# The Opportunity Cost Criterion for Land Allocation

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The present trend to more quantitative analysis for public decisions on land allocation has included studies based on the opportunity cost criterion. This encouraging trend could be promoted through improved use of the criterion. Two important improvements are the analysis of uncertainty and the generation and analysis of a whole schedule of land use plans. The paper illustrates these improvements through empirical application of linear programming to two land use problems in New South Wales.

## 1 Introduction

An encouraging trend in public decisions on land allocation is the increasing use of objective, economic analysis. The ideal of a full benefit-cost analysis, with estimates of all the net social benefits of all land uses, can rarely be achieved. But an analysis with the opportunity cost criterion is possible more often. The social opportunity cost of a particular land use is the net social benefit foregone in the next best alternative. This criterion is attractive for choices between an income-earning use and a use which generates no money income but provides unpriced goods and services. The current conflicts between agriculture and national parks or between forestry and national parks typify these problems. The opportunity cost of the unpriced uses can readily be estimated from the foregone earnings in agriculture or forestry.

Recent government investigations illustrate the use and relevance of opportunity costs. The Commonwealth Government used the criterion in the Fraser Island Inquiry[3] as one basis for its decision to refuse export licences for mineral sands. Similarly, the Working Group on the Woodchip Industry [4] estimated the loss in net money income to forest services through different levels of increased management for environmental objectives. For example, the net present value of the Manjimup Project in Western Australia was estimated to be $8,293,000 when all 420,000 hectares are cut for woodchips. The reservation of 100,000 hectares for environmental purposes reduces the yield of chips and reduces the net present value by (only) 8 per cent to $7,708,000 [4, p. 47]. In New South

Wales, the State Pollution Control Commission[7] used the criterion to support its decision to restrict softwood plantations on the Boyd Plateau.[1]

The criterion is usually implemented as follows. Assume that establishment of a national park will eliminate some income-earning uses and so cause a loss in net social benefit from those uses. The relevant government advisory body will consider these losses and may declare that the park will impose a significant economic cost (and so preservation should not take place). Alternatively it may declare that preservation has no significant opportunity cost or that the level of the opportunity costs cannot be judged as significant or insignificant. The procedure therefore is for a relevant body to offer an opinion on the size of a single opportunity cost relative to their judgement on the (unpriced) net social benefit of preservation. Even without values for the unpriced uses, these decisions could be improved with more detailed and more relevant opportunity cost information as this paper attempts to show.

The object of this paper is to promote the improved use of the opportunity cost criterion. More specifically the paper extends the estimation of opportunity costs through linear programming. The first extension introduces uncertainty and the second generates a schedule of land use plans each of which meets two social objectives in a specific weighted manner. Both extensions are illustrated through empirical application and show how the extra opportunity cost information might be used for allocation decisions. The possible land use activities are described briefly here and more fully in Hitchens[6] and Thampapillai[11].

## 2 Extension for Uncertainty

The criterion for land use choices must incorporate time and uncertainty since the analysis is necessarily *ex ante*. Further, present land uses may be suboptimal and so normative as well as actual land use plans must be considered. As the model demonstrates, the conventional linear programme can readily be adapted to allow for stochastic flows of future benefits and costs for each land type. This approach requires resource managers to estimate the probability of certain future events — in this case the probability of product prices. The appropriate field officers had little difficulty in estimating the necessary prices to identify the particular probability distributions for the Hitchens' study[6]. The approach is applied to a decision on land use on the north coast of New South Wales.

### 2.1 The Model

The combination of simulation and linear programming is a suitable framework to estimate and examine social opportunity costs. The model

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[1] Social opportunity cost is the lost net *social* benefit in the next best alternative. The applications to Fraser Island, woodchipping and the Boyd Plateau appear to estimate opportunity cost as lost net *money* benefit. This interpretation ignores the external costs and benefits of the alternative. It uses money prices which may be distorted by unemployment, protected or imperfect markets and ignores unpriced benefits and costs of the alternative. So net money benefits cannot usually equal net social benefits. In the two expirical examples of this paper net social benefits of the alternative are estimated with adjustments to market prices and valuation of the important unpriced benefits.

(Figure 1) has two key segments namely, the stochastic specification and simulation of prices (or other variables) and the linear programme itself. This combination generates more information than the conventional deterministic linear programme.

Start

| | |
|---|---|
| Event 1: | Simulation of product prices from the triangular probability distributions. |

| | |
|---|---|
| Event 2: | Calculation of social gross margins for the objective function |

Repeat
n times

| | |
|---|---|
| Event 3: | Maximise the objective function by linear programming |

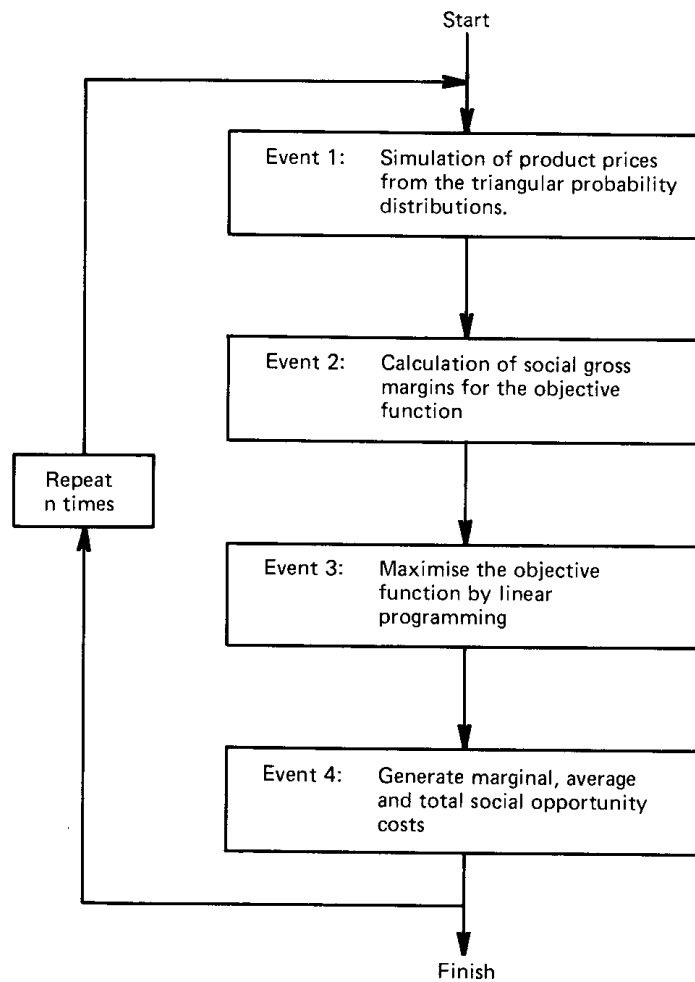| | |
|---|---|
| Event 4: | Generate marginal, average and total social opportunity costs |

Finish

Figure 1:   A flow-chart of the model for uncertainty

Application of the model can be divided into the four distinct events of Figure 1. This sequence is repeated $n$ times to provide a sample of feasible solutions which forms a probabilistic distribution of opportunity costs. This distribution supplements and overcomes the deterministic estimates and land use plans. As the example illustrates, this extra information may be helpful to land allocation decisions.

### 2.1.1 The Linear Programming Segment

Linear programming involves the optimisation of a linear objective function subject to constraints and non-negativity restrictions. The analyst must define the objective function as an annual income or annuity. He must collect data on the input-output coefficients, the level of each constraint, and social gross margins.[2] The analyst can then obtain the optimal level of the objective function by solving for the level of each activity.

The information from such an analysis includes the optimal annuity of social gross margin, the associated land use plan, the quantity of resources unused, the resources fully used and their marginal value products, and the non-basic activities and their marginal opportunity costs. Sensitivity estimates can be obtained by the procedure of right-hand-side and objective ranging. Objective ranging provides information on the incremental changes to the social gross margin coefficients of each basic activity for which the current solution remains optimal. Right-hand-side ranging provides information on the incremental changes to the constraints for which the marginal value product of each resource holds good. All of this information is important in considering the opportunity costs of land uses. The marginal value product of land is especially important because this is the marginal opportunity cost of that land use.

### 2.1.2 Simulation and the Objective Function

This extension for uncertainty rests on (a) identification of the item(s) which is subject to stochastic variation and (b) selection and specification of a probability distribution from which to simulate this variation. These two steps are now considered. The objective function is defined as the maximisation of the present value of the prospective social gross margins. The cost data and constraints seemed reliable and predictable in the particular empirical example. But the social gross margins were harder to estimate since product prices seemed likely to display random variations over time. The gross margins were therefore simulated stochastically.

The triangular probability distribution was chosen to specify the product prices. It can be defined by three unambiguous and easily understood parameters, can take a skewed form, and generally facilitates the use of probabilities. The distribution is unimodal and is uniquely defined by estimates of the following parameters of the particular variable: the minimum value of the variable, the 'most likely' value, and the maximum value.

Local resource managers and relevant research personnel were asked to estimate the three parameters for each probability distribution. The

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[2] Net social benefit (= social gross margin) equals producers' surplus when demand is completely elastic.

parameters were required for each product, namely grain sorghum, sugar cane, maize, sunflower, soybeans, vealers, weaners, cow and calf, steers, timber and mineral sands. For example, for timber the minimum value was $3.9 per cubic metre, the "most likely" value was $4.1 with a maximum value of $4.2. The values for maize were $60 per tonne, $90 and $110 respectively — showing a greater variation than for timber. All prices were in real terms with 1975 as the base year.

Cassidy, Rodgers and McCarthy[2] present the theory and mathematical formulation for the triangular probability distribution. Practical application is summarised in Figure 1. The first step was to simulate or take a price from the distribution for each product (Event 1). Social gross margins were then calculated for each product as the price less variable costs (Event 2). The calculation included the necessary adjustments where money prices differed greatly from social prices.[3] These gross margins were inserted into the linear programme and the objective function was maximised in the usual way (Event 3). Finally opportunity cost data were generated (Event 4). This process was repeated $n$ times and was applied to the land use problem that is discussed next.

## 2.2 An Empirical Application

In 1968 the Simm Committee [10] proposed three national parks on the north coast of N.S.W., namely Angourie National Park of 4,370 hectares, Sandon River National Park of 3,200 hectares and Red Rock National Park of 1,740 hectares. The National Parks and Wildlife Service of NSW (NPWS) proposed a single park which would include all the Simm Committee proposals with an additional 30,400 hectares. The total area for the NPWS proposal is therefore 39,710 hectares. The model was applied to all four park proposals to evaluate their social opportunity costs (Hitchens [6]).

Each of these four park proposals was analysed separately. For each the linear programme is optimised with the set of most likely prices. The total social gross margin is noted. The park proposal is then constrained in, the model optimised and the new social gross margin is noted. The difference in these gross margins is the total social opportunity cost. This deterministic opportunity cost is noted in Table 1 for each park proposal.

Prices were then simulated from the probability distributions and the model applied as in Figure 1. Fifteen iterations were undertaken for each proposal and in each iteration a separate set of prices was simulated from the probability distribution (Event 1). In each iteration opportunity costs were generated (Event 4) and both total and marginal opportunity costs were analysed in the results.

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[3] The gross margin in linear programmes is conventionally defined as producers' surplus, that is producers' income less variable costs. A social gross margin is consumers' surplus and producers' surplus. Hitchens [6] estimated the social gross margins for beach sand mining after Fitzgibbons and Hendrikx [5]. The demand for the other activities were assumed to be infintely elastic and so there was no consumers' surplus. The margins were expressed as annuities.

## 2.3 Results

### 2.3.1 Probability distributions for total opportunity cost

The smoothing rule for sparse data, from Anderson [1], is invoked to convert the 15 separate observations on total opportunity cost (TOC) into a single probability distribution. A smoothed distribution of total opportunity costs was estimated for each proposal and that for the NPWS scheme is illustrated in Figure 2. The procedure is as follows: (1) rank the fifteen observations in ascending order for each national park, (ii) let the $k^{th}$ observation equal the $k/(n + 1)$ fractile, where $k = 1, 2, \ldots, 15$ and $n = 15$, (iii) plot the resulting fractile points and subjectively smooth a cumulative distribution function through these points.

A more formal analysis of the distributions for all four proposals is presented in Table 1. These data facilitate the approximation of the means and standard deviations following the Pearson and Tukey [8] formula.

$$\text{Expected TOC} \quad = f_{0.5} + 0.185 \, (f_{0.95} + f_{0.05} - 2f_{0.5}) \quad (1)$$

$$\text{Standard Deviation (TOC)} = (f_{0.95} - f_{0.05})/3.25 \quad (2)$$

where $f$ indicates the particular fractile.

Table 2 includes the means and standard deviations for the TOC distribution for each proposal along with the probability that TOC lies within one standard deviation from the mean.

Table 1: Total opportunity cost probability distributions for four park proposals*

| Cumulative Probability | Total annual opportunity cost is less than | | | |
|---|---|---|---|---|
| | Angourie | Sandon River | Red Rock | NPWS |
| 0.00 | $15,000 | $10,000 | $ 5,000 | $125,000 |
| 0.05 | $31,000 | $20,000 | $15,000 | $235,000 |
| 0.25 | $50,000 | $34,750 | $25,250 | $380,000 |
| 0.50 | $56,000 | $38,500 | $26,500 | $402,500 |
| 0.75 | $57,500 | $39,500 | $27,750 | $417,500 |
| 0.95 | $67,000 | $45,500 | $31,750 | $482,500 |
| 1.00 | $75,000 | $50,000 | $35,000 | $525,000 |
| Total opportunity cost at "most likely" prices† | $54,000 | $37,000 | $26,000 | $393,500 |

* The monetary figures are 1975 dollars.

† This is the deterministic total opportunity cost.

The results of Tables 1 and 2 provide the following important information for this land use decision. First, there is a high probability (about 80 per cent) for each proposal that the actual TOC will lie within plus or minus one standard deviation from the mean. The distributions are therefore peaked

compared to a normal distribution. Second, the TOC distributions are negatively skewed, and therefore the probability of the actual TOC being greater than the mean is high — approximately 60 per cent.

*Table 2: Characteristics of the total opportunity cost distribution for four park proposals\**

| Total annual opportunity cost | Angourie | Sandon River | Red Rock | NPWS |
|---|---|---|---|---|
| Mean | $53,410 | $36,373 | $25,344 | $386,313 |
| Standard Deviation (SD) | $11,077 | $ 7,846 | $5,154 | $ 76,154 |
| Possibility of being within one SD from the mean | 79% | 79% | 81% | 78% |
| Mean plus one SD | $64,487 | $44,219 | $30,498 | $462,467 |
| Probability of TOC lying within the mean plus one SD | 0.59 | 0.62 | 0.66 | 0.63 |

\* The monetary figures are 1975 dollars.

## 2.3.2 Probability distributions for marginal opportunity costs

So far the analysis has been restricted to the examination of each park as a separate and complete entity. However, such total opportunity cost data give no insight into the value of the marginal hectare but marginal opportunity costs do give such insights.

The marginal opportunity costs (MOC) were generated by right-hand-side ranging in the usual way. This technique provides information for the incremental changes to the land constraint for which the marginal value product of land is constant. The marginal value product of land is then the marginal opportunity cost of that particular land in park use. The MOC's for each land type from two of the fifteen sets generated are presented in Table 3 along with the mean and standard deviation of the MOC's, and the deterministic MOC.

There are two important points in relation to Table 3. The mean marginal opportunity cost of swamp-heath land is very low ($0.04) whilst its standard deviation is relatively high ($0.05). This indicates a high probability (47 per cent) that MOC for this land type is in fact zero. Second, the probability that land suitable for sugar cane will be sown to sugar cane is only 40 per cent. This explains the high standard deviation for this land type.

*Table 3: Marginal opportunity costs in 1975 dollars*

| Item | Land Type | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | Swamp forest | Steep land forest | Swamp heath | Flat land forest | Infertile heath | Fertile heath | Sugar cane land |
| | $ | $ | $ | $ | $ | $ | $ |
| For Standard or 'most likely' prices* | 0 | 0 | 0.00 | 0.30 | 105.3 | 121.7 | 144.0 |
| For price set 1 | 0 | 0 | 0.00† | 0.25 | 110.2 | 124.4 | 124.4 |
| . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . |
| For price set 15 | 0 | 0 | 0.04 | 0.42 | 112.9 | 129.2 | 120.17‡ |
| Mean MOC | 0 | 0 | 0.04 | 0.37 | 102.8 | 118.09 | 140.07 |
| Standard deviation of MOC | 0 | 0 | 0.05 | 0.133 | 16.05 | 15.95 | 37.85 |

* These are the deterministic marginal opportunity costs.

† The probability that the marginal opportunity cost of swamp heath is zero is 7/15, or 47%.

‡ Sugar cane is actually grown. The probability of sugar cane being grown is 6/15, or 40%.

The supply function for the NPWS park proposal is illustrated in Figure 3. This function is in fact the graph of MOC per land type against the cumulative area, in order of increasing MOC. The function assumes that MOC is constant per land type, that all hectares are equally desirable for preservation, and that preservation benefits are divisible by hectares. Procedures to relax these assumptions are discussed subsequently.

Each step in the MOC function represents the mean marginal opportunity cost for each land type, and each is associated with a normal probability distribution through the standard deviation. The supply functions for the park proposals provided the following information. The supply of land for each park becomes infinitely price inelastic at the limit of land available. The standard deviation of MOC for each land type are relatively large, especially for the sugar cane land (land type 7). So, if normality is assumed, the probability of the marginal opportunity cost of sugar cane land being between $177.92 and $102.22, (plus or minus one standard deviation) is 68.2 per cent. Some 93 per cent of the total region has marginal opportunity cost less than $1 per hectare.

Cumulative
Probability



Total opportunity cost ($ 000)
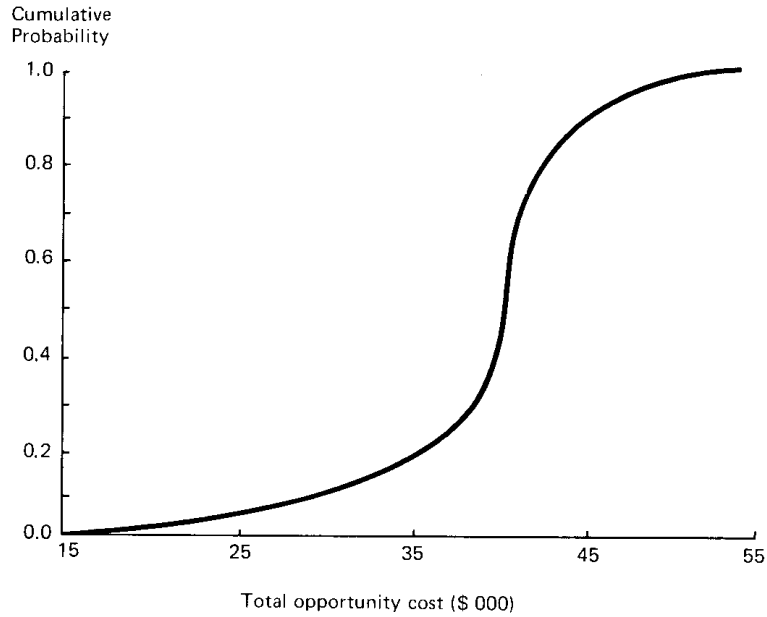
Figure 2:   The Cumulative Distribution Function (CDF) for the NPWS
park proposal.

Marginal Opportunity
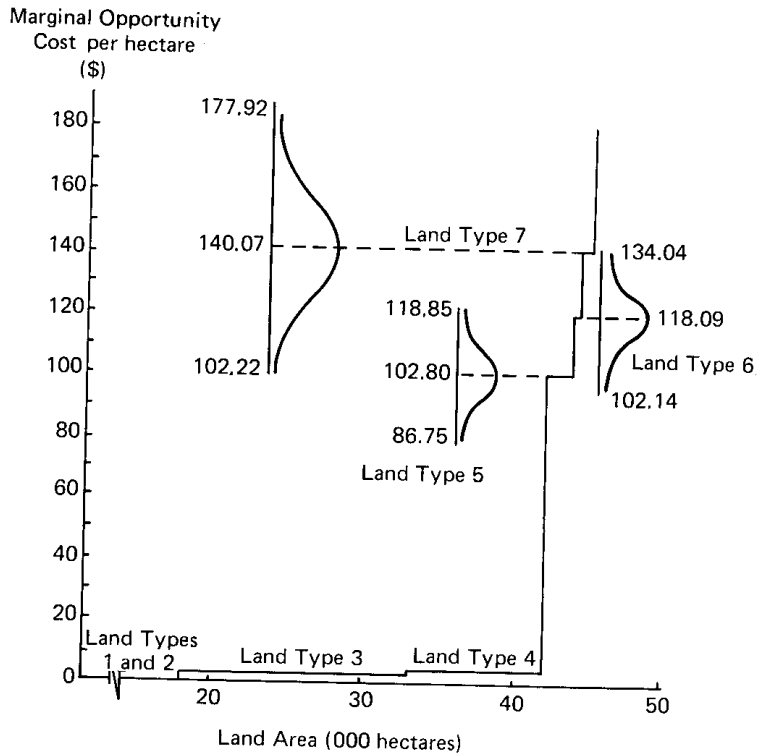Cost per hectare
($)



Land Area (000 hectares)

Figure 3:   The Marginal Opportunity Cost (MOC) Function for the NPWS
park proposal. (Showing means and one standard deviation
either side for three land types).

## 2.4 Using the Opportunity Cost Data

A linear programming model which incorporates uncertainty to estimate opportunity costs offers the following advantages for land use decisions.

(a) The model does not rely solely on present land uses. A true opportunity cost can only be determined from an optimal land use pattern.

(b) A probability distribution of total opportunity costs can be determined. In this example the distribution was negatively skewed that is, there is a high probability that the total opportunity cost is greater than the mean, or deterministic, value — this probability is 63 per cent for the NPWS proposal. In this example, a deterministic opportunity cost would dangerously underestimate the true opportunity cost.

(c) Linear programming readily provides data on the important marginal opportunity costs and so increases the range and depth of policy questions that can be considered. For example and considering Figure 3, can preservation be restricted to the first four land types since their opportunity cost is relatively low? These four land types represent some 90 per cent of the total region.

(d) The marginal opportunity costs also indicate that deterministic estimates for land types are dangerous. The large standard deviations, for sugar cane land especially, indicate a considerable degree of uncertainty as to the true marginal opportunity costs.

To use the opportunity cost data generated by the model effectively the decision maker is forced to examine the benefits of preservation in terms of how they measure up to the distribution of opportunity costs. There is no longer a single deterministic benchmark.

## 2.5 Evaluation of the methodology

The advantages of this methodology rest on the extra information that can be generated — as just discussed. The disadvantages concern the difficulties in collecting the extra data, the difficulties in fitting the problem into the linear programming format and the overall approach to probabilities. These disadvantages are now discussed in turn.

Resource managers must be able to define their attitude to uncertainty and articulate it for probability distributions of future prices. Hitchens satisfactorily collected the three necessary parameters for each distribution. The managers and researchers had some initial difficulty in understanding the notions of minimum, most likely, and maximum values. But after a short introduction, they soon grasped the ideas and provided the data. But without these data the method fails.

Hitchens' research time was limited, so two parts of the procedure were simplified. First, more than 15 iterations for each proposal would have been desirable. Second, reclassification of the land types would have further recognised some of the biophysical aspects of preservation. The social benefits of preservation may derive from indivisible blocks of land over several land types or from contigious blocks of several of the seven

land types (Figure 3). For example, the habitat of some wildlife species may cover several adjacent land types and may require preservation of a single unit of land. But the methodology as presented assumes all hectares are equally desirable for preservation and that preservation benefits are divisible by hectares.

The land types can be reclassified and constrained in a different way to overcome these assumptions. For example, boundaries of types can be defined by habitat boundaries and the marginal opportunity cost interpreted for this area as a whole rather than hectare by hectare. In other situations, each of the seven land types could be sub-divided for more precision. Then with constant prices in each iteration the marginal opportunity cost of each new land type would be constant as the area under money-uses is decreased to zero.[4]

But what of the overall approach to uncertainty through probabilities? The triangular probability distribution and the procedure to generate distributions of outcomes (Figure 2, and Figure 3) are quite standard [2]. Hitchens' contribution is to apply these conventional techniques for opportunity cost outcomes for land use decisions.

Faced with uncertain prices in the future, what can the analyst indicate about the land use choices? How does the model improve on deterministic estimates? The methodology generates a land use plan for the "most likely" prices — before the model of Figure 1 is begun. Information from this deterministic plan may be helpful for the decision. But the model, through uncertainty, seems to provide extra, useful information — as noted in the previous section. To expand the previous results, the deterministic opportunity cost for the NPWS proposal was $393,500 (Table 1). But there is a 63 per cent probability that this cost will be exceeded. Further the cumulative data of Table 1 indicate a 50 per cent probability that the actual TOC will be over $402,500 and a 25 per cent probability of more than $417,500. This extra information suggests that the deterministic figure is a serious underestimate. Thus in addition to a deterministic estimate, the policy-makers have extra information on distribution of opportunity costs. The information from the cumulative distribution function (Figure 2 and Table 1), lessens the need to define a specific set of future prices. The analyst can indicate, for example, that there is an $X$ per cent probability that total opportunity costs will exceed $\$Y$ — given the entire range of probable future prices. This extra information could improve many decisions on land allocation.

## 3 Extension for Schedules of Land Use Plans

Land use decisions often involve conflicts between an income objective and an objective of environmental preservation. When the preservation benefits can be assessed linear programming can generate a whole schedule of land use plans, each of which meets the two objectives in a specific way. The schedule then provides opportunity costs, or losses in net money benefits, over the whole range of possible decisions. Each plan in the schedule is, in fact, a point on a transformation curve of income against preservation benefits. The whole schedule is the curve itself. Presentation, display and analysis of this set of plans may assist the decision.

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[4] We are grateful to the reviewers for emphasising the need for these qualifications.

The present extension builds on the general opportunity cost procedures in Hitchens work. It is appropriate where the preservation benefits can be assessed and where a schedule of possible plans is useful for decision. Uncertainty could readily be incorporated into the present extension following Hitchens' procedures. However, uncertainty was not included so that Thampapillai[11] could focus on the problems in generating the whole schedule. The results of the present extension, as the transformation curve of Figure 4, are in fact an alternative way to present the information from Hitchens' procedure — but for just a single set of prices.

Empirical estimation of the schedule of plans rests on measurement of both objectives. Monetary income can be readily measured but measurement of the benefits of preservation requires the development of special money values. Thampapillai developed methods to value some particular environmental benefits in money and incorporated the results into a linear programme to estimate a transformation curve. The choice of land uses could now be guided by the extra opportunity cost data from the curve. This information is (a) the range of directions in which the present management of the study area could be improved, (b) the nature of the relationship between land uses and (c) the magnitude of conflict between uses.

## 3.1 Extending the Conventional Linear Programme

The conventional linear programme was adapted to provide transformation curves by (a) separating the income-producing and preservation activities in the objective function and (b) incorporating a weighting technique into the objective function. This technique facilitated the parametric variations to generate the trade-off function. The activities and constraints were conventional but the objective function involved the following different interpretation.

Separation of the two sorts of activity for separate aggregation gave the following objective function:

$$\text{Maximise } Z = \sum_{u=1}^{q} e_j x_j + \sum_{r=q+1}^{t} d_r y_r \tag{3}$$

where:

$j$ = 1, 2, . . . . . . . . , $q$, are commercial income producing activities,

$r$ = $q+1, q+2, \ldots t$, are activities producing preservation benefits,

$e_j$ = social gross margin per unit of the $j$th activity,

$x_j$ = level of the $j$th activity,

$d_r$ = social gross margin per unit of the $r$th activity,

$y_r$ = level of the $r$th activity,

$q$ = the number of activities which contribute to the monetary income objectives, and

$t$ = the total number of activities.

The term $\sum_{j=1}^{q} e_j x_j$ represents the aggregation of social gross margins $e$ from all activities $j$ contributing to the monetary income objective. The

term $\sum\limits_{r=q+1}^{t} d_r y_r$ represents the aggregation of social gross margins $(d)$ from all activities contributing to the environmental preservation objective $(r)$.

Derivation of data for the transformation curve required that the objectives be maximised at different levels between (100 per cent income maximisation, no preservation) and (no income maximisation, 100 per cent preservation). With separable components in the objective function, the different levels can be set by weighting the two separate objectives. The range of weights for each objective was defined such that at one extreme only the income objective was maximised while at the other only the environmental objective was maximised. This procedure accounts for all attainable combinations of the two objectives and so provides the necessary parametric variation. The final, weighted objective function is:

$$\text{Maximise } Z = (1 - \lambda) \left( \sum\limits_{j=1}^{q} e_j x_j \right) + (\lambda) \left( \sum\limits_{r=q+1}^{t} d_r y_r \right) \qquad (4)$$

The term $\lambda$ is the weight attributed to the preservation objective. The values of $\lambda$ are ranged parametrically between zero and one. Hence the weight on the income objective $(1 - \lambda)$ is implied by the value of $\lambda$. For example when $\lambda = 0.0$, only the monetary income objective will be maximised and when $\lambda = 0.1$ the two objectives will be maximised together and will be weighted in the ratio income: preservation = 9:1. By changing the values of $\lambda$ between zero and one, an infinite set of weighted combinations of levels of each objective could be achieved.

The trade-off function was derived by parametrically changing the value of $\lambda$ from zero to one. For each $\lambda$, the value of each objective was aggregated with estimates of benefits in constant dollars. The estimates for the income objective are represented by the values of $e_j$ when $\lambda = 0$, and for the preservation objective are represented by the values of $d_r$ when $\lambda = 1$. The aggregate values of each objective derived for each value of $\lambda$ can be plotted as points on a graph such as Figure 4 where the axes represent the two objectives. The locus of points is the transformation curve — or production possibility curve or trade-off function. Systematic changes in the weights provide a complete curve with its complete schedule of possible plans. The technique implies nothing about society's weight for one objective or the other. Then social data would be depicted as some sort of indifference curve and could then be used to define a single optimal point on the transformation curve.

### 3.2 An Empirical Application

The model was applied to a policy problem concerning choices between preservation uses and income-earning uses. Attempts are being made to preserve locations in northern New South Wales which are presently devoted to money-generating uses of agriculture, forestry, mining, water supply and housing. Preservation provides numerous non-monetary benefits due to retention of unique flora and fauna, features of historic and cultural importance, landscape and amenities for outdoor recreation. The successful derivation of transformation functions (as in Figure 4) rested primarily on the separation of objectives as equation (4) and the valuation

of $e_j$ and $d_r$ in the objective function. The values of $e_j$ were determined relatively easily from published and accessible data.[5] The method to estimate $d_r$ is now summarised from Thampapillai [11].
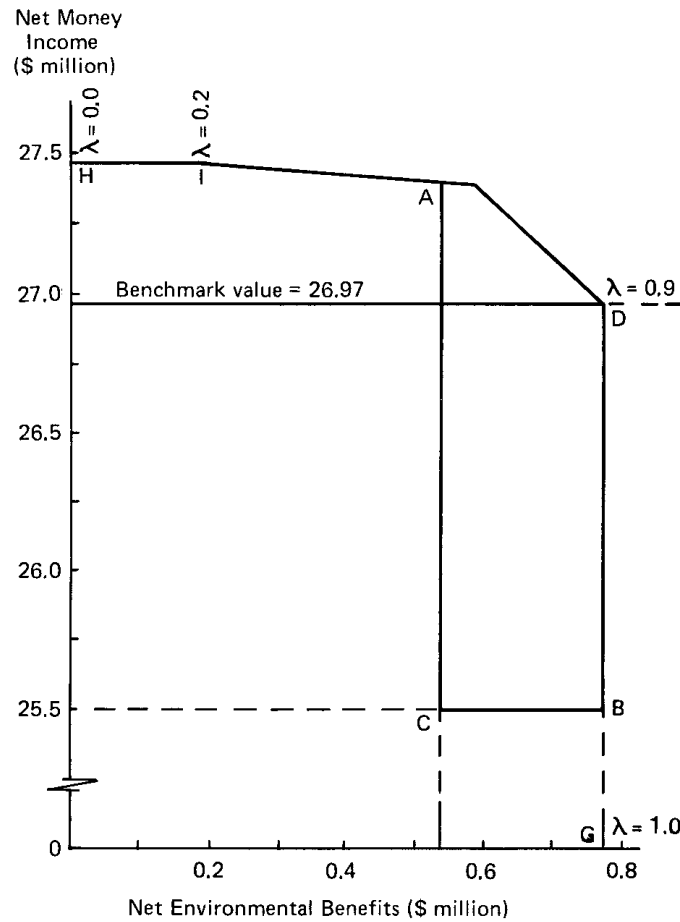
Net Money
Income
($ million)

Figure 4:    A Trade-off Function to depict the contribution of land use plans to two objectives. (The present position of the study area is denoted by C).

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Thampapillai estimated the preservation benefits through a land value method. Assume a competitive land market, a government agency that purchases land for preservation purposes, and social institutions which encourage agency decisions to follow social preferences. At the margin the price paid for land equals the present value of a stream of net social benefits from preservation of a particular block of land. The analytical task is now to identify these particular prices and generalise them to other blocks. Thampapillai[11] documented the difficulties with this standard method. While imperfect, the method appeared feasible because there had been recent purchases for preservation by government agencies and because there were several bidders for each block.

The prices in recent purchases for preservation were observed, previous uses were identified and some characteristics of the land were identified. The original money-income uses were classified as grazing, extensive grazing/woodland, eucalypt forestry, other native forest, pine forest, and mining. Then the prices paid for land in each of these classes were observed and "placed" on a continium. For example, the lowest price paid for grazing land was $300 per hectare with $550 as the highest. Presumably the highest price is paid for the area with the highest preservation benefits. The government agencies were questioned to discover whether the highest price was "normal" in this sense or whether it reflects some temporary feature of the market. If normal, the price was accepted as the politically established value (PEV) for preservation. If not, the highest "normal" price was accepted and in this way the PEV for grazing land was set at $515. The annuity of this present value is $51.5 — with a discount rate of 10 per cent.

This politically established value for the best preservation area was now generalised through a scoring model for all areas for potential preservation purposes. Let the best area score full marks on all relevant characteristics. Less suitable areas score a proportion of full marks and so from our land value method:

$$
\begin{array}{lcl}
\text{Net benefit from} & & \text{Politically} \\
\text{area } i \text{ in its} & & \text{established value} \\
\text{particular} & = & \text{for the appropriate} \quad \times \quad \text{proportion)} \quad (5) \\
\text{preservation purpose} & & \text{land class} \\
\end{array}
$$

For example, let the PEV for grazing land be $51.5 as above and let the score for area $i$ be 0.60 — or 60 per cent as useful for preservation as the best area. Then we have:

$$\text{Net benefit from area } i = \$51.5 \times 0.60 = \$30.9 \tag{6}$$

The scores were determined as follows. Consider a preservation purpose for which land must be suitable on the 10 characteristics of habitat for rare birds, habitat for rare animals, existing diversity of flora, existing diversity of fauna, rainforest density, aquatic habitat, waterfalls, landscape diversity, historical relevance and other visual benefits. Each area is scaled from 0.00 (lowest) to 0.10 highest on its suitability on each characteristic. The ten scalings were then summed into the score of, say, 0.60. If the land market were competitive, and if this scoring procedure were accurate, the net benefits would measure the flow of preservation benefits over time.

## 3.3 Using the Opportunity Cost Data

Money values for net social benefits (or social gross margins) of income producting activities were inserted for $e_j$ in equation 4. Money values for the net social benefits of environmental activities were inserted for $d_r$. The value of $\lambda$ was set at 0.0 and the programme run to maximize $Z$. The objective function maximises net money income when $\lambda = 0.0$. The value for net money benefits was graphed against the value for net environmental benefits to give point $H$ in Figure 4. The value of $\lambda$ was then parametized between 0.0 and 1.0 and the programme repeated to maximise the function for combinations of net money income and net environmental benefits. When $\lambda = 1.0$, net environmental benefits are maximised to give point $G$. The results from other values of $\lambda$ are shown on the curve $HG$ in Figure 4. Current (1976) price levels were used throughout and there was no analysis for uncertainty.

The present position of the region, with respect to the two objectives, was estimated by applying the same net social benefits per activity to the actual quantities of each activity and aggregating into sums for each objective. The present position is denoted by point $C$ in Figure 4 and is apparently sub-optimal.[6] Resources could therefore be reallocated and enterprises combined more efficiently to attain a point on the trade-off function. Movement to a point on segment $AB$ is Pareto-optimal.

### 3.3.1 The Relationship between Uses

The search for a suitable management strategy within segment $AB$ may be further narrowed by knowledge of relationship between objectives. The function displays a mix of competitive and supplementary relationships. In the region of supplementarity ($BG$ and $HI$) decision makers can be indifferent in terms of one objective. However, these regions of supplementarity lie outside segment $AB$ and in this case they do not help in narrowing the choice. In contrast, segment $AB$ displays a competitive relationship between objectives. The choice of an appropriate land use strategy from the region of competitiveness may be assisted by knowledge of the magnitude of conflicts between objectives, a discussion of which now follows.

### 3.3.2 Magnitude of Conflicts between Objectives

The conflict can be "measured" as the marginal opportunity cost of an objective which is the slope between specific points on the function. Since decision makers are often concerned with the impact of non-monetary objectives on monetary objectives, measurement of the conflicts as the opportunity cost may be useful. To simplify this measurement the following procedure was adopted.

   (a)   Consider the condition when only the monetary objective is maximised, that is when $\lambda = 0.0$. Let the maximum value of the social gross margin from all income-earning uses be denoted by $V_1$. In the absence of complementarity between objectives, $V_1$ represents the highest attainable value of these income benefits.

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[6] This conclusion assumes, *inter alia*, that land managers have the same objective as the linear programme.

(b) Next consider maximisation of both objectives together, that is when $0 < \lambda < 1$. Let the value of social gross margin derived under a particular condition here be denoted by $V_2$. Unlike $V_1$, the value of $V_2$ is variable because $\lambda$ can assume any value between zero and one.

(c) Finally consider the condition when only the preservation objective is maximised, that is when $\lambda = 1.0$. Let the social gross margin derived from the monetary objective be represented by $V_3$. The value of $V_3$ should represent the lowest attainable value of income benefits.

The opportunity cost of increasing the level of preservation uses ($OC_P$) is given by:

$$OC_P = (V_1 - V_2) \text{ when } 0 < \lambda < 1,$$

$$OC_P = (V_2 - V_3) \text{ when } \lambda = 1.0.$$

The opportunity costs so derived are presented in Table 4 and now discussed.

*Table 4: Estimating the marginal opportunity costs of increases in preservation*

| Weight between objectives | Total net monetary income* | Marginal Opportunity Cost of increase in preservation† ($m) |
|---|---|---|
| 1 | 2 | 3 |
| 0.0 | 27.47 | — |
| 0.1 | 27.42 | 0.05 |
| 0.2 | 27.22 | 0.20 |
| . | . | . |
| . | . | . |
| 0.8 | 26.40 | 0.70 |
| 0.9 | 26.00 | 0.40 |
| 1.0 | 0.20 | 25.80 |

\* From the $\sum_{j=1}^{q} e_j x_j$ part of the objective equation (4).

† The marginal opportunity cost is defined as the change in net monetary income from the previous land use plan (with a lower value of $\lambda$) to the present plan. For example 0.05 in column 3 = (27.47 − 27.42).

If decision makers were aware of society's preferences they could choose a point on the trade-off function, where the opportunity cost of the preservation objective is equal to the amount of income benefits society is prepared to sacrifice — and *vice versa*. More frequently however, decision makers lack the knowledge of true social preferences and may aim to achieve minimal level of conflicts between objectives. Under such circumstances a basis is required to assess whether the conflict between objectives is "large" or "small". Then, the search for appropriate land uses may be confined to the portion of the trade-off function with "small" conflicts between objectives. Hence the amount of income benefits society is prepared to sacrifice is needed as a bench mark. If the opportunity costs

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of the preservation objective exceeds the bench mark, then the conflict between objectives is large, and vice-versa. Thampapillai [11] defined the bench mark as the mean variation from the average annual income from the existing agricultural enterprises.

The bench mark was approximately $0.5 million. The maximum annual income from the study area is determined at the point on the trade-off function, where $\lambda = 0.0$ and is here equal to $27.47 million (Table 4). Hence a bench mark value for income benefits is

Bench mark value = ($27.47 − $0.50) million = $26.97 million.

In Figure 4 a line is drawn horizontally across at the bench mark value and this line intersects the trade-off function at point $D$. On the basis of point $D$, the trade-off function could be divided into two regions, namely region of small conflicts above $D$, and region of large conflicts below $D$. The best direction of improvement, (that is, segment $AB$ in Figure 4) was partly within the region of small conflicts and partly within the region of large conflicts. Hence, decision makers may narrow their search for an appropriate management strategy to the region of small conflicts within segment $AB$ — that is to segment $AD$. Thampapillai extended his analysis with sensitivity tests for values of the environmental benefits and the money-producing activities and for the levels of the constraints on the area of each land type.

# 4 Conclusions

Opportunity cost is an appropriate concept for land use allocation when net social benefits of all uses cannot be estimated. Indeed social opportunity cost is the net social benefit of the best foregone use and so is an integral part of the full benefit-cost analysis. In the Fraser Island Inquiry it was used as a basis for the estimate of any compensation to the miners. In the Boyd Plateau Inquiry the N.S.W. Government indicated acceptance of $200,000 as the annual opportunity cost of preservation. These applications of the concept by government advisory bodies indicate its convenience, relevance and acceptance.

The theme of this paper has been that the use of the criterion should now be improved. Linear programming has been applied to two land use problems, to illustrate possible improvements to generate more, and more relevant, data on opportunity costs. Like all quantitative methods, linear programming aims to develop and process information and is not a substitute for decision making. But importantly:

> Utilization of this discipline could permit management to shift much of its decision making activity from the technicalities of planning to the area of goals, policies and risks. [9, p. 297]

Estimates of opportunity cost for policy decisions should be improved in several directions. Deterministic estimates for a whole "park" or whole unit should be replaced by stochastic estimates for each land type and for administrative or other subdivisions of the unit — as illustrated for the land use problem in section 2 of this paper. The derivation of the complete range of land use plans and their usefulness to decisions was illustrated in section 3. The linear programme combined uses into separate plans which (a) maximised net money income (point $H$ in Figure 4), or (b) maximised

environmental preservation (point *G*), or (c) maximised the range of weighted sums of these two objectives (points between *H* and *G*). Together these plans cover the entire range of policy options and cater for the entire range of choice for these two important objectives. The monetary opportunity costs of land use changes for increases in preservation can readily be calculated. Then those plans which are Pareto-optimal for the present position can be identified. In Figure 4 any plan on *AB* of the transformation curve provides at least as much of both objectives as the present position *C*. The number of optimal plans can be reduced beyond *AB* if some benchmark can be established — as in section 3. The experience gained in these two studies suggests that these improvements in opportunity cost information are well within the capacity of existing land use inquiries and that linear programming is a suitable technique to provide this information.

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