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Advantages and Limitations of Benefit-Cost Analysis for Evaluating Investments in Natural Disaster Mitigation

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Natural disasters can be thought of as a sudden shock to the equilibrium of interrelations between natural systems and social systems. This results in a disequilibrium, the severity of which depends on both the magnitude of the disaster and the ability of the social system to absorb the shock (Albala-Bertrand 1993). Thus, a natural disaster with relatively low physical energy can have major social impacts if it occurs close to vulnerable human settlements and activities (for example, shantytowns in floodplains, hillside agriculture in deforested areas). Similarly a high-energy event can have modest social impacts if human settlements and activities are robust to disturbance (for example, due to building codes, windbreaks). Disaster mitigation is the activity of increasing the tolerance of the social system to the impacts of natural disasters. In areas subject to natural disasters, it is of great importance to analyze social investments within frameworks that allow consideration of the disaster risk exposure of the investments so that scarce development capital can be used in a risk-efficient manner.

Benefit-cost analysis is one means by which the economic effects of disaster mitigation and other social investments can be systematically evaluated. Since the impacts of natural disasters on development projects are inherently uncertain, risk must be explicitly introduced into benefit-cost analysis to obtain meaningful information for disaster mitigation. Although it is not uncommon for project benefit-cost analysis to include sensitivity analysis, it is less common to find more formal risk analysis incorporated. The purpose of this chapter is to examine the potential for using benefit-cost analysis to improve project analysis related to disasters and disaster mitigation.

Natural disasters and project analysis

Development projects represent the investment of capital resources to produce a future stream of benefits that will support economic growth, reduce poverty, or achieve other social objectives. Careful project analysis is one of the most critical determinants of a project's successful outcome (Gittinger 1982). Although various typologies are used to characterize the project planning cycle, the three main phases are identification, pre-feasibility analysis, and feasibility analysis. As the name suggests, the identification phase is the search for potential projects in which to invest development capital. The pre-feasibility phase requires a rough calculation of project benefits and costs to eliminate those with low or negative net benefits. Of course, projects also may be screened at the pre-feasibility stage on the basis of environmental impacts, equity effects, and other criteria in addition to economic return. Finally, feasibility analysis requires refined economic and technical analysis of the viability of a project.

Most economic analyses of projects do not explicitly consider natural disaster information. As usually practiced, benefit-cost analysis fails to account for the fact that future project benefits may be highly uncertain if they are prone to the effects of natural disasters (Kramer and Grieco 1989). This is particularly true in developing countries where a high proportion of natural disasters occurs (Long 1978). The problem with ignoring risk is that a project implemented in an area subject to disasters may fail to realize the positive economic performance suggested by an ex ante benefit-cost analysis.[1] For example, if a tropical storm severely damages crops or if an earthquake seriously damages a new hydroelectric project, an agricultural development project's loan repayment may be jeopardized. Ideally, scarce capital funds should be invested in sectors with less vulnerability to natural disasters, or the projects should be redesigned to include effective disaster mitigation activities. This would prevent development projects from being hampered by economic analysis whose treatment of disaster risk is incomplete.

Several methods have been proposed for incorporating disaster information into benefit-cost analysis. Limited-information approaches include cutoff periods, discount rate adjustments, sensitivity analysis, and several game theory methods. These limited-information approaches allow analysts to recognize the impacts that natural disasters can have on project feasibility but are crude in their ability to convey useful information to decisionmakers. If sufficient information is available to estimate the probability distribution of a project's stream of net benefits, several other approaches are possible, particularly safety-first analysis, mean-variance analysis, and stochastic dominance analysis. Each of these methods for incorporating disaster risk into the economic analysis of projects can improve investment decisions and help to avoid costly mistakes. Yet the methods are only as good as the underlying data, which are often inadequate for accurately characterizing disaster risk.

Risk-modified, benefit-cost analysis

The literature on benefit-cost analysis has long recognized the need to incorporate risk when project benefits and costs are uncertain (Mishan 1982). Various methods have been proposed for incorporating uncertainty, and these can be readily applied to assessing the risk associated with natural disasters. One set of methods is appropriate when partial information is available about the risk of natural disaster. A second set of methods can be applied when the analyst has enough information to estimate probability distributions of natural disaster events. The advantages and limitations of these risk-modified, benefit-cost methods will be considered below.[2]

Limited-information approaches

Various approaches can be used to determine the risk of natural disaster when information is limited. These include applying a cutoff period, adding a risk premium to the discount rate, using game theory approaches, such as maximin-gain and minimax-regret, and employing sensitivity analysis.

CUTOFF PERIOD

One of the simplest methods for dealing with uncertainty is to apply a rule-of-thumb cutoff period that dramatically shortens the assumed life of the project. This crude approach might be used if the primary concern is loan repayment rather than long-term development. In this case, economic feasibility relies on sufficient benefits to cover the project's investment costs in a relatively short time frame of perhaps two or three years. The logic of this approach is that net benefits are so highly variable beyond a selected cutoff date that they should be ignored in project evaluation.

Even this approach requires some information on natural disasters to guide the analyst. Episodic data on natural disasters or previous damage assessments can give the analyst a rough idea of the magnitude of disaster risk. Thus, for an agricultural project, a short payback period might be required if the project appears subject to a high risk of flooding or landslides. Note, however, that a short cutoff period is no guarantee that a project will be economically successful. A natural disaster might occur in the first year of the project and seriously disrupt the flow of benefits. The cutoff period approach is deficient since it does not deal with uncertainty in a systematic way and should only be used when a meager amount of information is available.

DISCOUNT RATE ADJUSTMENT

A second rule-of-thumb approach is to add a risk premium to the discount rate when there is significant uncertainty. The discount rate adjustment has the effect of giving less weight to increasingly uncertain future benefits and costs. Adding a risk premium is consistent with what has been observed in the private sector; loan managers generally charge higher interest rates for riskier investments. To use this approach, the analyst must first determine a risk-free discount rate and then determine the appropriate risk premium (Dasgupta and Pearce 1972). The risk-adjusted discount rate becomes:

$$r_t = \frac{1}{(1 + i = j)^t} \qquad (4\text{-}1)$$

where i is the risk-free rate, j is the risk premium, and t is the time period. To determine the risk premium, the analyst has to have some, albeit limited, information about natural disasters, similar to that used for the cutoff period approach.

Although it is relatively easy to employ, this approach reduces the expected value of a project's net benefits by a compound and arbitrary factor and does not recognize differences in the degree of uncertainty across different components of a project (Mishan 1982). This approach also reduces the worth of all future benefits whether or not they are subject to uncertainty.

Game Theory Approaches

In conducting an economic analysis of a project, especially at the pre-feasibility stage, an analyst may be aware of the possibility of impacts caused by natural disasters but may be unable to assign objective or subjective probabilities to the various states of nature that may occur. For example, records may exist of historical events such as earthquake damage to crops or buildings. Using such data, it may be possible to estimate roughly the benefits from a development project under varying degrees of natural disaster severity. One can then use several game theory approaches to guide investment decisions. Two are discussed here: maximin-gain and minimax-regret. Both use decision rules that focus on loss avoidance

The maximin-gain criterion focuses on security of outcome by avoiding the worse possible result (Dasgupta and Pearce 1972). For this criterion, the decision rule is to compute the minimum payoff for each alternative and select the alternative with the highest minimum payoff. This can be illustrated with an example for a development project that generates agricultural benefits and offers protection from floods (Kramer and Florey 1987). Suppose three flood control alternatives can be included in the project at equal cost. Due to lack of more detailed information, the analyst considers two possible states of nature: heavy precipitation and normal precipitation. If precipitation is heavy, the net present values of the three flood mitigation schemes are $100 million, $120 million, and $150 million. If precipitation is normal, the mitigation alternatives provide net benefits of $30 million, $60 million, and $20 million, respectively. Project benefits are lower in the event of normal precipitation, since the primary objective of the project is flood control. The example is presented below:

Benefit matrix for alternative mitigation options

Option	*Heavy precipitation*	*Normal precipitation*
Option 1	$100 million	$30 million
Option 2	$120 million	$60 million
Option 3	$150 million	$20 million

The maximun-gain criterion would lead to the selection of option 2 since its minimum payoff is $60 million, which is larger than the minimum payoff of the other two options. This game theory method uses only part of the available information by focusing only on the worse outcome. It implies a conservative bias in project selection and hence might inhibit long-term development if used to guide social investments.

An alternative game theory approach is known as the minimax-regret criterion (Dasgupta and Pearce 1972). This criterion can be applied as follows. For each option, the actual payoff is subtracted from the potential payoff, where potential payoff is the amount that could have been realized if the state of nature was known in advance. This difference is defined as regret. For each option, the maximum regret that could occur is identified, and the option with the smallest maximum regret is chosen.

For the flood mitigation example above, option 3 would have the greatest benefit if heavy precipitation occurs. If option 1 had been selected, the regret associated with not selecting option 3 would have been $50 million ($150 million to $100 million). If option 2 had been selected, the regret would have been $30 million ($150 million to $120 million). If the state of nature had been normal rather than heavy precipitation, option 2 would have generated the greatest benefit, $60 million, and the regret would have been $40 million for option 3 and $30 million for option 1. Consider-ing both states of nature—heavy and normal precipitation—the maximum regret would have been \$50 million, \$30 million, and \$40 million, respectively, for options 1, 2, and 3. Hence, the minimax-regret strategy would lead to the choice of option 2 since it has the smallest maximum regret.

While the minimax-regret criterion is superior to the maximin-gain criterion because it uses all of the information in the benefit matrix, it still embeds a conservative bias. Furthermore, it implies cardinally measured utility since it measures regret by the difference between actual and potential outcome (Dasgupta and Pearce 1972).

SENSITIVITY ANALYSIS

Sensitivity analysis is perhaps the most widely used method to consider the impacts of uncertainty in benefit-cost analysis. Generally a table is presented showing the effects of changes in key parameter values on economic feasibility, such as net present value or benefit-cost ratio. The values might be varied by one standard deviation, although a more typical approach is to use arbitrary adjustments of 10 or 20 percent (Irwin 1978).

Sensitivity analysis could be useful in identifying which variables are important in determining project feasibility even when there is limited information about the occurrence and severity of a natural disaster. Furthermore, it could help to identify where mitigation might have the highest payoff. Although this approach is useful in identifying the relative importance of key variables in influencing a benefit-cost analysis, it does not consider the amount of uncertainty in key parameters or give any information about the relative riskiness of alternative investments.

Probability-based approaches

The limited information methods described above can be a useful first step in introducing considerations of natural disasters into the economic analysis of projects. Because they are not data intensive, these methods may be particularly relevant at the pre-feasibility stage of project analysis. However, for conducting feasibility analysis of a major project subject to considerable disaster impacts, the analyst would be advised to obtain probabilistic information on key variables. If probability distributions of natural disaster events can be obtained and linked to economic variables, a more rigorous and informative analysis can be conducted. Typically only a few variables that enter into a benefit-cost analysis are treated as stochastic, for example crop yields. Other variables are treated as known. The decision about which variables to treat as random will depend on both the availability of data and on the analyst's judgment about which variables are most important. This judgment may be based in part on an earlier sensitivity analysis. Once the decision is made about what to treat as stochastic, one can estimate probability distributions from historical data or from experts' subjective judgments. The various probability distributions can be combined to generate a probability distribution of net present value, internal rate of return, or some other feasibility measure.

Empirically, a probabilistic benefit-cost analysis can be carried out using stochastic simulation methods.[3] These methods draw random samples from specified probability distributions. If the random variables are believed to be correlated—for example, rice and maize yields—multivariate distributions can be used. The random draws are fed into a benefit-cost analysis, and the resulting summary statistics are recorded. The procedure is repeated many times to generate a probability distribution of net present value or another feasibility measure. This generated distribution can then be used to convey information about the riskiness of the project in question.

Once the probability distribution of project benefits is available, it can be used in a variety of ways to rank investment alternatives. First, it can be used simply to compare expected net present value across projects. This is basically equivalent to a standard benefit-cost analysis in which one uses the most likely values of the important economic variables. The disadvantage of comparing expected outcomes is that such a comparison does not use all of the information in the probability distribution. Furthermore, it assumes that decisionmakers are risk neutral and hence indifferent between projects with equal means but different degrees of dispersion. If this was the case, one should have ignored risk to begin with. To make better use of the risk information at hand, other approaches are preferable. These include safety-first analysis, mean-variance analysis, and stochastic dominance analysis. Each will be discussed below.

SAFETY-FIRST ANALYSIS

This method focuses attention on the downside risk associated with project investments. If decisionmakers are concerned about the potential damages resulting from natural disasters, they may wish to use a decision criterion that emphasizes the lower tail of a probability distribution of project benefits. This is particularly useful if project benefits exhibit nonsymmetric distributions like the beta. One way to operationalize the safety-first decision rule would be to solve the following problem:

(4-2) *Maximize* $\overline{NPV}$
subject to $Pr\ (NPV < t) \leq a$

where Pr is probability, t is a critical threshold value, and a is a small probability level, such as 5 percent. This decision rule chooses projects with the highest mean return subject to the constraint that returns have a small chance of falling below a critical threshold level.

An interesting alternative formulation has been proposed for dealing with projects that have potential impacts on the survival of endangered species (Randall 1991). Known as a safe minimum standard, the emphasis of this formulation is even more explicit in minimizing risk:

(4–3) *Minimize* $Pr\ (Z < u)$
subject to $OC \leq A$

where Z is size of the species' population, u is a critical threshold for the population, OC is the opportunity cost of protecting the habitat, and A is a socially determined level of acceptable cost. In other words, in selecting project alternatives, the probability that the endangered species population will fall below a critical threshold is minimized as long as the opportunity costs of doing so (forgone development alternatives) are not unacceptably high.

MEAN-VARIANCE ANALYSIS

Another method for using probabilistic benefit-cost information is to compare the means and variances of the distribution of returns from different projects (see Keeney and Raiffa 1976). In particular, decisionmakers may want to consider tradeoffs between higher expected return and lower risk. A project with less chance of being undermined by a natural disaster might be chosen over a project with higher expected return but subject to greater disaster risk.

According to Dasgupta and Pearce (1972), the decision rule can be stated as follows:

(4–4) *Maximize* $U = E - bV$

where U is utility of project returns, E is expected return, b is a risk-aversion coefficient between 0 and 1, and V is variance of return from the project. The higher b is, the greater the aversion to risk.[4] This decision rule simultaneously considers the mean and variance of returns for each project. The second term in the expression serves to penalize projects with greater risk.

The mean-variance approach to decision-making is prevalent in financial decision analysis but is seldom applied to benefit-cost analysis. For financial analysis, procedures have been developed to elicit risk-aversion parameters to guide decisionmaking. An appropriate risk-aversion parameter for social investment decisionmaking is difficult to determine. However, by reporting means and variances for different projects or different versions of the same project, analysts can provide decisionmakers with information on the tradeoffs between expected return and risk. Those decisionmakers can then apply their own subjective weights in comparing projects.

STOCHASTIC DOMINANCE ANALYSIS

The final method for comparing probabilistic information on project returns is stochastic dominance analysis. This method is the most general technique used to compare probability distributions. It is consistent with axiomatic-based expected utility theory and does not require the strong assumptions of mean-variance analysis. Stochastic dominance analysis allows probability distributions to be ranked for different classes of risk averters. Using entire distributions of returns, alternative projects can be ranked. This approach has been applied to risky problems in the financial and agricultural economics literature but has not been used to examine the effects of natural disasters on the feasibility of development projects. However, it holds considerable potential as a rigorous method for ranking risky projects or different mitigation options.

Empirical issues

To use the probabilistic approaches discussed above, two empirical issues must be addressed: estimating probability distributions and evaluating nonmarket environmental impacts of natural disasters.

Estimating probability distributions

It is essential to estimate the probability distributions for natural disasters, crop yields, and other key variables. The distributions can be estimated with standard statistical techniques if historical data are available. For example, if the historical records indicate that hurricanes have struck an area in two of the past twenty years, a probability of 0.1 would be assigned to the likelihood that a hurricane would occur in any given year. If stochastic simulation methods are employed, a particular type of probability distribution (for example, normal or uniform) would be assumed and random draws that reflect historical frequencies would be generated. Probabilities based on historical frequencies are often referred to as objective probabilities.

When historical data are not available or when environmental changes have occurred that would render historical frequencies a poor predictor of future events (such as extensive deforestation causing an increase in landslides), the analyst may wish to use subjective probabilities. Subjective probabilities reflect personal judgments about the likelihood of different states of nature. Since most decisionmaking is based on decisionmakers' subjective probabilities, subjective probability is now widely accepted for supporting decision analysis (Bessler 1984). Project analysts could use subjective probabilities from disaster experts about the likely occurrence of tidal waves, landslides, floods, and other natural disasters. They might also consult agricultural experts (including farmers) about the probability of different yield levels given various states of nature.

Various methods are available for eliciting subjective probabilities from decisionmakers (see Norris and Kramer 1990 for a review). One simple and effective approach is known as the triangular distribution method because of the shape of its probability distribution function. The apex of the distribution is at the mode, and the other two angles occur at the upper and lower end of the distribution. Thus only three values are needed to estimate the distribution: the mode and the maximum and minimum values.

Evaluating nonmarket environmental impacts of natural disasters

When natural disasters affect market activities, it is relatively straightforward to estimate the economic impacts For example, disruptions in the transportation sector can be valued based on lost commercial traffic and damage to infrastructure. However, natural disasters often have impacts on the environment that are not readily monetized based on market prices. In such cases, nonmarket valuation methods are needed to estimate the impacts of natural disasters. These methods, which have come into fairly widespread use over the past decade, are briefly reviewed below (for more detailed descriptions of the methods, see Braden and Kolstad 1991; Freeman 1993; for applications in a developing-country context, see Kramer and others 1993; Munasinghe 1993). Each is a means of estimating shadow prices for changes in environmental quality.

TRAVEL COST METHOD

This method has been developed to estimate the recreational demand for particular sites when market prices are not available. The principle underlying this approach is that people spend time and money to travel to a recreational site, and these expenditures can be interpreted as a price, or willingness to pay, for the site.

To implement this valuation method, visitors to sites are surveyed to determine their costs of travel to the sites. In addition, data on socioeconomic characteristics are collected. Statistical regression analysis of the data is then used to estimate a demand function for the site. If a natural disaster such as a hurricane alters the possibility of using a recreational site, such as a beach area, the travel cost method could be applied to substitute sites to measure the economic losses associated with having fewer recreational opportunities.

CONTINGENT VALUATION METHOD

Another approach that is used to estimate nonmarket values is to ask people directly about changes in their welfare. This approach is based on a questionnaire administered to a sample of the population. Through a series of questions, an attempt is made to get respondents to reveal their willingness to pay for environmental services. For example, people can be asked to assign a value to a national park area damaged by a natural disaster. The question might be phrased as "How much would you be willing to pay to restore the park to its pre-disaster state?" Using sample survey methods, the contingent valuation responses can be generalized to a larger population to estimate aggregate damage to resources.

There are some potential biases with the contingent valuation approach. For example, people's responses are for a hypothetical market and may not reflect their behavior if they were confronted with an actual market. Another problem is known as strategic bias. Fishermen may state a very high willingness to pay in hopes that this will lead to a wetlands area being preserved or restored. However, these biases can be overcome with proper questionnaire design and statistical analysis.

LAND PRICE ANALYSIS

Although many environmental attributes are not traded in markets, their presence may have an effect on property values. Land prices may be lower for land parcels subject to flooding or landslides. By statistical analysis, the component of land values attributable to environmental amenities or disamenities can be estimated if data are available on land prices, environmental characteristics, and other real estate characteristics for a large number of land parcels. Using multiple regression techniques, the contribution of natural hazards to land prices can be determined. This amount will be a measure of people's willingness to pay to avoid the hazard. A limitation of this approach is the difficulty of obtaining sufficient data on land parcels, especially in developing countries.

PRODUCTIVITY ANALYSIS

Productivity analysis uses a biological production function to measure the effects of environmental change on the productivity of a resource. This change in productivity is then measured in monetary terms using prices for the affected resource product. For example, a demand function could be estimated for fish to determine the benefits provided by wetlands habitat destroyed by hurricane. If the presence of wetlands before the natural disaster provided breeding areas and increased food supply for various fisheries, and these fisheries were commercially exploited, then the value of the lost or degraded wetlands could be measured by the dollar value of the decline in fish catches resulting from the wetlands damages.

This is a clear example of the need for an interdisciplinary approach. Biological information is needed on the effects of wetlands on the size and harvest of fish populations. This information can then be used to determine the contribution of the wetlands to the fish catch, and benefits can be calculated from the change in economic activity.

OPPORTUNITY COST ANALYSIS

This method values environmental resources based on the cost of replacing the services of a resource destroyed by a natural disaster. For example, if a wetland assimilates waste, the benefit of those services can be given a value by calculating the least-cost alternative of substituting for those services. If a wetland filters out nutrients from agricultural runoff, then the absence of the wetland would require some substitute way of preventing those nutrients from entering downstream waters in order to maintain the same level of water quality. For example, farmers might be required to change their agricultural technologies to reduce their fertilizer application rates or to increase the uptake of nutrients by their crops. By estimating the incremental cost of the new technologies, an economic value can be assigned to the waste assimilation services of a degraded wetland.