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INFORMATION AND THE CONCEPT OF OPTION VALUE

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I. INTRODUCTION

Ever since the seminal article by Weisbrod [1964], there has been a widespread interest among resource economists in the concept of option value. Weisbrod argued that, in contemplating an action with irreversible consequences such as the destruction of a national park, one must recognize that many people would be willing to pay something to preserve the option of visiting the park in the future. Private market calculations will overlook this option value if there is no mechanism by which the owner of the park can charge for it, but it certainly should be included in any social benefit cost analysis of the destruction of the park. This conclusion has been widely accepted. However, because Weisbrod's argument was developed in a fairly informal manner, it has stimulated a lively debate as to the precise definition and measurement of the option value concept.

Two broad interpretations have emerged. The first, presented originally by Cicchetti and Freeman [1971] and refined by Schmalensee [1972], Bohm [1974] and Graham [1981], interprets option value as a risk premium arising from uncertainty as to the potential future value of the park if it were preserved. As Smith [1982] and others have pointed out, the passage of time per se is not essential to the formulation of this concept. The second interpretation, advanced by Arrow and Fisher [1974] and independently by Henry [1974], focuses explicitly on the intertemporal aspects of the decision and stresses the irreversibility of the destruction of the park and the flow of information over time. In Henry's words, "[T]he mere prospect of getting fuller information [about the future value of the park], combined with the irreversibility of the non-preservation alternative, brings forth a positive option value in favor of preservation."[2] Unlike the other one, this interpretation does not require any assumption of risk aversion on the part of park users.

This paper is concerned with the Arrow-Fisher-Henry (AFH) time-dependent concept of option value, which has been the subject of two recent articles in this journal. Conrad [1980] argues that it is equivalent to another concept arising in decision theory, the expected value of information. Greenley, Walsh, and Young [1981] (henceforth GWY) report the results of an empirical study aimed at measuring the AFH option value of recreational waterways in the Platte River Basin, Colorado. Here I will show that the AFH option value is not necessarily the same as the expected value of information and, indeed, may exceed it. I will also examine the quantity measured by GWY and suggest that it corresponds to something closely related to the AFH concept but distinct from it.

In order to reach these conclusions, I first develop a general model of irreversible investment, which is presented in section II. Using this model, in section III I compare the definitions of option value offered by Arrow and Fisher and by Henry and show that they are equivalent. I then provide an alternative, equivalent characterization of option value in the light of which Conrad's claim is evaluated. In section IV, I offer an interpretation of the quantity measured by GWY. In section V, I go on to consider the effect on option value of an increase in the uncertainty surrounding the future benefits and costs of irreversible development. Arrow and Fisher show for one particular case that an increase in future uncertainty raises the option value and increases the advantage of postponing development initially. I show that this conclusion is not generally true, but I also provide a set of conditions under which it becomes valid. Finally, in section VI, I consider two possible generalizations of the analytical framework adopted to this point. I show that my analysis of option value readily carries over to a situation where one assumes that the passage of time brings partial rather than perfect information about the future consequences of development. However, I show that the concept of option value is not well-defined when one assumes that, instead of a binary choice between development and no development, there is a continuum of possible levels of development. The conclusions are summarized in section VII.

II. A MODEL OF IRREVERSIBLE INVESTMENT

In this section I will outline a model of irreversible investment which combines the main features of Henry's [1974] analysis together with that of Arrow and Fisher [1974]. The model will be used in the following sections to characterize the concept of option value and explore some of its properties. Assume that there are two time periods, $t = 1, 2$. The decision concerns d_t, the amount of land developed during period t. The units of measurement will be chosen so that the maximum possible level of development (the minimum possible level of preservation) is unity,

(1) $$d_1 \leq 1, \qquad d_1 + d_2 \leq 1.$$

In addition, a key assumption is that any development is irreversible

(2) $$d_t \geq 0, \qquad t = 1, 2.$$

Associated with any development program is some level of net benefits, B, representing both the benefits of development and the benefits of preservation. Let B_t be the benefits accruing in period t. For simplicity I assume that the overall benefit function is additive with respect to the two periods' benefits

(3) $$B = B_1 + B_2,$$

although the results discussed below would also hold with a benefit function of the more general form $B = B(B_1, B_2)$. The first period's benefits depend on the amount of land developed during that period, d_1, while the second period's benefits depend both on the total amount developed over the two periods, $d_1 + d_2$, and on the amount developed specifically during the second period, d_2. Moreover, I assume that these second period's benefits involve an element of uncertainty, here represented by the random variable θ. Thus,

(4) $$B_1 = B_1(d_1)$$
$$B_2 = B_2\,(d_1 + d_2,\ d_2;\ \theta).$$

It is immaterial to the argument which follows whether or not there is also uncertainty concerning the first period's benefits.[3]

In order to interpret these benefit functions, it many be useful to think of them as taking the form

$$B_1(d_1) = B_{1d}(d_1) + B_{1p}(d_1)$$

$$B_2\,(d_1 + d_2,\ d_2;\ \theta) = B_{1d}(d_1 + d_2,\ d_2;\ \theta) + B_{2p}(d_1 + d_2;\ \theta).$$

The function B_{1d} measures the benefits of development in the first period net of capital and operating costs, while B_{1p} measures the benefits of preservation. Similarly, B_{2d} and B_{2p} represent development and preservation benefits in the second period. The first argument of B_{2d} reflects the benefits of development net of operating costs, while the second argument reflects the capital costs of the development occurring in the second period. It follows that $B_2(\cdot)$ is nonincreasing in its second argument.

This formulation is very general and is susceptible of a variety of interpretations. For example, B_{1p} and B_{2p} may include both "user benefits," accruing to those who visit the site, and "nonuser benefits" or "existence values." Similarly, B_1 and B_2 may pertain to different generations, in which case B_{2p} could incorporate a "bequest value." All of the benefits are calculated as of the beginning of the first period and, thus, may incorporate a discount factor. Moreover, they may be measured in money or, more generally, in units of utility. Since the social decision is based on the expected value of net benefits, $E\{B\}$, this formulation allows for any type of risk preference.

The social decision involves the maximization of expected benefits with respect to d_1 and d_2 subject to (1) and the irreversibility constraints (2). The decision on d_1 is made at the start of the first period, but there are two possible scenarios for the decision on d_2. One scenario is that d_2 is also determined at the start of the first period or, equivalently, it is determined at the start of the second period but no more information about θ is available then than before. The other scenario is that the specific value of θ is known at the start of the second period, and the choice of d_2 can be postponed until that time in order to incorporate this information.

In the first scenario, d_1 and d_2 are chosen so as to maximize

$$V(d_1, d_2) = B_1(d_1) + E\{B_2\,(d_1 + d_2, d_2; \theta)\}$$

subject to (1) and (2). Denote the solutions by d_1^* and d_2^*, and let $V^* \equiv V(d_1^*, d_2^*)$ be the expected overall benefit under this optimal decision. In the second scenario where information becomes available over time, whatever the level of d_1, d_2 will be chosen in the second period so as to maximize $B_2\,(d_1 + d_2, d_2; \theta)$ subject to $d_2 \geq 0$ and $d_1 + d_2 \leq 1$. Denote the solution as a function of d_1 and θ by $d_2 = f(d_1; \theta)$. In the first period, when the value of θ is not yet known, the decision is to maximize

$$\hat{V}_1(d_1) = B_1(d_1) + \{B_2\,[d_1 + f(d_1; \theta), f(d_1; \theta); \theta]\} \tag{5}$$

subject to $0 \leq d_1 \leq 1$. Denote the solution by $\hat{d}_1$. Given θ, the second period decision will be $\hat{d}_2 = f(\hat{d}_1; \theta)$. The expected overall benefit associated with this solution is $\hat{V} \equiv \hat{V}(\hat{d}_1)$.

In order to compare the two scenarios, it is useful to reformulate the decision problem in the first scenario by applying the two-stage maximization principle. Define $V^*(d_1)$ by

$$V^*(d_1) = B_1(d_1) + \max_{\substack{d_2 \\ 0 \leq d_1 + d_2 \leq 1 \\ 0 \leq d_2}} \left[E\{B_2(d_1 + d_2, d_2; \theta)\} \right]. \tag{6}$$

Then, d_1^* maximizes $V^*(d_1)$ subject to $0 \leq d_1 \leq 1$, and $V^* = V^*(d_1^*)$. For comparison, the maximand in the second scenario, (5), can be written as

(5')
$$\hat{V}(d_1) = B_1(d_1) + E\left\{\max_{\substack{d_2 \\ 0\le d_1+d_2\le 1 \\ 0\le d_2}} \left[B_2(d_1 + d_2, d_2; \theta)\right]\right\}.$$

As noted above, $\hat{d}_1$ maximizes $\hat{V}(d_1)$ subject to $0 \le d_1 \le 1$. Thus, the difference between the scenarios depends on the difference between the two functions $V^*(d_1)$ and $\hat{V}(d_1)$. Each of these functions measures the expected benefits over both periods as a function of the initial amount of development, d_1, given that the amount of development in the second period is optimally chosen subject to the irreversibility constraint and the limitation of the information structure in the scenario. The quantities V^* and $\hat{V}$ are the expected benefits with an optimal choice of development in both periods. Their difference, $\hat{V} - V^*$, is known in the literature on decision theory as the expected value of perfect information (EVPI).

Without imposing some further structure on the model, one can say only a few things about the two scenarios. For any amount of development in the first period, it is clear that one cannot be worse off under the second scenario than under the first since, from (5') and (6),[4]

(7) $$\hat{V}(d_1) - V^*(d_1) = E\{\max B_2(d_1 + d_2, d_2; \theta)\} - \max E\{B_2(d_1 + d_2, d_2; \theta)\} \ge 0.$$

However, if there is full development in the initial period, then it makes no difference whether or not information becomes available in the second period because it is impossible to adjust the stock of developed land further:

(8)
$$\hat{V}(1) = V^*(1) = B_1(1) + E\{B_2(1, 0; \theta)\}.$$