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OPTION VALUE: THEORY AND MEASUREMENT

by

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In this paper we provide a theoretical review of option value and its relationship to a more familiar concept in decision analysis, the value of information. We further show how option value might be measured with the aid of a partly realistic and partly hypothetical example. Finally, we consider how contingent valuation techniques might be used to estimate option value.

Option Value: Theory and Measurement

1. Introduction

The purpose of this paper is to review the role played by irreversibilities and the lack of perfect information in decision making. A secondary purpose is to suggest how the theoretical results can be used in an empirical analysis with an emphasis on the contingent valuation approach.

As we shall show, whenever a decision has the characteristics that one of the possible outcomes is irreversible, and there is some prospect of gaining better information about the future benefits and costs of these outcomes, a kind of extra benefit attaches to the reversible outcome. This extra benefit is known as option value, and it can, and properly should, affect a choice among the outcomes. Although the concept (of option value) is quite general, and applies in a positive sense to private decisions, the discussion in this paper is in the setting of a public decision involving natural resource development.[1]

The plan of the paper is as follows. In section 2, we show how conventional decision analysis needs to be modified to deal with the special characteristics of decisions made under the conditions we have described. In section 3, we consider the relationship of option value to the value of information, a more familiar concept in decision analysis. In section 4, we present a partly hypothetical example designed to show how one would move toward empirical application. Section 5 continues the focus on application with a discussion of an alternative approach to estimating option value: the increasingly popular technique of contingent valuation.

2. A Model of Decision Under Uncertainty and Irreversibility[2]

Our model is based on the original formulations of Arrow and Fisher (1974) and Henry (1974), but we adopt the more transparent notation and approach of Hanemann (1983). The decision problem is: How much of a tract of wild land should be developed in each of two periods (present and future)? We choose units of measurement such that the maximum level of development (or preservation) is just unity. Then there are three substantive assumptions. First, development in any period is irreversible. Second, the benefits of development in the first period are known; those of development in the second period are not. These assumptions capture the essential features of our problem. A third, made more for ease in obtaining unambiguous results, is that benefits are a linear function of the level of development.[3]

Let us interpret the assumed structure to indicate both its rationale and its limits. The benefits associated with a given level of development are the benefits of development and any remaining benefits of preservation. For the first period, these are $B_1(d_1)$, where d_1 is the level of development. Note that $0 \leq d_1 \leq 1$. Since the relationship between B_1 and d_1 is assumed to be linear, first-period benefits will be maximized by choosing either $d_1 = 0$ or $d_1 = 1$. Thus, the problem is restricted to a choice of corner solutions. The argument would be more complicated were we to consider uncertain second-period benefits as well, but this key restriction carries over.

Second-period benefits are $B_2(d_1 + d_2, \theta)$ where d_2 is the amount of land developed in period 2 and θ is a random variable.[4] Thus, second-period benefits depend on development in periods 1 and 2 and are uncertain. Notice that $d_2 \geq 0$ and $d_1 + d_2 \leq 1$. We shall assume that the problem is to maximize expected benefits over both periods. This is one particular way of dealing with the uncertainty. It is not, however, as restrictive as it may seem since we have not specified that benefits are measured in money units. If, for example, benefits are measured in utility units, then our formulation is equivalent to the quite general expected utility maximization. But note that the results we shall obtain do not depend on risk aversion.

The remaining structural element of the problem involves the behavior of uncertainty over time. More specifically, we consider two possible cases. In the first, nothing further is learned about the value of θ by period 2 so that d_1 and d_2 are chosen in period 1. In the second, the value of θ is learned by period 2 so that it makes sense to defer a decision on d_2 to period 2. Now comes a very important assumption. It is that the learning in case 2 does not depend on first-period development, d_1. For the kind of uncertainty we are trying to capture, this seems appropriate. Uncertainty is largely about the future (period 2) benefits of preservation—for example, the value that may be discovered in some indigenous species. This will be determined not by developing its habitat but by undertaking research into its medicinal or other properties. The research is not endogenous to our problem; but we do assume that the answer it yields, concerning the value of θ, does not depend on the development of the tract in question.

Now let us write the expressions for the value to be maximized under each information structure. Where no new information is forthcoming by the second period, define $V^*(d_1)$ by

$$V^*(d_1) = B_1(d_1) + \max_{\substack{d_2 \\ 0 \le d_1 + d_2 \le 1 \\ 0 \le d_2}} \{E[B_2(d_1 + d_2, \theta)]\}. \tag{1}$$

Then, the maximum value is $V^* = V^*(d_1^*)$ where d_1^* maximizes $V^*(d_1)$ subject to $0 \le d_1 \le 1$.

Where new information is forthcoming, define $\hat{V}(d_1)$ by

$$\hat{V}(d_1) = B_1(d_1) + E[\max_{\substack{d_2 \\ 0 \le d_1 + d_2 < 1 \\ 0 < d_2}} \{B_2(d_1 + d_2, \theta)\}]. \tag{2}$$

The maximum value in this case is $\hat{V} = \hat{V}(\hat{d}_1)$, where $\hat{d}_1$ maximizes $\hat{V}(d_1)$ subject to $0 \le d_1 \le 1$.

What can we say about value-maximizing or optimal development in the first period in each case? Clearly, since $V^*(d_1)$ and $\hat{V}(d_1)$ are different, d_1^* and $\hat{d}_1$ will be different. A natural hypothesis is that $\hat{d}_1 \leq d_1^*$ since it would seem to make sense to put off development, which is irreversible, if there is a prospect of better information about the benefits it will preclude. Put differently, if the decision maker ignores the prospect of better information and simply replaces random variables with their expected values, first-period development will be too great. We can prove this result not in general but where the choice is between no development ($d_t = 0$) and full development ($d_t = 1$). Recall that this is precisely the choice implied by our linearity assumption.

Then, we wish to compare the alternatives of developing and preserving in each information setting. Where no information is forthcoming, we have

$$V^*(0) = B_1(0) + \max \{E[B_2(0, \theta)], E[B_2(1, \theta)]\} \tag{3}$$

and

$$V^*(1) = B_1(1) + E[B_2(1, \theta)]. \tag{4}$$

Thus,

$$V^*(0) - V^*(1) = \begin{cases} B_1(0) - B_1(1) & \text{if} \quad E[B_2(1, \theta)] \geq E[B_2(0, \theta)] \\ B_1(0) - B_1(1) + E[B_2(0, \theta)] - E[B_2(1, \theta)] \\ \text{otherwise} \end{cases} \tag{5}$$

and

$$d_1^* = \begin{cases} 0 & \text{if} \quad V^*(0) - V^*(1) \geq 0 \\ 1 & \text{if} \quad V^*(0) - V^*(1) < 0. \end{cases} \tag{6}$$

Observe that, if $E[B_2(1, \theta)] \geq E[B_2(0, \theta)]$, the current development decision when no information is forthcoming is based solely on a comparison of current preservation and development benefits.

Where new information is forthcoming, we have

$$\hat{V}(0) = B_1(0) + E[\max\{B_2(0, \theta), B_2(1, \theta)\}] \tag{7}$$

and

$$\hat{V}(1) = B_1(1) + E[B_2(1, \theta)]. \tag{8}$$

Thus,

$$\hat{V}(0) - \hat{V}(1) = B_1(0) - B_1(1) + E[\max\{B_2(0, \theta), B_2(1, \theta)\}] - E[B_2(1, \theta)] \tag{9}$$

and

$$d_1^* = \begin{cases} 0 & \text{if} \quad \hat{V}(0) - \hat{V}(1) \geq 0 \\ 1 & \text{if} \quad \hat{V}(0) - \hat{V}(1) < 0. \end{cases} \tag{10}$$

Note that $V^*(1) = \hat{V}(1)$. With full development in the first period, total value over both periods must be the same since the development is locked in for the second period regardless of what is learned about the random variable θ in the first.

We still have not shown the relationship of d_1^* to $\hat{d}_1$. For this, just one more step is needed. From the convexity of the maximum operator and Jensen's inequality, it follows that

$$\hat{V}(0) - V^*(0) = E[\max\{B_2(0, \theta), B_2(1, \theta)\}] - \max\{E[B_2(0, \theta)], E[B_2(1, \theta)]\} \geq 0. \tag{11}$$

Since $\hat{V}(1) = V^*(1)$, it follows from (11) that $\hat{d}_1 \leq d_1^*$. This means that optimal first-period use of the area is less likely to be full development ($d_1 = 1$) when it is possible to learn about the benefits precluded than when it is not.

3. Option Value and the Value of Information

The concept of option value put forward by Arrow and Fisher, Henry, and Hanemann falls out quite naturally from the model presented in the preceding section. Option value, in this interpretation, is the gain from being able to learn about future benefits that would be precluded by development if one does not develop initially—the gain from retaining the option to preserve or develop in the future. In our terminology this is

$$OV = \hat{V}(0) - V^*(0). \tag{12}$$

From equation (11), option value OV is nonnegative and, from (9), when $E[B_2(1, \theta)] \geq E[B_2(0, \theta)]$,

$$\hat{V}(0) - \hat{V}(1) = B_1(0) - B_1(1) + OV, \tag{13}$$

i.e. in this case the current development decision should be based on an assessment of current preservation and development benefits plus option value.

It is tempting to identify this concept of option value with another one familiar in decision theory: the value of information or, more precisely, the expected value of perfect information.[5] However, the identification is not quite correct. Option value in this interpretation is a conditional value of information—conditional on $d_1 = 0$.

The <u>unconditional</u> value of information is $\hat{V}(\hat{d}_1) - V^*(d_1^*)$ or, in other words, the gain from being able to learn about future benefits provided d_1 is optimally chosen in each case. This may not mean $\hat{d}_1 = d_1^* = 0$. Two other outcomes are possible: $\hat{d}_1 = d_1^* = 1$ and $\hat{d}_1 = 0$, $d_1^* = 1$. (Note that $\hat{d}_1 = 1$, $d_1^* = 0$ is ruled out by the result that $\hat{d}_1 \leq d_1^*$.) If $\hat{d}_1 = d_1^* = 1$, the value of information is $\hat{V}(1) - V^*(1) = 0$; whereas option value is still $\hat{V}(0) - V^*(0) \geq 0$. If $\hat{d}_1 = 0$ and $d_1^* = 1$, the value of information is $\hat{V}(0) - V^*(1)$. Option value is once again greater than the value of information since $\hat{V}(0) \geq \hat{V}(1) = V^*(1) \geq V^*(0)$. To summarize, then, option value is not identical to the value of information in the development decision problem. The option value is, instead, a conditional value of information—conditional on retaining the option to preserve or develop—and, moreover, is equal to or greater than the (unconditional) value of information.

4. Toward Empirical Application

An example will be helpful both in illustrating these concepts and in showing how they might play a role in an empirical analysis. In this section we present a partly realistic, partly hypothetical example: the breeding of a perennial corn from a related wild grass preserved in a remote, mountainous region of Mexico. The empirical analysis here is of what might be called the "engineering-economic" variety. In the next section we offer some observations on an alternative approach to empiricising option value: contingent valuation.

The perennial corn—actually a form of teosinte, a wild species that is corn's closest relative—offers potential benefits in the area of disease resistance as well since it is immune to several major corn virus diseases. But let us focus on just the benefit of perennial growth. Before proceeding, we note that the plant was discovered as the result of a deliberate search, high in a remote region of the Sierra de Manantlán in the Mexican state of Jalisco (Vietmeyer, 1979). The potential benefit would have been wiped out by a decision to replace it with a modern high-yield hybrid or to develop the tract in some other way.

The point is that it is the search and the research now underway that may lead to something of value, not a decision to develop the tract.

Suppose, then, that the demand for corn is given by

$$x_d = 23.7 - 8.6\ p,$$

where quantity is measured in billions of bushels per year and price in dollars per bushel, and supply (with current seed species) is given by

$$x_s = -420 + 213.2\ p.$$

These equations represent a simplified version of the U. S. demand and supply functions for corn estimated by Chambers and Just (1981).

The breeding of a new species of corn, possible only if the tract in question is preserved, would cause a shift in the supply curve. For simplicity, we assume that only the intercept of the supply curve would be affected and not the slope; the new supply curve is $x'_s = -\theta + 213.2\ p$. The benefit of a supply shift is the change in consumer and producer surplus, i.e. the change in the area between old and new supply curves, as shown in Figure 1. We model the uncertainty of the economic value of habitat protection by treating θ as a random variable which is uniformly distributed over some range $[\theta_*, \theta^*]$. Actually, two types of uncertainty are involved: If the tract is preserved, we cannot be sure that a new species of corn will subsequently be discovered and, even if one is, we cannot be sure that it will lead to a cheaper supply than the species already in use. To keep the analysis simple, we combine both types of uncertainty and assume that they are embedded in the distribution of θ.

Of course, in this example we are "cheating." We know a wild grass related to corn has been discovered, so only the second uncertainty remains. There are two ways of thinking about the example. First, note that the probability of producing a successful hybrid depends on whether or not the tract is preserved. A single specimen of wild grass would offer poorer prospects. Second, we might think of the option value as of, say, 1976, the year before the discovery. Option value today is presumably different. In deciding the fate of an area, researchers ordinarily would not know whether anything of value in future economic activity will be discovered. The area would need to be studied, the natural populations inventoried, and some guesses made as to the probabilities of ultimately producing anything of value. Since our purpose in this paper is not such a detailed empirical application, we simply note what would be required and proceed to indicate how the resulting information could be used to calculate option value.

In our earlier paper we derived expressions for expected second-period, or future, benefits of preserving the tract in the first period, assuming, as noted, a uniform distribution for θ. This is $E[B_2(0, \theta)]$ in the terminology of section 2. A similar assumption is made about the distribution of a random variable, ξ, governing the benefit from developing the tract; and a similar expression is derived for $E[B_2(1, \xi)]$.

Given the assumed structure and parameters of the model, the intercept of the supply curve with the vertical axis in Figure 1 occurs at a price of about $1.97 per bushel. We assume that, under the most favorable possible circumstances, preserving the natural ecosystem might lead to the discovery of a new species of corn whose supply curve intercepts the vertical axis at a price of $1.25 per bushel; this corresponds to setting $\theta_* = 266.5$ (= 1.25 x 213.2). In this event, the benefit from preservation amounts to $\max[B_2(0, \theta)]$ = $6.82 billion.[6] In less favorable circumstances, however, the intercept of the new supply curve will be higher than $1.25 and the benefits of preservation will be smaller. We assume that the probability of reaping any (positive) benefit from preservation is 0.25; this corresponds to $\theta^* = 880.5$. Finally, we assume that the maximum possible benefits of development are of the same order of magnitude as those of preservation and set $\max[B_2(1, \xi)]$ = $7 billion (that is, $\xi^* = 7$), and that there is a 90 percent probability of obtaining a positive benefit from development, which corresponds to $\xi_* = -0.77778$.

Resulting values for $E[B_2(0, \theta)]$, $E[B_2(1, \xi)]$, $\hat{V}(\cdot)$, $V^*(\cdot)$, and option value OV—based on the formulas derived in our earlier paper—are given in Table 1. Notice that $\hat{V}(0) - \hat{V}(1) = B_1(0) - B_1(1) + OV$. Although the expected future benefits of development greatly exceed those of preservation ($3.111 billion vs. $0.763 billion), the option value amounts to $0.328 billion; no development should be undertaken unless the current benefits of development (B_1) exceed those of preservation (B_0) by more than $0.328 billion. However, a myopic decision which ignored the possibility of acquiring further information as to the likelihood of discovering a new species of corn would develop if the current benefits of development exceed those of preservation by any positive amount.

5. Option Value and Contingent Valuation

In many applications, contingent valuation (CV) has emerged as the preferred technique for assessing the economic value of natural environments. How does CV relate to the concept of option value discussed in this paper? Can it be used to measure this concept? In principle, it certainly can. Indeed, CV can enter the analysis at two possible levels. One is measuring the single-period benefit functions, $B_1(d_1)$ and $B_2(d_1 + d_2, \theta)$. Its use here would be entirely conventional. But it could also be used at a different level. One could imagine conducting a CV survey of the planner or decision maker to elicit a monetary measure of option value.

How might this work? Instead of trying to get at the terms in the formula for option value, equation (11), directly, as in the engineering-economic calculation in the preceding section, CV would take quite a different approach based on the interpretation of option value as a conditional value of information. The CV question would be something like the following: What would you (as a decision maker concerned to use the resources of a site efficiently) be willing to pay for information about future benefits of preservation and development, information that would be available before you had to decide whether to preserve or develop in the future, assuming you do not foreclose the option to preserve in the future by choosing to develop now? This is admittedly a bit complex—more complex, certainly, than the conventional CV question. But remember that we are now hypothetically querying a sophisticated decision maker, not a member of the general public. Further, the question could be prefaced by some words of explanation and could, no doubt, be phrased more articulately in a particular application. It does, however, capture the essence of the concept of option value put forward in this paper.

A significant feature of CV surveys is the distinction between willingness to pay (WTP) and willingness to accept (WTA) as monetary measures of value. When a CV survey is conducted, at least one of those question formats must be employed—or something equivalent to it. Not infrequently, CV researchers have discovered substantial differences in the responses to the two types of questions. A theoretical explanation of how such differences could arise in a conventional utility maximization context was recently developed by Hanemann (1989b), building on the work of Randall and Stoll (1980). The point that we want to emphasize is that similar differences could also arise in the context of a CV survey administered to a planner for the purpose of eliciting option value. This may seem strange. The empirical example presented in the preceding question contained no overtones of the distinction between WTP and WTA: Just how could it arise in connection with the option-value concept being considered in this paper? In the remainder of this section, we answer that question and also identify the circumstances under which the WTP and WTA measures of option value would coincide.

It was noted above that the benefit functions $B_1(\cdot)$ and $B_2(\cdot)$ used in sections 2 and 3 could be measured in either utility or money units. For the example in section 4, these benefits were, in fact, measured in monetary units. However, in order to investigate the distinction between the WTP and WTA measures of option value, it is necessary to pay explicit attention to the underlying utility model that generates the benefit functions. Thus, the divergence between WTP and WTA is firmly rooted in the functional structure of the underlying utility model.

A CV measure of the conditional value of information, or option value, can be defined for WTP by the equation

$$u(y, 0) = u(y - c, \bar{I}), \tag{14}$$

where $u(\cdot)$ is the planner's utility function, y is income (for example, gross regional product), and the second argument I is information about future benefits. In equation (14), c represents the maximum amount of income the planner would be willing to forego for an improvement in information from $I = 0$ (no information, as on the left-hand side of (14)) to $I = \bar{I}$ (in our model, perfect information).

A similar WTA measure is defined by the equation

$$u(y + c', 0) = u(y, \bar{I}), \tag{15}$$

where c' is the minimum additional income the planner would require if information were not forthcoming.

Under what conditions will $c = c'$? A sufficient condition is that the utility function has the form

$$u(y, I) = v(y + h(I)) \tag{16}$$

for some functions $v(\cdot)$ and $h(\cdot)$. Equation (14) can then be rewritten as

$$v(y + h(0)) = v(y - c + h(\bar{I})), \tag{14'}$$

which implies that

$$c = h(\bar{I}) - h(0). \tag{17}$$

Similarly, equation (15) can be rewritten as

$$v(y + c' + h(0)) = v(y + h(\bar{I})), \tag{15'}$$

which implies that

$$c' = h(\bar{I}) - h(0), \tag{18}$$

so that $c = c'$.

The significance of the functional structure in equation (16) is that income is a perfect substitute for (some transformation of) information about future benefits from development or preservation. This is entirely consistent with the analysis of WTP and WTA in Hanemann (1989b), which shows that perfect substitution between a public good and the available private market goods is a sufficient condition for WTP for the public good to coincide with WTA. Notice also that c and c' can be interpreted as the value of information and, accordingly, as (WTP and WTA) measures of option value.

We have shown how a CV survey might be used to elicit a planner's option value. To do this, we considered information as a good, over which (along with regional income) the planner's preferences are assumed to be defined.

Alternatively, we might go back to underlying preferences for preservation and development as in the earlier sections of the paper. In this approach, given the additive form of the two-period benefit function, it is natural to postulate an underlying utility model of the form

$$u = u_1(y_1, d_1) + u_2(y_2, d_1 + d_2, \theta). \tag{19}$$

In the present context this is the planner's utility function. The variables θ, d_1, and d_2 are defined as above, while y_t is income—for example, gross regional product—in period $t = 1, 2$. Thus, the planner—acting on behalf of the public—has preferences for income and preservation/development. There are costs associated with development and, possibly, preservation of the natural environment in each period; let these be denoted by k_{1t} and k_{2t} for $t = 1, 2$. Hence, the level of the planner's utility that would be associated with a policy of $d_1 = d_2 = 0$, to be denoted u_{00}, is

$$u_{00} = u_1(y_1 - k_{10}, 0) + u_2(y_2 - k_{20}, 0, \theta)$$

while the level of her utility that would be associated with a policy of $d_1 = 0$, $d_2 = 1$, to be denoted u_{01}, is

$$u_{01} = u_1(y_1 - k_{10}, 0) + u_2(y_2 - k_{21}, 1, \theta).$$

Observe that these utility levels are random variables, by virtue of their dependence on θ. In terms of utility units, the concept of option value defined in (11) may now be expressed as:

$$OV_u = E[\max\{u_{00}, u_{01}\}] - \max\{E[u_{00}], E[u_{01}]\}. \tag{20}$$

In order to proceed it is convenient to rewrite the formula in (11) by subtracting $B_2(1, \theta)$ from both terms on the right-hand side and rearranging to obtain:

$$OV = OB - OD \tag{21}$$

where

$$OB \equiv E[\max\{0, B_2(0, \theta) - B_2(1, \theta)\}]$$

and

$$OD \equiv \max\{0, E[B_2(0, \theta) - B_2(1, \theta)]\}.$$

It is shown in Hanemann (1989a) that the quantities OB and OD can each be interpreted as correction factors that would be required if the planner myopically proposed to decide on the initial level of development, d_1, solely by reference to the first-period benefits and costs of development, $B_1(0) - B_1(1)$, in disregard of the subsequent (second-period) impacts. In the present context, however, these two quantities and the formulation in (21) are needed because they facilitate the development of WTP and WTA measures of option value.

In utility units the analog of (21) is

$$OV_u = OB_u - OD_u \tag{22}$$

where

$$OB_u \equiv E[\max\{0, u_2(y_2 - k_{20}, 0, \theta) - u_2(y_2 - k_{21}, 1, \theta)\}]$$

and

$$OD_u \equiv \max\{0, E[u_2(y_2 - k_{20}, 0, \theta) - u_2(y_2 - k_{21}, 1, \theta)]\}.$$

Now, define the random variables WTP_θ and WTA_θ by

$$u_2(y_2 - k_{20} - WTP_\theta, 0, \theta) \equiv u_2(y_2 - k_{21}, 1, \theta) \tag{23}$$

$$u_2(y_2 - k_{20}, 0, \theta) \equiv u_2(y_2 - k_{21} + WTA_\theta, 1, \theta). \tag{24}$$

Observe that WTP_θ and WTA_θ must have the same sign. If they are positive, then the planner prefers preservation over development in the second period and WTP_θ represents the maximum amount of second-period regional income that she would be willing to sacrifice to ensure preservation rather than development in that period, while WTA_θ represents the minimum amount of incremental regional income that she would wish to obtain in that period in order to agree to forego preservation. Conversely, if they are both negative, then the planner prefers development to preservation and WTA_θ represents the maximum amount of second-period regional income that she would be willing to sacrifice to ensure development, while WTA_θ is the minimum amount of incremental regional income that she would wish to obtain in that period in order to agree to forego development. Using these quantities, the monetary WTP measure of option value that corresponds to (22) is

$$OV_{WTP} = OB_{WTP} - OD_{WTP} \tag{25}$$

where

$$OB_{WTP} \equiv E[\max\{0, WTP_\theta\}]$$

$$OD_{WTP} \equiv \max\{0, E[WTP_\theta]\}$$

while the WTA measure of option value that corresponds to (22) is

$$OV_{WTA} = OB_{WTA} - OD_{WTA} \tag{26}$$

where

$$OB_{WTA} \equiv E[\max\{0, WTA_\theta\}]$$

$$OD_{WTA} \equiv \max\{0, E[WTA_\theta]\}.$$

Under what conditions will these two monetary measures of option value coincide? Clearly, a sufficient condition is that $WTA_\theta \equiv WTP_\theta$. That, in turn, will occur if the second-period utility sub-function has the form, analogous to equation (16),

$$u_2(y, d, \theta) = T[y + \gamma(\theta, d), \theta) \tag{27}$$

for some functions $T(\cdot)$ and $\gamma(\cdot)$, since then

$$WTP_\theta = WTA_\theta = (k_{21} - k_{20}) + \gamma(0, \theta) - \gamma(1, \theta). \tag{28}$$

Again, the significance of the structure assumed for the utility function is that income is a perfect substitute for (some transformation of) the level of development $d_1 + d_2$.

6. Concluding Remarks

This paper has examined the role of irreversibilities and imperfect information in decision making, with reference to the concept of option value. We have explored two methods of measuring option value in the context of an empirical decision problem. One method, exemplified in section 4, is to conduct the engineering-economic analysis required to calculate the conditional value of information—in effect, to perform the analysis that an ideal planner would undertake. The other method, discussed in section 5, is to conduct a contingent valuation (CV) survey of the planner herself. With regard to the latter approach, we have made a distinction between a CV survey targeted at eliciting her preferences for information, viewed as a primitive commodity, versus a survey targeted at eliciting her preferences for development/preservation. In both of these cases, it is possible for a distinction between WTP and WTA values to arise whenever the primitive commodity—information or development/preservation—is not perfectly reducible to money income in the planner's eyes. With the example in section 4, all outcomes are reducible to money as far as the planner is concerned, which is why the issue of the distinction between WTP and WTA does not arise. But it is an empirical question whether or not she has this type of preferences. To the extent that she does not—to the extent that additional market commodities (GNP) are not a perfect substitute for either environmental preservation or information—then it is important to recognize that the distinction between WTP and WTA which underlies much of the CV literature also arises in the context of measuring option value.

Footnotes

[1]What we refer to as option value has also been called quasi-option value (Arrow and Fisher, 1974). There is another, quite different, concept of option value associated with the work of (among others) Schmalensee (1972), Bohm (1975), and Graham (1981) that is static and involves risk preferences.

[2]This section and the next are based on our earlier paper in the annual *Advances in Applied Microeconomics* (Fisher and Hanemann, 1986).

[3]It has been shown that the qualitative nature of the results we shall obtain does not change, if the benefit functions are concave [Epstein (1980); Freixas and Laffont (1984); and Jones and Ostroy (1984)].

[4]Second-period benefits can be viewed as present values. We suppress the discount factor here because it would not affect our results.

[5]This is suggested by Conrad (1980).

[6]To simplify the computations, benefits are on an annual basis, undiscounted.

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Table 1

Calculation of Option Value
(billions of dollars)

$E[B_2(0, \theta)]$	0.763
$E[B_2(1, \xi)]$	3.111
$\max[B_2(0, \theta)]$	6.82
$\max[B_2(1, \xi)]$	7.0
$[V^*(0) - V^*(1)] - [B_1(0) - B_1(1)]$	0
$[\hat{V}(0) - \hat{V}(1)] - [B_1(0) - B_1(1)]$	0.328
OV	0.328