, cost-benefit analysis does offer the following range of ways by which these analytical limitations can be moderated.

- Perform sensitivity analyses on the best estimates of each cost and benefit.
- Calculate expected values of the net-benefits.
- Estimate and include option values as the willingness to pay for insuring that a good or environment will be available in the future.
- Generate probability distributions of each cost and benefit, and use the stochastic dominance technique and risk simulation to identify preferred options.

Typically, the Precautionary Principle is to be applied in situations where both the probability of environmental damage and the value of the damage are unknown. The information available to the analyst is therefore restricted to the costs and benefits of other outcomes in the decision, and perhaps to probability distributions for these other outcomes. The analyst can therefore, only calculate partial net present values of each management option. It is from this level of information that the current analysis begins. The difference between the partial net present value for the existing situation and that for an option to defend the environment is the required community willingness to pay—and the opportunity cost of implementing a precautionary measure.

The use of probability distributions, and stochastic dominance in a risk simulation, offers useful ways to extend a cost-benefit analysis to take greater account of some of the inherent uncertainties in environmental management. Then the preferred option, using the partial net present values, can be identified through the criterion of first degree stochastic dominance. The stochastic dominance approach, therefore, provides a comprehensive way to explore the application of the Precautionary Principle.

The use of the criterion of first degree stochastic dominance requires only the assumption that the marginal utility of income is positive—increases in income lead to increases in utility. The further assumption, that marginal utility of income diminishes as income rises, permits use of the criterion of second degree stochastic dominance. This criterion can assist in the choice of options when first degree stochastic dominance cannot be applied.

4. Method: combining expected utility, risk, defensive-expenditures

Application of risk simulation to this type of environmental problem requires that the theoretical consistency of expected utility maximization be combined with stochastic dominance techniques, and with the empirical usefulness of monetary assessments of the costs and benefits. Lesser (1989) has provided a method to achieve this.

4.1. THE CONCEPTS

The expected utility approach to economic choices rests on the belief that "... individual consumers can incorporate risk [and uncertainty] in a rational manner such that decisions which maximize the consumer's expected utility would be made" (Lesser, 1989, p39). Individuals make decisions to maximize their expected utility, so changes in welfare for society as a whole could be measured directly if an aggregate utility function for all individuals could be specified. In this way, risk and uncertainty can be incorporated in a theoretically consistent manner—that is, in a manner which maximizes expected utility. However, according to Lesser (1989), there have been no applied studies that postulate utility functions incorporating societys' aversion to risk and uncertainty. Nor do there appear to be any studies that have first postulated a utility function incorporating risk and uncertainty, and then derived estimates of willingness to pay to measure benefit. Just *et al*. (1982) and Hausmann (1981) discuss the traditional reasons for this omission from the literature.

The method involves the generation of probability distributions for each cost and benefit, estimation of net-benefits, and the application of the stochastic dominance criteria. It allows the analyst to impose a preference order on a set of options without knowledge of the underlying preferences as such. Stochastic dominance allows for pairwise comparisons of risky prospects such that all individuals, whose utility functions belong to a given set, will prefer one of the prospects. In this way, it provides theoretically-correct orderings of options without the need for specific utility functions. As Zerbe and Dively (1994) argue, this ordering is consistent with maximization of expected utility without any knowledge of the decision-makers utility functions. As they further show, this approach facilitates the estimation of how much the community would have to pay to support a particular option—a substantial argument for the method.

4.2. THE MODEL

We begin with an indirect utility function and solve for the value of the net-benefit, or compensating variation measure of consumers surplus. We then go on to incorporate the measure into utility functions, and to derive distributions of partial net-benefits from each of several precautionary options. This measure of net-benefit is the maximum amount that an individual would be willing to pay to obtain an option or a good. In the present research, the net-benefits refer to all the outcomes except those directly from the preservation of the particular environment, and each management option offers several kinds of cost and benefit. The present value of these net-benefits is therefore referred to as a partial net present value, and the difference between partial net present values of options is the amount the community is required to pay for one option rather than another.

We adopt Hicks' concept of compensating variation (CV) as the measure of net-benefit, and define the CV of an option as follows.

> *The benefit is measured as the reduction in income (or amount the individual is willing to pay) after the option has been undertaken, that would leave the individual at the same level of utility as before the option.*

Thus:

$$\text{Utility before the change} = \text{utility after the change} \tag{1}$$

This identity may be expanded in the context of the case-study.

$$U(Y, Q_{be}, Q_{aog}) = U(-WTP, Q_{ba}, Q_{aog}) \tag{2}$$

where Y is income, Q_{be} is quantity of benefits from the water allocation in the option which represents the existing situation, Q_{ba} is quantity of benefits after a new option has been implemented, and Q_{aog} is quantity of all other goods that are consumed. Thus if Q_{ba} exceeds Q_{be}, the willingness-to-pay (WTP) for Q_{ba} must exceed zero—assuming the option that brings the change is considered beneficial and can be treated in isolation from changes in the rest of the economy. The willingness to pay for a particular option that provides Q_{ba} is the measure of the benefit for that particular option. In this case, the quantity of, and benefits from, all other goods stay the same.

To apply this kind of utility function and concept of benefit, suppose that the decision maker must choose between two options G and H, and that there are m states of the world. We now attempt to order these two options, using stochastic dominance. For option G, we can define its benefit (WTP) for each state (i) of the world through the following equation.

$$U_i(U_i, Q_{be}, Q_{aogi}) = U_i(Y_i - WTP_{baGi}, Q_{baGi}, Q_{aogi}) \tag{3}$$
$$\text{for } i = 1\ldots,\text{m}$$

Similarly for H,

$$\text{U}_i(Y_i, Q_{be}, Q_{aog}) = U_i(Y_i - WTP_{baHi}, Q_{baHi}, Qaogi) \tag{4}$$
$$i = 1\ldots,\text{m}$$

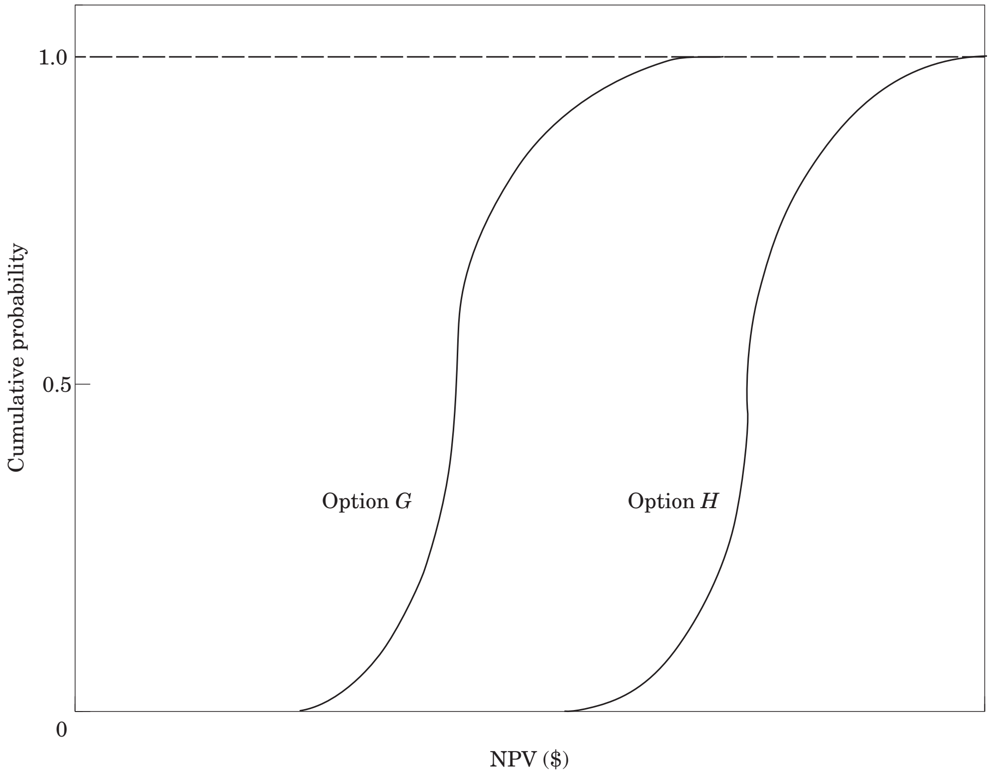

Figure 1. Distribution of net present values for two options (G and H), where each option is associated with a particular level of damage to the environment.

If probabilities P_i, ($i=1\ldots,m$) exist for any given state of the world i, Equations (3) and (4) can be used to derive probability density functions [$f_G(WTP)$ and $f_H(WTP)$] and cumulative probability functions [F(G) and F(H)] for the net-benefits of each option. The expected utility associated with a given option, following von Neumann and Morgenstern (1947), is equal to $\Sigma\ P_i.U_i$.

Under what conditions can stochastic dominance help to rank the two options G and H? If $WTP_{hi} > WTP_{gi}$ for all states of the world i, then F(H) >F(G) for all states of the world. That is, the cumulative probability function F(H) always lies to the right of F(G) as in Figure 1. The community is therefore willing to pay more for option H than option G in all states of the world, and so the decision maker always prefers H over G—following the criterion of first-degree stochastic dominance.

When F(H) dominates F(G) in this way, the principles of stochastic dominance can be used to derive bounds on willingness-to-pay. By restricting attention to utility functions solely dependent on income, upper and lower bounds for willingness-to-pay for particular options will be consistent with the maximization of utility. For example, in the case where option H dominates option G, the lower bound is the minimum amount necessary for the two options to be preferred equally. To determine this bound, the inferior distribution is shifted to the right so that for some state j, F(G)=F(H). The upper bound is the maximum amount necessary for option G just to dominate option H over all states of the world. It is the amount that gives the necessary parallel shift for F(G) >F(H).

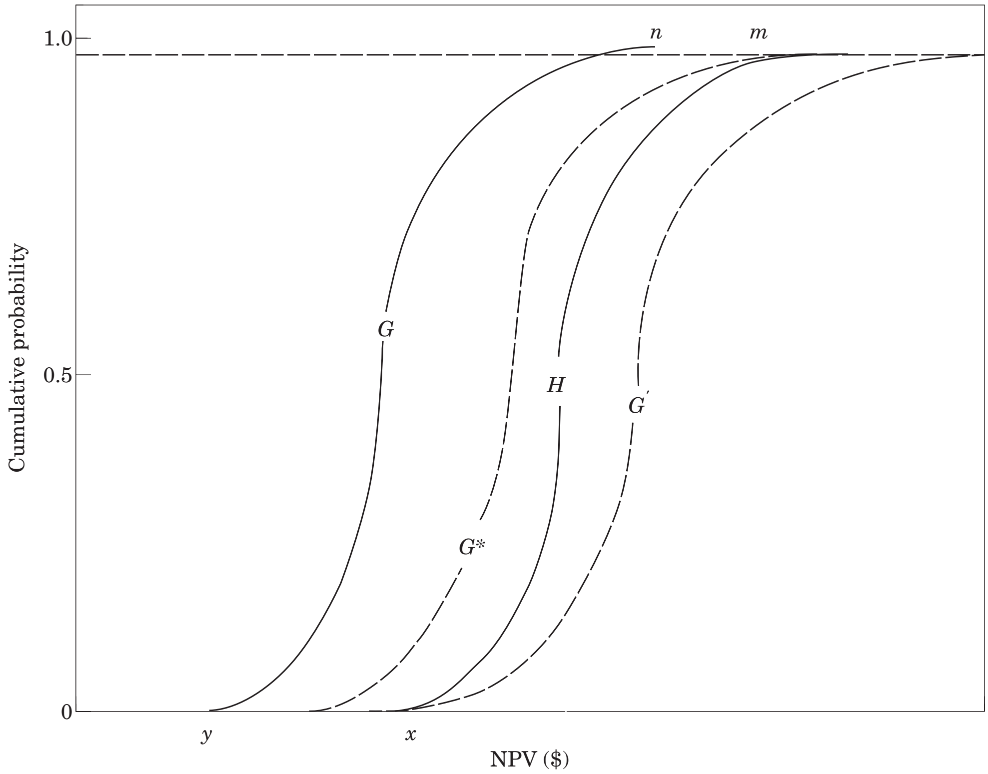

Figure 2. Estimation of bounds to the required defensive expenditure for option *G* to be adopted.

Derivation of these policy-relevant bounds, following Lesser (1989), is illustrated with the cumulative probability functions of options *G* and *H* in Figure 2. Option *G* has a lower net present value at all levels of probability, and so is more costly than option *H*. But assume it provides the extra unpriced benefit of less environmental damage. These bounds are derived as follows.

(a) The sum $xy is the difference between the lowest net present values of options *G* and *H*. Assume it is also the largest difference between the two functions. Add $xy to all values for option *G* and we have function *G′* which just touches function *H at x but otherwise lies to the right of H*. Function *G′* is now equal to, or dominates, *H* over all its length. The sum $xy is the maximum value that the unvalued benefits of option *G* must have, for *G* to be preferred over *H*. The sum $XY is also the maximum that the community would be required to expend, or bear as an opportunity cost, for *G* to be adopted over *H*.

(b) The sum $mn is the difference between highest net present values of options *G* and *H*. Assume it is also the smallest difference between the two functions. Add $mn to all values for option *G* and we have function *G** which just touches function *H at m. Function H* is now equal to or dominates *G* over all its length. The sum $mn is the minimum value that the unpriced benefits of option *G* must have, for *G* to be preferred over *H*. Equally, the sum $mn is the minimum that the community would be required to expend, or bear as an opportunity cost, for *G* to be adopted over *H*.

(c) We therefore have the:
- maximum value that the community is required to pay (xy) to obtain the unvalued advantages of *G* over *H*, and the
- minimum value that the community is required to pay (mn) to obtain the unvalued advantages of *G* rather than *H*.

4.3. THE PROCEDURE

A direct way to implement the model is: (a) to convert the uncertainty inherent in the economic estimates for each variable into estimates of risk, defined as probabilities that the level of each variable will occur; (b) to calculate net present values for each management option; (c) to analyse the distributions of partial net present values in terms of stochastic dominance; and (d) to identify the amounts the community must pay for precautionary options to defend the environment. The levels of ecological risk associated with each option can then be considered explicitly by the decision-makers, along with economic and other considerations. Following Francis (1992), the steps in this kind of risk simulation may be detailed as follows.

(a) Define the management options, one of which will preserve the environment—according to best available knowledge.
(b) Express the attainments on the economic variables in terms of probabilities. For simplicity, these probabilities might be expressed as triangular probability distributions using the minimum, mean and maximum values of each variable.
(c) Determine the distribution of net present values associated with each management option, where each option is associated with some level(s) of preservation of the environment (as options *G* and *H* in Figure 1).
(d) Derive information on the partial net present values of each option—when the benefit of preservation cannot be assessed.
(e) Derive information on the maximum and minimum amount the community would have to pay to adopt precautionary options.

This procedure is applied to the following case study. All the major economic variables, except the benefits from preservation of the environment, were estimated as indicated above. The net present values of the different options are only partial net present values because they exclude preservation benefits. But the difference between the net present values of the "preservation option" and the existing situation, is the required defensive expenditure.

5. The case study

5.1. AN ENVIRONMENTAL ISSUE—ALLOCATIONS FOR THE ENVIRONMENT

Water allocation for the environment is an important issue for Australia, and the continued health of Australia's major water systems depends partly, on the maintenance of riparian environments. The Barmah-Millewa forest-wetland is one of the major riparian environments that are under threat of serious and irreversible damage. Extensive regulation of the River Murray system has created flow regimes that are incompatible with the natural system. However, the consequences and effectiveness of different management options in halting or reversing the negative trend are uncertain. In acknowledgement of the importance of riparian environments, the Murray Darling

(A) **Current situation**-no water is specifically allocated to the forest-wetland. However, flows into the forest-wetland do occur but the timing, frequency and depth is out of sinc with the natural regime. Ibis breeding grounds and some stressed areas of woodland are allocated water on an *ad hoc* basis when it is plentiful.

(B) **Allocation of water (100 GL/yr)** - approximately half the forest will receive water depending on its management and the effectiveness of the small scale works in distributing the water. However, timing, frequency and flood depth to most of the forest-wetland area will continue to differ from a natural regime.

(C) **Increased allocation of water (912 GL/mth)** - approximately 84% of the forest will receive water at the right time (that is, during the winter/spring months), but only for 5 out of 10 years instead of the required 9 out of 10 years. Areas will remain permanently inundated during the summer and all year round due to high river levels which prevent summer drainage.

(D) **Near natural flows** - water volume, frequency, and timing of floods would be in accordance with natural flood events. This option attempts to recreate the pre-regulation flooding.

Figure 3. Watering options for Barmah-Millewa forest-wetland.

Basin Commission (MDBC) recently obtained an assessment of the watering needs of the Barmah-Millewa forest-wetlands, which drew on many years of scientific research (Maunsell, 1992), but which was fraught with uncertainties concerning flow volumes into and through the forest-wetland and the impacts of different management options on vegetation associations and distributions.

5.2. OPTIONS FOR WATER ALLOCATION

Based on the Maunsell Report and water supply data from the past 100 years, the MDBC simulated many different watering scenarios (Figure 3). From this, and in consultation with the community, the federal government opted for an allocation of 100 gigalitres per year for environmental purposes. From the same scenarios documented and examined by the MDBC, we chose two further options; (A) the current situation of zero allocation to the forest wetland; and (C) increased allocation of 912 GL per month when the Ovens River system is in flood. The original MBDC simulations provided data for a fourth option of near-natural flows (D), which was not formally assessed by the Murray Darling Basin Commission. This option was developed with the help of MDBC staff. While the present regulatory structures cannot easily be removed to achieve a natural flow regime, a 50% reduction in allocation to irrigation would create the desired regime. The weirs (dams) can be kept close to capacity for most of the year, leaving water from rain and flood events in the winter/spring season to top the weir and result in near-natural floods. In 1997 the Governments of the four states through which the Murray River flows, agreed to cap the available water for irrigation at *i*1993–1994 levels with a view to progressive reductions—lending support to the viability of (D) as a real option.

6. Data Collection

6.1. ESTIMATES OF COSTS AND BENEFITS

The Murray Darling Basin Commission provided benefits and costs for each option. However, monetary values for water and timber outputs were taken from Young and Mues (1993) to better reflect true social values or shadow prices.

(a) *Annualised cost of small scale works.* Construction of small scale works is required to divert water to distribute it within the forest.
(b) *Value of hydro-electricity.* The quantity and net-value of hydro-electricity generated at both Hume and Dartmouth dam is dependent on the quantity of water through the turbine, the average head of water, and the different values placed on electricity at different times of the year. The value is taken as quantity of electricity sold times its market price.
(c) *Recreation value of Lake Hume.* Based on user surveys, Pak Poy and Kneebone (1988) estimated the quantity of recreational use of Lake Hume and the local recreational expenditure if the Lake were full all year. If water were taken directly from the lake to create artificial floods in the Barmah-Millewa forest, water levels in the lake and recreational use will be lower than they are under the current water allocation.
(d) *Opportunity cost of irrigation.* This opportunity cost is measured as the water shortfall to irrigation farmers times the shadow price of water. The shortfall is the difference between supply and demand and the shadow price of water is estimated to be between \$9 and \$61 per ML (Young and Mues, 1993).
(e) *Value of timber production.* The value of timber output for each option is derived from the relationship between the frequency of flooding, the yield of timber, and log values. Log royalties range from \$32.50 to \$39/m3 (Young and Mues, 1993). Timber yields, and hence timber revenues, increase with the allocation of increasing amounts of water to the forest.
(f) *Cost of salinity.* The relationship between changed flows and the level of salinity was modelled by the Murray Darling Basin Commission. The cost of salinity on domestic, industrial and agricultural water users was estimated for each option.

6.2. CORRELATIONS BETWEEN VARIABLES

To ensure that the net-present values are as realistic as possible, correlations between costs and benefits are modelled as correlation coefficients within the risk simulation. If

TABLE 1. Correlation coefficients for Option D

Variables	Opportunity cost to irrigators	Hume recreation	Timber output	Salinity
Opportunity cost to irrigators	1 − 0·8	0·8	0·0	
Timber output		1	− 0·8	− 0·6
Hume recreation			1	0·6
Salinity				1

there is a relationship between two variables, the range of stochastic values must be skewed accordingly. For example, if timber benefits increase while recreation value decreases, then there is a negative relationship to be modelled. Hence, the values for each of the variables selected in each iteration of the simulation must be high values for timber when there are low values for recreation—and vice versa.

To illustrate, the correlation coefficients of Table 1 were adopted for option D. Increases in timber revenue are associated, relatively strongly, with increases in opportunity costs to irrigators. But increases in timber revenue are equally as strongly associated with decreases in benefits of recreation at the Hume Weir. In options B and C, increased water allocations to the forest are associated with increased costs to recreation because the water storage in Hume Weir is significantly effected. For option D, however, the weir is kept close to full most of the year with forest watering being sourced from natural flood events.

The relationship between salinity and opportunity costs to irrigation could be both positive and negative depending on circumstances. If the water allocated to the forest stayed in the forest there would be a cost to irrigation but salinity benefits would be unchanged. If the water passed through the forest and were used by irrigation, the opportunity cost would remain unchanged while the benefits to salinity would be decreased. If the water passed through the forest and was not used by irrigation, the flushing effect would increase the benefits to salinity but also increase the opportunity cost to irrigation. The relationship is clearly very complex and therefore a zero correlation was used in the matrix which means the range of values for both variables would not be skewed in any particular direction.

7. Analysis and Results

Option A is the current situation with no specific water allocation to preserve the wetland, and so provides the benchmark. All the costs and benefits for the other options are extra to, or changes from, option A. Thus partial net present values were only calculated for options B, C and D.

7.1. THE PARTIAL NET PRESENT VALUES

The partial values, excluding any environmental benefit values, were calculated as "best" (or most likely values), expected values (using the average of the minimum, best,

TABLE 2. Partial net present values for each option at 5% rate of discount ($m)

Option	"Best"	Expected	Stochastic Min	Stochastic Mean	Stochastic Max
B	−0·943	−2·522	−9·747	−0·668	4·924
C	−7·045	−16·702	−48·828	−15·911	1·644
D	91·023	27·680	−187·466	27·426	144·409

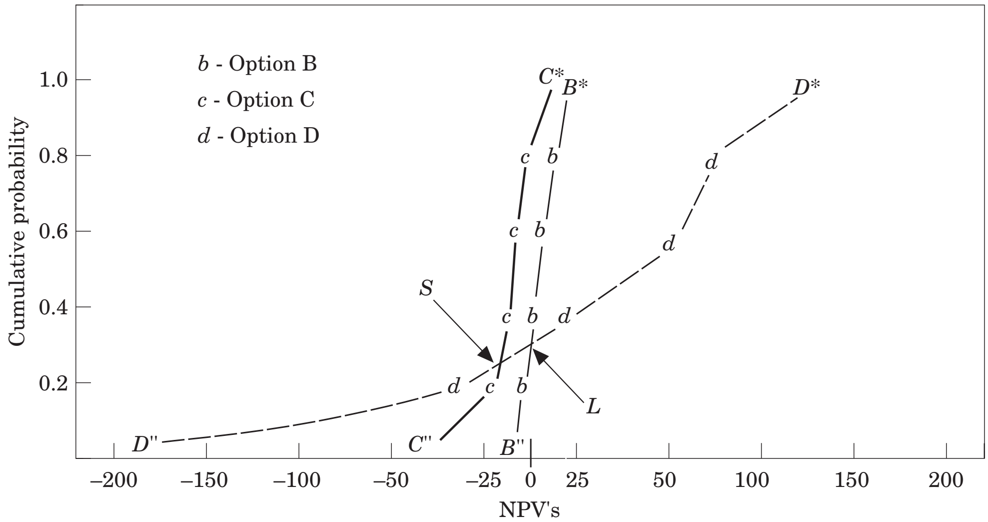

Figure 4. Partial net present values for each option ($m, at 5%).

and maximum values for each cost and benefit), and the range of values from the stochastic analysis. These net present values are now summarized in Table 2.

The cumulative probability functions for the partial net present values, at 5%, for each option are shown in Figure 4. Each function shows the range of present values in a cumulative fashion. Consider the cumulative probability function of option B. There is a probability of 1.0 ($P=1.0$) that the present value is less than (the maximum of) $4.924m, a probability of 0.6 ($P=0.6$) that it is less than $0.294 m, and a probability of 0.0 ($P=0.0$) that is less than (its minimum value of) −$9.747m. These functions illustrate the complete range of partial net present values.

7.2. SENSITIVITY TESTS ON THE CORRELATIONS

The relationships between the variables have been specified through correlation coefficients, as described in section 6.2. The effects of changes in these correlations were assessed in a sensitivity analysis on the net present values of option D. Three correlations were tested because they involved the variables of relatively large magnitude. These were the correlations between opportunity cost to irrigators and Hume recreation, opportunity cost to irrigators and timber revenue, and timber revenue and Hume recreation. The coefficients were reduced from their values of −0.8, 0.8, and −0.8 respectively to −0.2, 0.2, and −0.2 respectively. In this way, the direction of the relationship was maintained, but the strength of the relationship was reduced from strong to weak. The results were as follows.

- The levels of the mean NPV fell by a maximum of 0.7%, but did not rise.
- The levels of the maximum NPV fell by a maximum of 3.1%, and rose by up to 0.03%.
- The levels of the minimum NPV fell by a maximum of 2.0%, and rose by up to 0.5%.

On this basis, changes in the correlations have little effect on the net present values.

7.3. THE REQUIRED DEFENSIVE EXPENDITURE

The functions of Figure 4, and the partial net present values of Table 2, can now be interpreted in terms of the amounts the community would be required to pay to achieve desired levels of prevention of irreversible damage. The values are already in terms of changes from the base option A, so we can interpret them directly in this manner.

As explained earlier, the maximum (minimum) requirement to pay is the maximum (minimum) amount that the cumulative density function for an option would have to be shifted for the option to just dominate the existing situation. These maximum and minimum sums ($m) are shown in Table 3.

Thus, the maximum that a risk-averse society would have to be prepared to pay to adopt D, to eliminate the likelihood of irreversible damage is $187·466m. The minimum values are negative because in the most favourable situation, a net-benefit would be incurred. The information derived from this extended risk simulation enables the analyst to pose the following important questions about the requirements.

- Is the community prepared to pay a maximum of $9·747m to reduce the likelihood of irreversible damage from existing certainty to "high"?
- Is the community prepared to pay a maximum of $48·828m to reduce the likelihood of irreversible damage from existing certainty to "low"?
- Is the community prepared to pay a maximum of $187·466 m to eliminate the likelihood of irreversible damage?

TABLE 3. Minimum and maximum amount the community must be willing to pay (WTP) for reduction in risk

Option	Maximum WTP $	Minimum WTP $	Likelihood of irreversible damage
B	9·747	−4·924	"High"
C	48·828	−1·644	"Low"
D	187·466	−144·409	"Nil"

The latter question is, of course, central to the application of strict Precautionary measures. The community must be prepared to accept the possibility of a maximum cost of $187·466 m if it prefers to adopt a highly precautious approach—even though the mean stochastic net present value for option D is only $27·426m. What is more, the stochastic results suggest that there is a 30–35% chance that the partial net present value will actually be less than $0. This means there is a 30–35% chance that the community would be required to bear a loss to defend this particular environment.

7.4. CHOICE OF A PRECAUTIONARY OPTION

The effective choices are to remain with option B, or move to the more precautionary options of C or D. With a risk simulation, the choice would initially be made with the criterion of first degree stochastic dominance. If a clear choice is impossible on that criterion, second order stochastic dominance would be used, and then second degree stochastic dominance with respect to a function. The choice of option is now reviewed on this sequence of three criteria.

The curves of Figure 4, and their underlying partial net present values, provide the information to choose options based on the criteria of first and second degree stochastic dominance. The curves for options B, C and D all crossed the "origin" of NPV = $0. So none of these options dominate option A in the first degree. However, option B dominates option C in the first degree. The curves for options B and D, and C and D cross each other, and therefore neither B nor C dominate D or vice versa, in the first degree. The criterion of second degree stochastic dominance must therefore be applied to choose between the options. Consider Figure 4. For option B to be preferred to option D, area B"D"L must exceed area LB*D*. In other words, the area of the figure where B dominates (B"D"L) must exceed the area where D dominates (LB*D*) for B to dominate in the second degree. By observation, this is clearly not the case, and so option B does not dominate D and D does not dominate B. Options B, C and D were compared with each other in this way, with the following results.

- Option B does not dominate D, and D does not dominate B.
- Option C does not dominate D, and D does not dominate C.
- Option B does dominate option C.

The information to choose between the options, so far, is therefore indeterminate. The choice must be made on the criterion of second degree stochastic dominance with respect to a function. The analyst must now specify an underlying utility function, particularly with respect to risk. But rather than specify the exact utility and risk preferences of the community, the analyst can specify a risk interval which includes a range of preferences. This interval is defined by the coefficient of absolute risk aversion (R). One option is now said to dominate another if its expected utility exceeds that of the other for all utility functions in the class specified by the interval. Accordingly the coefficient (R) was specified in the ranges 0·000 to 0·001, and 0·001 to 0·002 and the options compared. The results indicate that option D dominates options B and C, and that option B dominates option C. Thus D is the preferred precautionary option.

The analysis for stochastic dominance with respect to a function provides further information on the amount of extra money a community could pay for the dominant option and still be better off with that option. This amount depends on the level of risk aversion—a level that is captured by the coefficient of risk aversion. So the amount of extra money varies with the coefficient (R), as shown in Table 4. Thus at the minimum, the community could pay an extra $18·464 m for D and still be better off with D rather than B.

The major regional or distributional issue for option D is the 50% reduction in water to irrigators with its opportunity cost of $5·15 m per year, or $103 m as a present value. The analysis for stochastic dominance with respect to a function provides information on the extra costs that could be "borne" by the dominant option D, for D still to be preferred, as shown in Table 4. The minimum extra amount is $13·343 m for option D still to dominate B. This is equivalent to a 13% (13·343/103·000) increase

Table 4. Bounds of required willingness to pay for D, rather than remain with B or C ($m, at 5% partial NPV)

Option	Lower bound	Upper bound
	R = 0·000 to 0·001	
B	18·616	22·735
C	34·638	38·758
	R = 0·001 to 0·002	
B	13·343	18·464
C	30·518	34·638

in the opportunity cost—or say a reduction in irrigation water of 63% rather than 50%. The opportunity cost to irrigators could therefore be 13% higher and D would still be the preferred choice.

In 1995, the federal government declared a 100 gigalitre per year increase in water allocations for the environment (option B). This decision followed a process of scientific assessment of the watering needs of the Barmah-Millewa forest-wetland, and subsequent consultation with select community members. Atkins and Ward (pers. comm. 1995), of the Floodplain Ecology Group, considered the allocation to be a minimalist approach in terms of both costs to irrigators and the protection of the forest-wetlands. Option B was assessed here to be associated with the likelihood of continued deterioration of the existing vegetation leading ultimately to irreversible damage.

8. Conclusions: A guideline for environmental management

The choice of an option is, basically, a decision for government, and as such Arrow and Lind (1970) have argued that because the effects of any decision are spread over the whole population, the effect on individual households is negligible, and therefore allowances for uncertainty and risk are irrelevant to Government decisions. Nevertheless, there remain regional and environmental reasons to address uncertainty. First, the size of the effect, as a net present value, may be large for "a group" in society and the risks may be correlated to the income of that group. Second, the existence of irreversibilities and the ability of options to address those irreversibilities, necessitates some frame work for explicit recognition of uncertainties and risks. The concept of defensive expenditure, the Precautionary Principle, and risk simulation provide one such framework.

As Suter (1995) points out, it is not enough to simply say the environment is at risk of serious, irreversible damage without attempting to obtain more specific information. By extending the standard cost-benefit analysis through risk simulation, decision-makers can be provided with ecological, economic and social information for choosing between options of different precautionary strength. This framework captures many of the key issues in the application of the Precautionary Principle in the following ways.

- When the probabilities of irreversible damage and benefits of environmental preservation cannot be estimated, the simulation provides information on the likelihood of any option reducing the risk of serious and irreversible damage and a range of net costs to society of different precautionary options.

- The bounds, on the amounts the community must pay for one option to be preferred to another, provide essential further information on opportunity costs. In doing so, they provide a useful, and extended, sensitivity analysis.

While the application to the Barmah-Millewa forest-wetland is illustrative rather than conclusive, the risk simulation suggests the following results.

(a) Option D is preferable to options B and C, even for partial net present values.
(b) The Murray Darling Basin Commission recommended B, but they had no option D to consider, and option B is preferable to C, in terms of partial net present values.
(c) The mean values of the stochastic analysis suggest that the precautionary option D actually offers a positive net-benefit—even without any benefit for protection of the environment. On this basis (again), D is economically preferable.
(d) But there is a 30–35% chance that the net present value of D is less than \$0, so may involve net costs.
(e) Retention of the chosen option B may actually incur net costs to society.
(f) Estimates of particular costs, such as the opportunity costs to irrigation, show how *m* particular groups in the community need to be compensated to maintain their levels of welfare.

In light of the current policy developments, namely the capping of future water diversions to irrigation at 1993–1994 levels, there would seem to be strong public support for stricter precautionary measures that those proposed in option B.

The defensive-expenditure approach, in conjunction with risk simulation and the use of stochastic dominance techniques, provides a sound framework for considering questions about the level of precautionary action that is ecologically and socially desirable. Even in the absence of empirical data on society's willingness to pay to defend a particular environment, decision-makers can be provided with information about the inherent uncertainties with the trade-offs made clear, thereby improving their ability to apply the Principle of Precaution.

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