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# THE DECISION TO EXPLOIT AN IRREPLACEABLE RESOURCE IN AN UNCERTAIN WORLD

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**ABSTRACT**

New concepts for capital budgeting under uncertainty can be extended to exploitation of irreplaceable resources in an uncertain world. Discussion focuses on the decision to build dams in beautiful valleys where there is considerable uncertainty concerning true benefits and costs. Each decision not to build is repeatedly reviewed by successive administrators. It is shown that to avoid overbuilding the minimum acceptable benefit-cost ratio must be set above unity. The results easily extend to decisions to develop mineral resources or to utilize wilderness areas.

In an uncertain world, decisions to utilize a natural resource must be taken in a significantly more conservative way than in the same world with perfect certainty. This implies that the minimum acceptable benefit cost ratio on dams and other public works projects should exceed unity. These conclusions emerge from some of the new ideas on decision making under uncertainty that are appearing in the financial literature [1–3].

The concept of uncertainty used here is that of estimation error. This arises because no one can know the future, and decisions must be made on the basis of estimates of future conditions. Inevitably, different individuals trying to make decisions under conditions of uncertainty will reach somewhat different conclusions. Thus, uncertainty usually implies a divergence of opinion [4]. When different people look at the same problem they reach different conclusions.

The problems uncertainty poses for conservation can be seen by a simple fable. There is a land of many beautiful undammed valleys. The exact benefits





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and costs (including the environmental costs) of damming the different valleys are uncertain. Reasonable men might differ and do. The decisions on whether or not to dam a particular valley are made by the administrators of the water resources agency. These are all good and able men whose decisions on the merits of a particular project are unbiased in the statistical sense. This means that the expected value for the administrator's estimate of the benefits and costs of a particular project is equal to the true benefits and costs, although any particular estimate may be high or low.

The first administrator examines the set of possible projects and selects for damming the valleys where his estimates of benefits exceed his estimates of costs. In due course, this administrator is replaced by another good and able administrator. He has a new survey of the potential dam sites made and again constructs dams in all cases where the benefits appear to exceed the costs. This process continues for a number of administrators until most valleys are dammed. Finally, the dam building program is discontinued, and a conference held to assess the benefits and costs of the program as a whole. When this is done, it is the universal opinion that too many dams have been built even though every administrator was a good and competent man. In particular, when faced with the tasks of estimating benefits and costs for a set of projects, the expected value of benefits and costs was equal to the actual value for all projects evaluated by each administrator.

The problem can be seen using symbolic notation. Suppose there are decision makers who make their decisions on successive days (thus eliminating the notational complexities of having to discount the benefits and costs to a common date). As before, a decision to act is irreversible. Let $x_i$ be the benefit cost ratio as estimated by decision maker i. The estimates are drawn at random from a set of possible estimates whose mean is X, the actual value for the ratio. The risk preferences of all decision makers are such that all decision makers would wish to build the project if they knew that $X > 1$. Following conventional wisdom, each decision maker will decide to build the project if $x_i > 1$. Thus the project will be built if Max $x_i > 1$. If $n > 1$ and the standard deviation of the distribution of estimates $> 0$, this criterion will normally accept more projects than would be accepted by use of the criterion $x_i > 1$ (where i is any single integer), and more projects than would result from $X > 1$, although the inability to know X makes the latter inoperable. Thus, for the typical sequential decision problem involving irreversibility, the usual criterion of building the project if $x_i > 1$ is incorrect.

There appears to be a paradox here. However, its resolution is simple using an argument developed in the financial literature [5]. Although estimates for a *randomly* selected group of projects are equally likely to be high as low, this is not true for the set of projects selected for construction using estimated benefits as the criteria. The probability of a project being built is increased if its benefits are overestimated (or its environmental costs underestimated). Thus, for the set of projects selected for construction the benefits are expected to be overestimated, and the costs (including environmental costs) underestimated.

In principle, the solution for this problem is to use a higher value for the cut-off criterion. If public work projects are to be evaluated using benefit-cost ratios, the requirement for project approval should be a benefit-cost ratio significantly higher than one. If project approval is based on the internal rate of return, the required rate should be higher than the cost of capital or the social rate of discount. It is not clear what the optimum size of the adjustment should be but it clearly increases both with the magnitude of the uncertainty about the true benefit cost ratio or internal of return of the project, and with the number of decision makers who will have an opportunity to reverse the decision not to build.

To provide a simple illustration consider the case where a finite number of decision makers are involved and their decisions are made in such rapid sequence that they can be considered to make their decisions at a single time (thus eliminating the complications of applying different discount factors to the benefits and costs of each decision). In this case, the decision on whether to build or not will be based on the highest benefit cost ratio estimated by any of the administrators. If the statistical properties of the distribution of errors are known, the expected value of the maximum of any distribution can be calculated. For the normal distribution, with the errors independent of one another, the maximum of n drawings have been calculated and published by Tippet [6]. For instance, if there are to be ten opportunities to approve the project, the expected value for the maximum estimate (which is the one which will determine whether the project is built) will be 1.308 for a project with benefit equal to costs. If the goal is to accept projects with true ratios in excess of 1.0, the required cut-off must be 1.308.

The goal of rejecting projects unless their benefit-cost ratio exceeds 1.308 could be accomplished either by raising the cut-off benefit-cost ratio to 1.308 or dividing the estimated-cost ratio by 1.308 and then using 1.0 as the cut-off ratio. If there is just one decision to make either method is workable. However, if there are a series of decisions to be made, the applicable amount of uncertainty will vary from project to project. Rather than have a separate cut-off ratio for each project, it would be better to adjust the estimated ratio for each project.

## OTHER APPLICATIONS

Although the above problem has been discussed in terms of building dams in beautiful valleys, the problem is one that occurs whenever decisions are made whose effects are longer than the tenure of decision makers. Most water resource, highway and land use decisions are of this category. A particularly important application is to the preservation of wilderness or to the use of mineral resources. The benefits of retaining these resources are often highly uncertain and difficult to estimate. A decision not to consume a resource is likely to be reviewed every time decision makers change since there are usually interest groups that would benefit from consumption of the resource. Over a long period of time, the odds favor a decision to permit use of the resource. (Other aspects of decision making when effects occur over very long periods are discussed by Krutilla and Fisher [7].)

## LENGTHENING THE PERIOD BETWEEN REVIEWS

A possible solution for the problem described above is to lengthen the period between review of projects or land use decisions. If one was certain that conditions would never change one might urge one-time decision making. Once a decision was made to protect a resource it would never be reviewed. However, conditions do change and it is desirable to review decisions at intervals. (In fact, Congress cannot pass a law that cannot be rewritten by a later Congress.) However, it may be possible to provide for reviews at relatively infrequent intervals (say every ten years). One might also adopt a policy that decisions not to develop will be reversed only if events occur that were not anticipated originally.

Another possibility is to make more decisions through committees. At any one time the probability of a decision to develop being made by a committee is similar to that of the same decision being made by a single administrator. Both administrators and committee are likely to derive their power from approximately the same political process and to reflect the public opinions of the time. However, over a period of time there is a high probability that among a series of administrators there will be at least one who will choose to dam a particular river or to exploit a particular mineral despoit. With a wide range of opinions in the population, the normal luck of the draw will insure that sooner or later there will be a development-oriented administrator, or one who attaches a low value to the particular intangibles at risk. (What these intangibles are varies from project to project and administrators differ in which they emphasize.) Since a committee represents an average of a number of opinions, it is likely that over time the random fluctuations in its evaluations will be less than in those of a single administrator (of course, both will reflect long run changes in public opinion).

As argued earlier, the "uncertainty premium" should increase with the uncertainty about the true benefit-cost ratio. One way to accomplish this is to employ a committee and then require that decisions to develop require more than a simple majority, say a two/thirds majority. If the benefits and costs of a particular action are relatively certain, it will be easy to get the required majority even where benefits only slightly exceed costs. However, where the uncertainty is large the divergences of opinion are also likely to be large, and it will be difficult to get the required majority unless benefits exceed costs by a substantial amount. Of course, care should be taken to avoid a situation where the decision is really made by one man through allowing him to appoint a committee of people who agree with a decision he has already made.

One decision mechanism would be for the President to make an initial decision to preserve lands, and then to provide that this decision will remain fixed for a long number of years, or until reversed by Congress. The advantage of involving Congress is not that it has greater wisdom but that the turn-over in its collected wisdom (however one might measure it) is much less than the turn-over in Presidents, or administrators of agencies. If Congress is not involved, decisions not to develop are likely to be reviewed at least as often as Presidents change and perhaps every time the head of an agency is replaced. Congress is also a large committee whose very size provides a high degree of protection against decisions to develop resulting merely from random fluctuations in evaluations of benefits and costs. Finally, the presence of both a Senate and a House and the possibility of a Presidential veto provides a degree of "conservativeness" (reluctance to reverse decisions already made) that is desirable for the reasons described above.

## CONCLUSIONS

New concepts for capital budgeting under uncertainty can be extended to exploitation of irreplaceable resouces in an uncertain world. Discussion focuses on the decision to build dams in beautiful valleys where there is considerable uncertainty concerning true benefits and costs. Each decision not to build is repeatedly reviewed by successive administrators. It is shown that to avoid overbuilding the minimum acceptable benefit-cost ratio must be set above unity. The results easily extend to decisions to develop mineral resources or to utilize wilderness areas.

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