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Working Paper No. 21

Cost-Benefit Analysis with Applications to Animal Health Programmes: Allowing for Project Risk in CBA

by

S.R. Harrison

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S.R. Harrison[2]

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[1] See page 1

[2] School of Economics, The University of Queensland, St. Lucia Campus, Brisbane QLD 4072, Australia
Email: c.tisdell@economics.uq.edu.au

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The Commissioned Organization is the Queensland Department of Primary Industries. Collaborating institutions in Australia are CSIRO-ANHL, Geelong, Victoria and the University of Queensland (Department of Economics; Department of Geographical Sciences and Planning). In Thailand, the collaborating institutions are the Department of Livestock Development (National Institute of Animal Health; Disease Control Division), Chiang Mai University (Department of Agricultural Economics; Department of Animal Husbandry) and Thammasat University (Faculty of Economics). The collaborating institution in Laos is the Department of Livestock and Veterinary Services. Dr F.C. Baldock, Senior Principal Epidemiologist, Queensland Department of Primary Industries is the Project Leader in Australia and Dr P. Chamnanpood, Senior Epidemiologist, Thai Department of Livestock Development is the Project Leader in Thailand. Professor Clem Tisdell and Dr Steve Harrison, Department of Economics, University of Queensland are responsible mainly for the economic component of this project.

'The overall goal of this project is to develop and evaluate the .necessary tools to provide decision-makers with reliable animal health information which is placed in context and analysed appropriately in both Thailand and Australia. This goal will be achieved by improving laboratory diagnostic procedures; undertaking research to obtain cost-effective population referenced data; integrating data sets using modern information management technology, namely a Geographical Information System (GIS); and providing a framework for the economic evaluation of the impact of animal diseases and their control.

A number of important diseases will be targeted in the project to test the systems being developed. In Thailand, the focus will be on smallholder livestock systems. In Australia, research will be directed at the northern beef industry as animal health information for this sector of livestock production is presently scarce.'

For more information on *Research Papers and Reports Animal Health Economics* write to Professor Clem Tisdell (c.tisdell@economics.uq.edu.au) or Dr Steve Harrison,(s.harrison@uq.edu.au) Department of Economics, University of Queensland, Brisbane, Australia, 4072.

This is number four of a set of six papers by Dr S. Harrison on 'Cost-Benefit Analysis with Applications to Animal Heath Programmes' to be published in this series Research Papers and Reports in Animal Health Economics.

Papers in this Set

1. Cost-Benefit with applications to Animal Health Programmes: Basics of CBA, Research Paper or Report No. 18.

2. Cost-Benefit Analysis with Applications to Animal Health Programmes: Complexities of CBA, Research Paper or Report No. 19.

3. Cost-Benefit Analysis with Applications to Animal Health Programmes: Spreadsheet Implementation of Discounted Cash Flow and Risk Analysis, Research Paper or Report No. 20.

4. Cost-Benefit Analysis with Applications to Animal Health Programmes: Allowing for Project Risk in CBA, Research Paper or Report No. 21.

5. Cost-Benefit analysis with applications to Animal Health Programmes: Valuation of Non-Market Costs and Benefits, Research Paper or Report No.22.

6. Cost-Benefit Analysis with Applications to Animal Health Programmes: Animal Health Programmes and Information Systems, Research Paper or Report No. 23.

Cost-Benefit Analysis with Applications to Animal Health Programmes: Allowing for Project Risk in CBA

ABSTRACT

This discussion paper will briefly examine the concepts of risk and uncertainty, and the relevance of risk to decision making about animal health programs. Various techniques for dealing with uncertain cash flows will then be discussed, with particular emphasis on three extensions to the cost-benefit analysis, viz. sensitivity analysis, risk or venture analysis and stochastic dominance analysis. Finally, practical suggestions will be made as to choice of approach.

Keywords: Animal health programs, risk and uncertainty,

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Cost-Benefit Analysis with Applications to Animal Health Programmes: Allowing for Project Risk in CBA

1. INTRODUCTION

It is typical of animal health programs spanning a number of years into the future that costs and benefits - and, in particular the latter - are estimated subject to a high degree of uncertainty. That is, the estimates of cash flow variables are simply best-guess point values from perhaps wide probability distributions of random cost and benefit variables. A variety of methods have been devised to take account of risk and uncertainty in cost-benefit analysis. These are designed to provide additional information so that program accept/reject decisions and choices between alternatives can be made which accord with decision makers' attitudes to risk.

This discussion paper will briefly examine the concepts of risk and uncertainty, and the relevance of risk to decision making about animal health programs. Various techniques for dealing with uncertain cash flows will then be discussed, with particular emphasis on three extensions to the cost-benefit analysis, viz. sensitivity analysis, risk or venture analysis and stochastic dominance analysis. Finally, practical suggestions will be made as to choice of approach.

2. RISK AND UNCERTAINTY CONCEPTS

Before discussing methods of taking account of project or program risk, it is appropriate to consider some definitions and concepts of risk in the context of management decision making.

2.1 "Risk" versus "uncertainty"

When funds are to be invested now which will result in revenue being generated for perhaps decades into the future, it is obviously impossible to predict the payoff with a high degree of confidence. We describe the fact that there will be a distribution of cash flow variables (product prices, input costs) and hence of overall project performance by saying that the payoff is subject to "risk" or "uncertainty". Typically, costs early in the life of a project can be predicted with a high degree of confidence, but project benefits - especially those furthermost into the future - can only be guessed at.

Many definitions may be found for the terms *risk* and *uncertainty*. Both terms refer to lack of knowledge about future values of random variables. In a practical sense, variables with enter cash flows do not take predictable single-point or deterministic values; rather, they can only be predicted within a range of values, some sub-intervals of which appear more likely than others. That is, they are random or stochastic variables, for which our knowledge of values could be expressed in the form of probability distributions. Random and unpredictable variation may arise due to

- Weather
- markets (input and product)
- technological change
- legal and institutional factors.

A distinction is sometimes drawn between the two terms. *Uncertainty* is defined as random variability for which the parameters of probability distributions cannot be specified on the basis of observed data. For example, when dealing with a *non-repeatable* event, there is no history of observations upon which to draw. *Risk* on the hand arises where an objective measure or estimate can be obtained of the probabilities: of the possible levels of a random variable. For example, the probability of a drought in a particular area at given time of the year could be established from an analysis of daily rainfall records over many years.

In practice, it is rarely possible to obtain reliable objective probabilities for predicting future outcomes, and in terms of the above definition uncertainty is more common than risk. This comment can be applied even to rainfall, if climatic change is taking place. Hence, in practice probability distributions of cash-flow variables are often estimated subjectively, based on whatever records are available and also on personal judgement. The *subjective probability distributions* estimated in this way can then be used for further analysis. This is sometimes described as converting uncertainty to *quasi-risk*. Nowadays, economists take the view that most events of importance to business and economic decisions are essentially non-repeatable, hence they tend to not make any distinction between risk and uncertainty. Rather, the terms are frequently used interchangeably, though sometimes term “risk” only is used. No distinction will be made in the remainder of this paper.

2.2 Examples of risk in animal health programs

Improvements in animal health usually involve long-term programs, hence cash flows have to be estimated for many years into the future, with high uncertainty as to level of program effectiveness and consequent economic payoff. Uncertainty in livestock production can be viewed in terms of the four categories mentioned above, viz. weather, economic factors (prices and costs), technological change and legal and institutional factors. These factors will in turn have an impact on the returns from animal health programs.

The effectiveness of an animal health program will depend on the prevailing weather conditions, and factors such as livestock management, intermingling of stock, introduction of infected animals, vigilance of herdsmen and so on. Veterinary epidemiologists have come to recognize various types of *risk factors*.

Analysis of animal health programs requires assumptions about how livestock industries will develop in a region or country, and the size of livestock industries in the future. Development of livestock industries will be influenced by product and input prices and by government policies.

When progress is being made in eradication of a livestock disease, the time needed to complete the program cannot be predicted precisely. There is always the risk of a new outbreak. This has been the experience in the eradication of FMD in Europe, where many of the outbreaks have been sourced to "lab escapes". In a country with long borders and neighbours with less-developed veterinary services, the risk of disease reintroduction is high. When progress has been made towards eradication, and level of natural immunity has declined, if vaccination coverage is not high an *explosive outbreak* becomes a possibility. Another source of risk is of the outbreak of a new disease strain (e.g. a new FMD virus), a disease which has not been observed in an area previously, or even an entirely new disease.

In CBA of an animal health program, there is a need to make allowance for leakages in benefits and in effectiveness, depending on the level and timing of adoption of control procedures by livestock owners. The adoption rate will depend on institutional arrangements, e.g. with respect to the provision of vaccines and incentives to ensure widespread use.

With respect to legal and institutional factors, export livestock markets are often unstable with respect to prices and quota limits, and subject to intense political lobbying in the recipient countries. Suspicion of a disease outbreak or contamination of animal products with medication in the exporting country can lead to sudden closure of markets.

2.3 Objectives in estimating project risk

If the level of program risk is within the normal operating margin of a public agency, then it may not be much cause for concern. In this context, if a program is small in relation to the overall investment portfolio of the agency, then no specific measurement of risk may be required. Also, variability of cash flow variables may not be a major concern provided these variables do not take particularly adverse values, referred to as *downside risk*. But for major programs that can influence the overall financial position of the agency or the credibility of officials and politicians, explicit measurement of risk may be important. From the viewpoint of carrying out CBA, the task of the analyst then is to quantify risk and present information to the decision maker which will allow an informed decision to be made, taking account of both the expected payoff and the degree of uncertainty surrounding it.

Concern with project risk can take several dimensions. The concern may be in determining whether a particular project has a high likelihood of generating an acceptable rate of return, e.g. to assist in deciding whether to implement the project or as part of the analysis to support a request for funding. As well, uncertainty it may be regarded as a cost, i.e. a higher payoff may be needed to compensate for high uncertainty. We may wish to build both expected payoff and variance of payoff into a single project performance criterion, e.g. using certainty equivalents as discussed later. Uncertainty about effectiveness of particular treatments is likely to be a reason for lack of adoption of animal health measures by livestock owners.

CBA is often used to compare alternative project designs, and in this context we may wish to determine not only which option has the greatest expected payoff but also which has the most predictable or reliable outcome. If one approach to disease control is a greater gamble than another, it will be useful to livestock department to have some quantification of the relative risks. A program which relies on voluntary vaccination, and using protection for the most prevalent FMD strains only, may have a more uncertain NPV than another program which includes stronger compulsion measures.

2.4 Decision makers' attitudes to risk

There is a considerable literature on attitudes to risk and measurement of utility functions of decision makers with respect to unpredictable incomes (e.g. Anderson et al., 1977). Examples of people preferring risks are quite common, e.g. various forms of gambling. If a person purchases a ticket in the pools, the mathematical expectation of payoff (sum of possible payoffs multiplied by their probabilities) is negative. However, gambling in itself provides entertainment or utility for some people. In general, it is recognized that while some people are risk preferrers, the majority are risk averse. If faced with the choice between two investments which have the same expected NPV but differing variances; most people would choose the alternative with the lowest variance. Also, at particular stages of their lives, especially when young, some people are more inclined to take risks than at other stages. Similarly, new management in a firm or government agency may undertake risky investments in a bid to establish their market of public profile. Conservatism and reduced willingness to take risks appear to be a function of age.

3. METHODS OF INCORPORATION OF RISK IN CBA

There are a variety of methods which have been employed to incorporate risk into CBA. The choice depends to some extent on how important explicit recognition of risk is deemed to be, and how critical risk appears to be in terms of its impact on overall project viability or acceptability. The more widely used methods of dealing with risk are listed in Box 1. Some of these methods will be examined in detail, with examples provided, while brief comments only will be made about others.

Box 1: Methods for incorporating risk into CBA

TAKING CONSERVATIVE COST AND BENEFIT ESTIMATES
REQUIRING A SHORT PAYBACK PERIOD
LOADING THE DISCOUNT RATE WITH A RISK MARGIN
DERIVING CERTAINTY EQUIVALENTS FOR PROJECT BENEFITS
SENSITIVITY ANALYSIS
BREAKEVEN ANALYSIS RISK ANALYSIS
STOCHASTIC DOMINANCE ANALYSIS

3.1 *Simplistic methods of handling project risk*

Some of the methods of dealing with risk could be classed as token approaches or expedients which tend to provide limited or even misleading information for decision makers.

Taking conservative benefit and cost estimates. Perhaps the simplest approach is to take conservative estimates of project benefits or pessimistic estimates of costs. This yields levels of the performance criteria such that there is a high probability of achieving or surpassing these levels. If a project or program still appears economically viable after these adjustments, then there is enhanced confidence that it should be implemented. But if the project turns out to be marginal, there is no clear guidance as to whether it should be rejected. Benefits are often ‘shrunk’ in a rather arbitrary manner, and the approach provides little information to the decision maker about the level of risks faced. The emphasis is on protection against ‘downside risk’, and no recognition is given of the possibility of payoffs above the single-point estimates. When a conservative bias is taken, projects which are economically sound could easily be passed up.

Requiring a short payback period. For CBA of private projects, a short payback period (e.g. five to seven years) may be adopted. This makes use of partial information about the project payoff (only that up until the time when the cumulative discounted cash flow becomes and remains positive), and can penalise highly profitable but long-term investments such as disease eradication programs. However, it is a simple rule to apply, and the results are easy for management to understand. Further, this seems an appropriate and popular approach for agencies and firms with limited financial reserves. A government with a short election cycle may consider that taking the ‘long view’ will not help its re-election prospects.

Loading the discount rate with a risk margin. Raising the discount rate, and hence reducing the NPV, is a means of obtaining a conservative estimate of a project’s payoff. This has a similar effect to requiring a short payoff, i.e. increased weight is given to cash flows early in the project’s life. This also is a rather indirect and imprecise way of dealing with uncertain project benefits.

Deriving certainty equivalents for project benefits. A ‘certainty equivalent’ is an assured sum of money such that the decision maker is indifferent to this sum or the higher but uncertain actual payoff. For example, a person may regard an assured sum of $10000 in one years’ time as equally attractive to an expected payoff of $12000 with a standard deviation of

$3000, also to be received one year from now. Methods have been developed for estimating certainty equivalents for probability distributions, based on estimated or assumed utility functions of decision makers, e.g. see Anderson et al. (1977). When estimating producer surplus, if the level of risk aversion of livestock owners can be estimated, the assured amount of revenue which has the same value to them as the predicted but uncertain revenue can be derived and used in the cost-benefit analysis. For a decision-maker who is highly risk averse and a project which has a high level of risk, the certainty-equivalent income may be considerably lower than the expected income.

3.2 Sensitivity analysis

Sensitivity analysis is the most widely adopted method of measuring project risk. It involves identifying the parameters affecting cash flows, and reworking the discounted cash flow (DCF) analysis for a number of values of these parameters.[1] The corresponding range of values for NPVs, IRRs, and so on provide an indication of what the profitability outcome will be if parameter values turn out to differ widely from the best-bet estimates, that is, they indicate the robustness of performance criteria to errors in data estimates.

Sensitivity analysis should be carried out with respect to the variables for which changes in values are likely to have the greatest impact on overall project performance. These are likely to be the variables for which uncertainty is greatest, i.e. which have greatest dispersion in probability distributions of values. Since capital outlays are generally made early in a project's life, and their levels are reasonably predictable, these generally do not need to be subjected to sensitivity analysis. There are of course some exceptions to this rule; the costs of construction works are sometimes grossly underestimated.

Project operating costs often can be predicted with a reasonable degree of confidence. However, additional income arising as a result of a project and non-market costs and benefits typically are less predictable, and hence are candidates for sensitivity analysis. Also, it is a common practice to carry out sensitivity analysis with respect to the discount rate.

No fixed rules can be laid down as to the extent to which parameters should be adjusted in sensitivity analysis. Often three or four levels are taken for each uncertain parameter,

[1] Parameters may be regarded as particular random variables, or as measures of location (usually means) of these random variables.

balanced approximately symmetrically around the best-guess value. Optimistic and pessimistic values may cover variations of say plus and minus 30%, or approximate the range over which it is though that the parameter will lie with say 90% confidence.

Sensitivity analysis is preferable to taking conservative estimates of cash flows and conservative discount rates, and when more complex methods are not warranted should be carried out as a matter of course. If parameters governing cash flows are set up in a convenient form on a spreadsheet, it is a simple matter to change values in particular cells in the spreadsheet, record the new values of the performance criteria, and finally present the results in tabular form.

While sensitivity analysis can be conducted with respect to parameters one at a time, it is more useful to examine the combined impact of changes in parameter values. In this regard, a sensitivity analysis table can be drawn up to depict values of a performance criterion for combinations of values of say two or three uncertain cash-flow variables. An earlier discussion paper in this series (Harrison, 1996) illustrates how to derive a sensitivity analysis table using the spreadsheet Microsoft Excel.

Example 1

As an example of sensitivity analysis, consider a project which has annual cash flows as in Table 1. The immediate capital outlay is $25,000, project benefits are $15,000 at the end of each year, and project costs are $4000 spread equally at the beginning and end of year, while the discount rate is 8%. The obvious candidate variable for sensitivity analysis would be annual project benefits. Sensitivity analysis could also be carried out with respect to annual project costs. As well, the impact of varying the discount rate could be examined.

Table 1: Annual cash flows for a hypothetical project

Year	Project benefits ($)	Capital outlays ($)	Operating costs ($)	Net cash flow ($)
0	0	25000	2000	-27000
1	15000	0	4000	11000
2	15000	0	4000	11000
3	15000	0	2000	13000

Tables 2 to 4 provide examples of sensitivity analysis for this project. In Table 2, the NPV has been derived for four discount rates, from zero to 30% in steps of 10%. If the discount rate were to be much above 10%, the project would fail to return a positive NPV. This information is in fact known when the IRR is calculated (the IRR for this project is 13.76%).

Table 2: NPV as a function of discount rate

Discount rate (%)	NPV ($)
0	8000
10	1858
20	-2671
30	-6112

In Table 3, two parameters are varied simultaneously, viz. annual revenue and annual operating costs. NPV is calculated for four levels of each parameter, all 16 combinations being reported. This table indicates that NPV is more sensitive to changes in annual benefits than annual operating costs, over the particular ranges regarded as reasonable for each. If annual benefits were to fall to $12000, the project would incur a loss. Annual operating costs of $5000 could be covered, provided annual benefits were at least $15000.

Table 6.3: Sensitivity analysis with respect to annual benefits and operating costs

Annual operating costs($)	**NPV for annual benefits of**			
	12000	**15000**	**18000**	**21000**
3500	-3455	4276	12007	19738
4000	-4796	2939	10667	18389
4500	-6136	1596	9327	17058
5000	-7476	256	7987	15718

Table 4 illustrates how three factors can be combined in the same sensitivity analysis table. Here only three levels of each factor (annual benefits, annual costs and discount rate) are considered, but this still yields 3 x 3 x 3 or 27 combinations of values. A rather large amount of information is presented in the table. Basically, the message is that the project would not be economically viable if the annual benefits were only $12000, regardless of the annual operating costs and discount rate. Also, even if the revenue is $15000 a year, a combination of high operating costs and high discount rate would lead to a non-viable project.

Table 3: Sensitivity analysis with respect to three factors

Annual project benefits ($)	Annual project costs ($)	NPV for a discount rate of		
		4%	8%	12%
12000	3000	-191	-2116	-3816
	4000	-3021	-4796	-6362
	5000	-5852	-7476	-8908
15000	3000	8135	5616	3390
	4000	5304	2936	844
	5000	2473	256	-1702
18000	3000	16460	13347	10595
	4000	13630	10667	8049
	5000	10799	7987	5503

Sensitivity analysis, while tedious, is not difficult to carry out once a spreadsheet has been developed, and provides useful information about how robust the project profitability is in the face of higher costs (including the discount rate or cost of capital) and lower benefits. Limitations of the approach are that in practice it is not convenient to include more than about three or four uncertain parameters simultaneously (a second level heading could be provided under rate of interest in Table 4), and no information is provided to the decision maker about the likelihood of each NPV outcome.

3.3 Breakeven analysis

This is a variation of sensitivity analysis in which levels of the uncertain variables are sought for which the project or program just breaks even, i.e. the NPV is approximately zero or the IRR is approximately equal to the cost of capital. One tends to look for these breakeven values automatically when interpreting a sensitivity analysis table. Table 2 above indicates a breakeven discount rate of between 10% and 15% (consistent with the estimated IRR). Table 3 indicates, for example, that the breakeven level of annual revenue is between $12,000 and $15,000, depending on the level of operating costs.

3.4 Risk analysis

Risk analysis is an extension of DCF analysis in which the variability of performance of a project is estimated by fitting probability distributions to the cash flow variables considered to have high risk, and hence estimating the probability distributions of performance criteria. The analysis is designed to mimic the uncertainty in the environment (weather, market, etc.) in which the project is undertaken.

Once probability distributions are estimated or fitted for uncertain cash-flow variables, *Monte Carlo sampling* is used to select or *generate* random observations from *each* of the distributions. Annual cash flows are then derived using the values selected from the probability distributions (one value from each distribution), and DCF analysis is carried out to yield the various performance criteria. This analysis yields a *single* sample value for each performance criterion.

The above sequence of steps (generating a random values for each uncertain value, calculating the cash flow sequence, deriving performance criteria) is repeated a large number of times (called *replicates*). In this way, a large number of random values of each of the performance criteria is generated. For example, 100 or more random observations of NPV may be obtained, and presented in table form. Each of these values will be a random observation from the probability distribution of NPV consistent with the distributions which have been estimated for the cash-flow variables.

A further stage in risk analysis is to sort the values of each of the performance criteria into say ascending order, and to convert them *to cumulative relative frequencies*. In this way, *estimates* are obtained of the *cumulative probability distributions* of the performance variables. Often summary statistics such as means, quartiles and ranges are also derived. Results may be presented in table or graph form. It is then possible to read off estimated probabilities of various levels of performance, e.g. of making a negative NPV or of making an IRR of greater than 30%. Relative to sensitivity analysis, this approach provides more information to the decision maker.

Probability distributions should be estimated for the variables which are expected to have the greatest level of uncertainty and greatest impact on overall project performance. As an example, in a livestock vaccination program probability distributions could be attached to variables such as vaccination coverage rate, protection rate, disease outbreak frequency and number of years until effective control is achieved.

Probability distributions of cash-flow variables may be estimated from historical data or by subjective means. While use of historical relative frequencies would appear to provide a more sound basis for estimation of probabilities, there is a credibility gap in projecting past values into the future. For this reason, subjective estimates by ‘experts’ or people who could be expected to have a sound knowledge of livestock systems probably is a sounder approach.

Of course, having to estimate probability distributions means that more effort is required in the analysis. A number of levels and associated probabilities are required for each parameter, rather than simply the best-bet level. It has been observed that in practice some people are unhappy with being forced to estimate a parameter as a single figure, and are quite willing to provide best-guess, optimistic and pessimistic values, from which probability distributions can be inferred.

A wide variety of forms of distributions have been used in risk analysis. The simplest form is what is sometimes called *discrete* or *empirical* distributions, where probabilities are estimated for say four discrete levels of a variable. Various continuous probability distributions are also applied, including the normal, triangular, rectangular, beta and Weibull distributions. Methods have been developed for *synthetic sampling* from each of these distributions, e.g. see Cassidy et al. (1970), Newman and Odell (1971). In general, the distributions are taken as independent of each other and independent within variables over time (i tertemporally independent). However, more refined sampling methods can be developed which allow for correlations between variables and correlations within variables over time, e.g. see Harrison and Cassidy (1979).

Risk analysis - or *venture analysis* as it is sometimes called - can be carried out by writing a computer program in one of the (third generation) programming languages, such as FORTRAN, Cor BASIC. Alternatively, a *macro* could be written as part of a spreadsheet package. While the technique has been well known for more than 20 years, the programming effort required has been a disincentive for using it. Recently, a risk analysis add-on to the spreadsheets Lotus 1-2-3 and Microsoft Excel called @RISK has been developed, which makes risk analysis considerably easier and has promoted many applications, e.g. McGregor et al. (1993).

Example 2

Suppose that with respect to the Example 1, the project benefits and costs cannot be predicted with certainty. However, it is possible to place probability distributions on them. Let us take, as a hypothetical example, that the three cash flow streams (annual benefits of $15,000, capital outlays of $25,000 and annual operating costs of$4000) are now the expected values of random variables; further, these variables follow normal distributions with standard deviations of $3000, $500 and $2000 respectively[2].

A small BASIC computer program has been written to carry out a risk analysis with respect to these distributions. A *simulation* experiment has been conducted in which 50 sets of observations or *replicates* are taken of the cash flows, and NPV and IRR are calculated for each replicate. These values are presented in Table 5. The values have been sorted into ascending order of magnitude, and sorted values are also presented in the table. It is apparent from Table 5 that the project could incur a loss or negative NPV, and that the NPV could be as low as about -$8000. However, positive NPV values appear more likely, and a value of up to about $15,000 appears possible.

Table 5 also indicates cumulative relative frequencies; since there are 50 observations, these run from 0.02 to 1.00 in steps of 0.02. A cumulative relative frequency of 0.3 for example indicates that the fraction 0.3 of NPV observations is less than this level. These cumulative relative frequencies are *estimates* of 'less than' cumulative probabilities[3]. From inspection of Table 5, there is an estimated probability of about 0.25 that the project will make a loss (negative NPV), or an estimated probability of about 0.75 (1-0.25) that the NPV will be positive. Similarly there is an estimated probability of about 0.2 that the NPV will exceed $10,000. The median outcome (associated with an estimated probability of 0.5) is an NPV of about $2500, and the mean outcome is an NPV of $4200.

The cumulative relative frequency distributions may also be expressed in graphical form, as in Figure 1. The graph is readily drawn from the spreadsheet of NPV values. NPV is represented on the horizontal axis, and cumulative relative frequency of the vertical axis. The curve, while not regular, always moves upwards to the right, i.e. the greater the reference NPV level the greater the estimated cumulative probability that the actual NPV will be less than this level. The virtue of this form of presentation that it is easier to interpret than the table. It is immediately apparent that there is a considerable risk of a negative NPV, but that values over about $5000 are also highly probable. The graphical representation is also relevant to stochastic dominance analysis, as discussed below.

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[2] An alternative would be to attach probability distributions to the particular price or quantity items from which these cash flows are derived.

[3] The cumulative relative frequency curve is sometimes referred to as a cumulative (probability) density function or CDF. While it is not unusual to refer to the results of risk analysis as probabilities, it should be borne in mind that the computer output arises from a relatively small *sample* of simulated performance, and that the probability distributions for cash flow variables typically are estimated by highly subjective means. Hence it is appropriate to think of the distribution derived for say NPV as representing *sample* rather than *population* data.

Table 5: Computer output for risk analysis

Replicate number	NPV	Sorted NPV	Cumulative rel. freq.
1.	10428	-7731	0.02
2.	-538	-3885	0.04
3.	447	-3312	0.06
4.	12005	-1957	0.08
5.	830	-1944	0.10
6.	923	-1772	0.12
7.	-861	-1538	0.14
8.	6652	-1226	0.16
9.	2472	-1171	0.18
10.	6730	-861	0.20
11.	10212	-538	0.22
12.	11540	-462	0.24
13.	13677	417	0.26
14.	417	447	0.28
15.	4381	663	0.30
16.	6530	830	0.32
17.	2762	863	0.34
18.	11119	923	0.36
19.	-1944	1576	0.38
20.	13075	1577	0.40
21.	14282	1924	0.42
22.	1577	2294	0.44
23.	-1957	2358	0.46
24.	2512	2472	0.48
25.	-3312	2512	0.50
26.	13419	2525	0.52
27.	863	2762	0.54
28.	-1772	2834	0.56
29.	2294	3619	0.58
30.	2358	4381	0.60
31.	-3885	4830	0.62
32.	7382	6530	0.64
33.	1924	6652	0.66
34.	15232	6730	0.68
35.	-462	7353	0.70
36.	-7731	7382	0.72
37.	663	8389	0.74
38.	4830	8922	0.76
39.	8922	9232	0.78
40.	3619	10212	0.80
41.	8389	10428	0.82
42.	-1171	11119	0.84
43.	-1226	11540	0.86
44.	9232	12005	0.88
45.	12204	12204	0.90
46.	2525	13075	0.92
47.	7353	13419	0.94
48.	-1538	13677	0.96
49.	2834	14282	0.98
50.	1576	15232	1.00
Means	4236	4236	

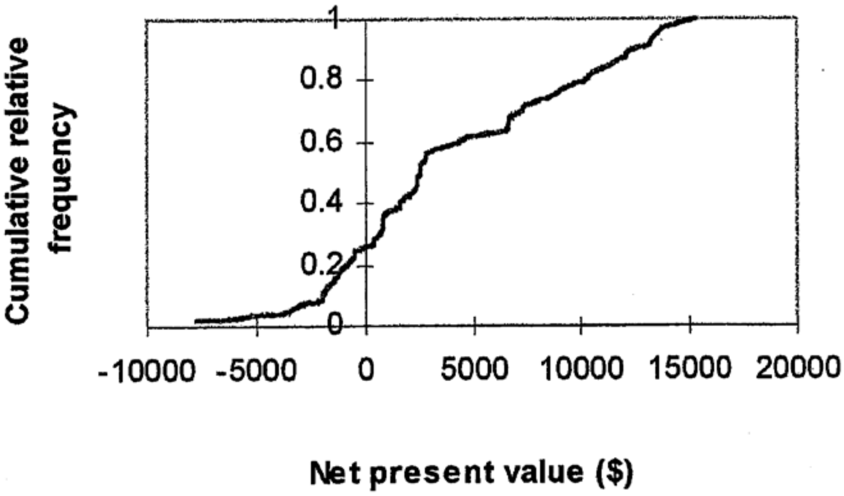

Figure 1: Cumulative relative frequency curve

Note that the above risk analysis has been carried out for a fixed discount rate of 8%. If the discount rate were say to be raised, this would move the cumulative relative frequency curve to the left, a lower NPVs being associated with any cumulative relative frequency. A sensitivity analysis could still be conducted with respect to discount rate, with results presented graphically as CDF curves which would be approximately parallel to each other.

To summarise, an inspection of the estimated distribution of profitability criteria (preferably in sorted form) or a graph of the cumulative relative frequency curve yields considerable additional information concerning the probabilities of various levels of project performance, relative to point estimates of performance or even sensitivity analysis tables.

3.5 Stochastic dominance analysis

Sometimes it is necessary to compare two or more alternative projects or programs, or variations to the design of a single project, where performance under each is uncertain. The comparison needs to be not only in terms of expected levels of performance criteria, but also in terms of their distributions or variability. The technique of *stochastic dominance analysis* (SDA) may be used for this purpose. This technique allows us to compare the attractiveness of alternative projects in terms of relative locations of cumulative relative frequency (or density) curves (CDFs). To carry out SDA, the CDFs of each project option are estimated using risk analysis. In this sense, SDA is an extension of risk analysis; that is, it is designed to help interpret the results of risk analysis of alternative projects. A brief introduction only to

SDA will be provided here.

For SDA, it is necessary to know the decision maker's attitude towards risk, i.e. whether they are *risk averse, risk neutral or risk preferrers*. As indicated earlier, a substantial amount of research has indicated that decision makers in general tend to be risk averse, that is, they are prepared to sacrifice some amount of expected payoff for a lower level of variance of payoff[4].

Suppose two alternative project options A and B have CDFs of net present value as in Figure 2. Since the curve for B is entirely to the right of A, at any cumulative probability level the payoff for B is greater than that for A. Option B is said to *dominate* A, such that a rational decision maker would not be interested in A. This situation is referred to as *first stage stochastic dominance* (FSD).

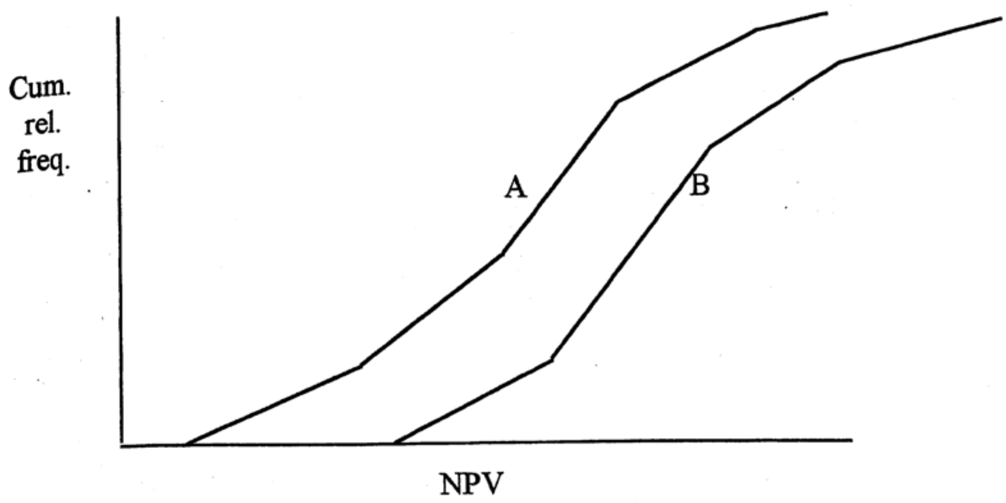

Figure 2: An example of FSD

A more complex case arises when the CDFs cross, as depicted in Figure 3. Here neither project has an NPV greater than the other at all cumulative relative frequency levels, so it becomes much more difficult to determine whether one project is superior to the other. This is where stochastic dominance anlaysis becomes useful. Provided we have some information – or are prepared to make some assumptions – concerning the decision makers' attitudes

[4] Risk aversion is sometimes represented conceptually in terms of an expected *value/variance* or EV indifference frontier or map for an individual or agency.

towards risk, it is often possible to state which is the preferrred project or program. Using increasingly strong assumptions, the preferred option can be identified in terms of second stage or third stave stochastic dominance (e.g. see Anderson et al., 1977). The decision rules are based on the variance and higher statistical 'moments' of the NPV distributions.

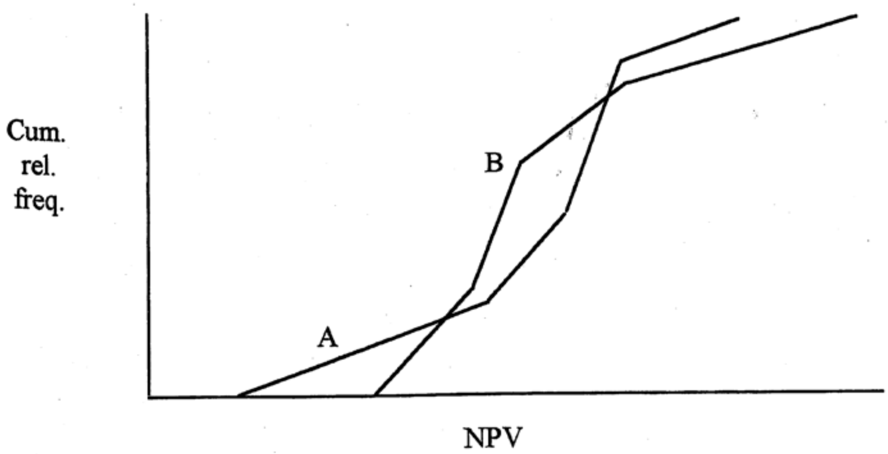

Figure 3: Intersecting CDFs, where higher degree stochastic dominance may apply.

4. CONCLUDING COMMENTS

The terms risk and uncertainty typically are used as synonyms, both referring to unpredictable future outcomes with respect to markets, climate, technology and the legal and institutional framework. Depending on the level of risk of a project, and the magnitude of the project in terms of an agency's overall investment portfolio, various methods may be chosen to measure project risk. These range from simple approaches such as conservative estimates of project benefits and sensitivity analysis, to more complex techniques such as risk and stochastic dominance analysis.

In general, taking risk into account in CBA increases the amount of data collection and analysis which has to be carried out. Hence the extent to which risk should be incorporated in the analysis will depend on the importance of having the extra information. The fact that elegant methods or risk analysis are available does not mean that their use will always be warranted. In practice it is usually advisable (and expected of the economist) to carry out a sensitivity analysis of performance criteria with respect to the most uncertain cash-flow variables (usually benefit variables) and the discount rate. Once cash flows (or budgets generating them) have been entered on a spreadsheet, it is a relatively simple matter to vary parameter values and note the new NPV or IRR values. Increasingly, the technique of risk analysis is being undertaken to accompany CBA. Development of simulation software to complement spreadsheets has made this a reasonably easy task. Stochastic dominance analysis tends to not be widely used.

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