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Iulie Aslaksen and Terje Synnestvedt

Are the Dixit-Pindyck and the Arrow-Fisher-Henry-Hanemann Option Values Equivalent?

Abstract:
The relationship between the concept of option value in the literature on environmental preservation and the financial theory of option value is discussed by Fisher (2000), suggesting an equivalence between the two concepts. In a recent paper, Mensink and Requate (2004) argue that Fisher's claim is incorrect. In this paper we clarify Fisher's argument by drawing on the article by Hanemann (1989), whereby we find the conditions for the Arrow-Fisher-Henry-Hanemann (AFHH) and the Dixit-Pindyck (DP) option value concepts to coincide or not. The main point is that the AFHH option value is derived under the assumption that investment does not take place in the first period, neither in the closed-loop nor in the open-loop strategy, whereas the analysis of the DP option value is based on the assumption that investment in the open-loop strategy takes place in the first period.

Keywords: Option value, Uncertainty, Information, Irreversibility, Environment

JEL classification: D81, Q20

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Address: Iulie Aslaksen, Statistics Norway, Research Department, P.O. Box 8131 Dep., 0033 Oslo, Norway. E-mail: iulie.aslaksen@ssb.no

Terje Synnestvedt, Norwegian School of Management BI, P.O. Box 580, 1302 Sandvika, Norway. E-mail: terje.synnestvedt@bi.no

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1. Introduction

Concepts of option value, reflecting the value of postponing an irreversible investment decision if new information may occur, have been developed independently within environmental economics and the theory of investment under uncertainty. In the investment literature, the Dixit-Pindyck (DP) option value was developed in the papers by Pindyck (1991) and Dixit (1992) and presented in Dixit and Pindyck (1994). In the literature on environmental preservation, the Arrow-Fisher-Hanemann-Henry (AFHH) option value was developed in the papers by Arrow and Fisher (1974), Henry (1974), and Fisher and Hanemann (1986). Hanemann (1989) captured the earlier approaches into a consistent framework.

The AFHH option value is developed within a setting where the future cost of current irreversible environmental damage is uncertain and there could be a gain by postponing the decision until new information about the costs arrive. Dixit and Pindyck use the concept option value as the value of having the possibility of postponing an investment-decision when future net earnings is uncertain, in other words the difference between expected net present value of an investment opportunity and the net present value of an investment. In terms of the finance theory this is the value of having a call option. For a literature review see Hanemann (1989), Cogging and Ramezani (1998) and Fisher (2000).

Although developed in quite different settings, there are strong similarities between the AFHH and the DP option value. The conceptual platform for both approaches is that by undertaking an irreversible (investment-) decision a firm or a social planner loose the opportunity to use new information. More recently, Fisher (2000) suggested that the AFHH option value is equivalent to the DP option value in the context of investment decisions under uncertainty.

Mensink and Requate (2004) argue that Fisher' claim is incorrect. In this paper we clarify Fisher's argument by drawing on the article by Hanemann (1989), whereby we find the conditions for the two option value concepts to coincide or not. The main point is that the AFHH option value is derived under the assumption that investment does not take place in the first period, neither in the closed-loop strategy where investment takes place after uncertainty is resolved, nor in the open-loop strategy where investment takes place before uncertainty is resolved, whereas the analysis of the DP option value is based on the assumption that investment in the open-loop strategy does in fact take place in the first period. Using the notation of Fisher, d_1^* denotes the open-loop investment decision in period

1 and $\hat{d}_1$ denotes the closed-loop investment decision in period 1. The decision variables d_1^* and $\hat{d}_1$ can be either zero (not invest) or one (invest). The default assumption of the AFHH option value is that $\hat{d}_1 = d_1^* = 0$ (do not invest in period 1), whereas the default assumption of the DP option value is that $d_1^* = 1$ (invest in period 1 in the open-loop setting). While Fisher fails to notice that the equivalence of the AFHH option value and DP option value does not hold for $d_1^* = 1$, Mensink and Requate fail to notice the equivalence of the AFHH and DP option values for $d_1^* = 0$.

2. The Fisher option value model

As a background for the comparison of the two option values, we first present Fisher's option value model and the first-period investment decisions in some detail. Hence, this section corresponds exactly to Section 2 in Fisher (2000) with the same equation numbers.

Consider the problem, as set out in Fisher and Hanemann (1986), of choosing whether to preserve or develop a particular area of land, in the present or next period. The development is irreversible. Future benefits of development and preservation are uncertain, but information is obtained with the passage of time. We assume that uncertainty about future benefits is resolved at the start of the second period. Let the benefit from first-period development, net of environmental costs (the benefits of preservation), be $B_1(d_1)$, where d_1, the level of development in period 1, can be zero or one. The present value of the benefit from second-period development is $B_2(d_1 + d_2, \theta)$, where d_2 can be zero or one and θ is a random variable. Note that, if $d_1 = 1, \; d_2 = 0$.

Let $\hat{V}(d_1)$ be the expected value over both periods as a function of the choice of first-period development $(d_1 = 0 \text{ or } d_1 = 1)$ given that second-period development, d_2, is chosen at the start of the second period when we learn whether or not $d_2 = 0$ or $d_2 = 1$ yields greater benefits. At the start of the first period, when d_1 must be chosen, we have only an expectation of the maximum. Then, we have, for $d_1 = 0$,

(2.1) $$\hat{V}(0) = B_1(0) + E\left[\max_{d_2} B_2(d_2, \theta)\right] = B_1(0) + E\left[\max\left\{B_2(0,\theta), B_2(1,\theta)\right\}\right].$$

If $d_1 = 1$, we have

(2.2) $$\hat{V}(1) = B_1(1) + E\left[B_2\left(1,\theta\right)\right].$$

With development in the first period, we are locked into development in the second $\left(d_1 = 1 \Rightarrow \left(d_1 + d_2\right) = 1\right)$. To get the decision rule for the first period, $\hat{d}_1$, compare (2.1) and (2.2):

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

and choose

(2.4) $$\hat{d}_1 = \begin{cases} 0 & \text{if } \hat{V}(0) - \hat{V}(1) \geq 0 \\ 1 & \text{if } \hat{V}(0) - \hat{V}(1) < 0. \end{cases}$$

Now, let us suppose that, instead of waiting for the resolution of uncertainty about future benefits before choosing d_2, we simply replace the uncertain future benefits by their expected value. This would be appropriate if we did not expect to receive information, over the first period, that would permit us to resolve the uncertainty. In this case, the expected value over both periods, for $d_1 = 0$, is

(2.5) $$V^*(0) = B_1(0) + \max\left\{E\left[B_2\left(0,\theta\right)\right], E\left[B_2\left(1,\theta\right)\right]\right\}.$$

Second-period development, d_2, is in effect chosen in the first period, to maximize expected benefits in the second period, because we do not assume that further information about second-period benefits will be forthcoming before the start of the second period. For $d_1 = 1$,

(2.6) $$V^*(1) = B_1(1) + E\left[B_2\left(1,\theta\right)\right] = \hat{V}(1).$$

As before, development in the first period locks in development in the second. Comparing (2.5) and (2.6),

(2.7) $$V^*(0) - V^*(1) = B_1(0) - B_1(1) + \max\left\{E\left[B_2\left(0,\theta\right)\right], E\left[B_2\left(1,\theta\right)\right]\right\} - E\left[B_2\left(1,\theta\right)\right]$$

and

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

How do the decision rules in (2.4) and (2.8) compare? First, notice that

(2.9) $$\left[\hat{V}(0) - \hat{V}(1)\right] - \left[V^*(0) - V^*(1)\right] = \hat{V}(0) - V^*(0),$$

since $\hat{V}(1) = V^*(1)$. Then

(2.10) $$\hat{V}(0) - V^*(0) = E\left[\max\left\{B_2(0,\theta), B_2(1,\theta)\right\}\right] - \max\left\{E\left[B_2(0,\theta)\right], E\left[B_2(1,\theta)\right]\right\}.$$

Finally,

(2.11) $$\hat{V}(0) - V^*(0) \geq 0$$

from the convexity of the maximum function and Jensen's Inequality, which states that the expected value of a convex function of a random variable is greater than or equal to the convex function of the expected value of the random variable. Intuitively, an informed decision cannot be worse than an uniformed decision.

It is this difference, $\hat{V}(0) - V^*(0)$, that has been interpreted as option value in the environmental literature. It may also be considered a (conditional) value of information, however, the value of information about future benefits *conditional* on retaining the option to preserve or develop in the future $(d_1 = 0)$.

At this point it is useful to supplement Fisher's explanation with the discussion in Hanemann (1989) of the conditional value of perfect information. First, the option value expression (2.9) can be restated as

(2.12) $$OV = \left(\hat{V}(0) - V^*(0)\right) - \left(\hat{V}(1) - V^*(1)\right).$$

The first term, $\hat{V}(0) - V^*(0)$, is the conditional value of perfect information, the gain from information with respect to the choice of d_2 conditional on setting $d_1 = 0$. Similarly, $\hat{V}(1) - V^*(1)$ is the value of perfect information conditional on setting $d_1 = 1$. But, from (2.6) the latter is zero. The irreversibility creates an asymmetry: If one decides to preserve initially $(d_1 = 0)$, the decision can always be reversed later when more accurate information about the consequences of development is obtained, whereas the decision to develop now $(d_1 = 1)$ cannot be reversed, and any subsequent information has no economic value. Thus, a decision to set $d_1 = 0$ preserves flexibility, and the option value is the value of this flexibility.

Hanemann here points to the analogy between the AFHH option value and the financial option value developed by Black and Scholes (1973). Setting $d_1 = 0$ gives an option to preserve or to develop in the future which is worth $\hat{V}(0)$ in present value. Thus, in terms of the financial literature, $\hat{V}(0)$ is the value of the option and $\hat{V}(1)$ is its price (opportunity cost).

Moreover, Hanemann observes that it follows from (2.11) that $\hat{d}_1 \le d_1^*$. Hence, there are three possible outcomes: $\hat{d}_1 = d_1^* = 0$, $\hat{d}_1 = d_1^* = 1$ or $\hat{d}_1 = 0, d_1^* = 1$. By using (2.4), (2.6) and (2.8), Hanemann shows that the following relationships hold for these three outcomes,

$$(2.13)\; OV = \begin{cases} \hat{V}(0) - V^*(0) = OV^{AFHH} & \text{if} \quad \hat{V}(0) \ge V^*(0) \ge V^*(1) \quad \text{for} \quad \hat{d}_1 = d_1^* = 0 \\ \hat{V}(1) - V^*(1) = 0 & \text{if} \quad V^*(1) \ge \hat{V}(0) \ge V^*(0) \quad \text{for} \quad \hat{d}_1 = d_1^* = 1 \\ \hat{V}(0) - V^*(1) = OV^{AFHH} + OV^{PP} = OV^{DP} & \text{if} \quad \hat{V}(0) \ge V^*(1) \ge V^*(0) \quad \text{for} \quad \hat{d}_1 = 0, d_1^* = 1 \end{cases}$$

where

$$(2.14) \qquad OV^{PP} = V^*(0) - V^*(1)$$

is the pure postponement value as defined by Mensink and Requate.

The first case corresponds to $\hat{d}_1 = d_1^* = 0$. From (2.4) and (2.8) it follows that $\hat{d}_1 = 0$ corresponds to $\hat{V}(0) \ge \hat{V}(1)$ and $d_1^* = 0$ corresponds to $V^*(0) \ge V^*(1)$, hence $\hat{d}_1 = d_1^* = 0$ corresponds to $\hat{V}(0) \ge V^*(0) \ge V^*(1)$ as stated in (2.13). In this case the option value equals the AFHH option value. The second case corresponds to $\hat{d}_1 = d_1^* = 1$. There is no option value when investment takes place in the first period. The third case corresponds to $\hat{d}_1 = 0, d_1^* = 1$. The expression for the option value is obtained from

$$(2.15) \qquad OV = \hat{V}(0) - V^*(1) = \hat{V}(0) - V^*(0) + V^*(0) - V^*(1) = OV^{AFHH} + OV^{PP} = OV^{DP}.$$

The pure postponement value is negative in the case of $\hat{d}_1 = 0$, $d_1^* = 1$, as this case corresponds to $\hat{V}(0) \ge V^*(1) \ge V^*(0)$. Hence, $V^*(0) - V^*(1) < 0$, reflecting the loss from postponing investment in the open-loop strategy when there is no gain from future information. In this case the option value equals the DP option value as discussed by Mensink and Requate (2004). When the open-loop strategy implies that first period investment is optimal, $d_1^* = 1$, the DP option value is less than the AFHH option value. The pure postponement value is also negative in the case of $\hat{d}_1 = d_1^* = 1$. Since the option value is zero, there is no gain in postponing the investment.

In the first case, $\hat{d}_1 = d_1^* = 0$, the pure postponement value is positive, reflecting the positive option value of not investing in the first period. It follows from the optimality condition for d_1^* that the pure postponement value is positive when $d_1^* = 0$ and negative when $d_1^* = 1$. Note that the pure postponement value is defined in terms of the open-loop strategy, hence it only represents the time aspect, not the information aspect of the decision problem.

3. The Mensink-Requate interpretation of the Dixit-Pindyck option value

Dixit and Pindyck (1994) define their option value $F_0 - \Omega_0$ in the text on page 97 and 98, as the difference between the full opportunity, F_0, the net present value of the whole investment opportunity optimally deployed, and the termination value, Ω_0, the net payoff of the project to the firm, if it has to decide in the first period whether to invest or not. The termination value, Ω_0, is defined as

(3.1) $$\Omega_0 = \max\left\{V_0 - I, 0\right\}$$

where V_0 is the expected present value of the revenues the firm gets if it invests and I is the investment cost. Dixit and Pindyck denote Ω_0 as the termination value, since the decision to invest or not in the first period terminates the decision process. The full opportunity, F_0, is defined as

(3.2) $$F_0 = \max\left\{V_0 - I, \frac{1}{1+r} E\left[\max\left\{V_1 - I, 0\right\}\right]\right\}.$$

Here Ω_0 corresponds to the open-loop strategy, and F_0 corresponds to the closed-loop strategy. In the notation of the Fisher model, we have that

(3.3) $$V_0 - I = V^*(1) = \hat{V}(1).$$

Hence, (3.1) can be rewritten

(3.4) $$\Omega_0 = \max\left\{V^*(1), 0\right\},$$

and (3.2) corresponds to

(3.5) $$F_0 = \max\left\{\hat{V}(0), \hat{V}(1)\right\}.$$

The DP option value thus becomes

(3.6) $$OV^{DP} = F_0 - \Omega_0 = \max\left\{\hat{V}(0), \hat{V}(1)\right\} - \max\left\{V^*(1), 0\right\}.$$

Mensink and Requate interpret the Dixit-Pindyck option value as follows,

(3.7) $$OV^{DP} = F_0 - \Omega_0 = \max\left\{\hat{V}(0), \hat{V}(1)\right\} - NPV = \max\left\{\hat{V}(0), \hat{V}(1)\right\} - \max\left\{V^*(1), \overline{B}_0\right\}$$

where they have redefined Ω_0 as the net present value

(3.8) $$NPV = \max\left\{V^*(1), \overline{B}_0\right\}.$$

The default value $\overline{B}_0$ reflects the present value of the stream of payoffs which emerges if no investment is made, neither in period 1 nor in period 2. In the context of the Dixit-Pindyck option value, where focus is on establishing a firm, this default value is zero. In a context where a firm invests in order to substitute old technology, e.g. "becoming green", the default value would in general be positive. In environmental applications, too, the default value is generally different from zero, representing the benefit from preservation.

It is somewhat unclear what is obtained by introducing the default value $\overline{B}_0$. Mensink and Requate argue that the difference between $\overline{B}_0$ and $V^*(0)$ is crucial for explaining the relation between the AFHH and DP option values. However, both $V^*(0)$ and $\overline{B}_0$ represent the default values of open-loop strategies, and what matters for the option value is the first-period decision, that is, whether $d_1^* = 0$ or $d_1^* = 1$. As we will discuss in the following section, the relationship between the option values depends on the actual level of $\overline{B}_0$ and $V^*(0)$ in different situations. Moreover, Mensink and Requate assume that

(3.9) $$V^*(1) > \overline{B}_0.$$

This assumption implies that investment in the open-loop strategy is optimal in the first period, that is, $d_1^* = 1$. Mensink and Requate for some reason omit the discussion of the case where $d_1^* = 0$. Given this assumption and the assumption $\hat{V}(0) > \hat{V}(1)$, it follows that, as they show in (14) and (15),

(3.10) $$OV^{DP} = \hat{V}(0) - V^*(1) = \hat{V}(0) - V^*(0) + V^*(0) - V^*(1) = OV^{AFHH} + OV^{PP}.$$

In the special case where the actual value of $\bar{B}_0$ coincides with $V^*(0)$, (3.9) becomes $V^*(1) > V^*(0)$ and the case discussed by Mensink and Requate corresponds to the case $\hat{V}(0) \geq V^*(1) \geq V^*(0)$ as discussed in (2.13).

The assumption of $\Omega_0 = V_0 - I = V^*(1) > \bar{B}_0$ implies that investment takes place in the first period, that is, $V^*(1) > V^*(0)$ in the terminology of the Fisher model. However, recall that the AFHH option value $\hat{V}(0) - V^*(0)$ is defined under the assumption that investment does not take place in the first period in the open-loop strategy, so that $V^*(0) > V^*(1)$. This point is not stated explicitly, neither by Mensink and Requate, nor by Fisher in his comparison of his own and Dixit-Pindyck's model. The DP option value as interpreted by Mensink and Requate corresponds to the case $\hat{d}_1 = 0$ and $d_1^* = 1$. In order to make an appropriate comparison of the DP and AFHH option values, the case $\hat{d}_1 = d_1^* = 0$, where investment is postponed, both in the closed-loop and open-loop strategy, need to be considered as well.

4. The analogy between the AFHH and DP option value models

We will now explain the difference between the AFHH and DP option values in terms of the open-loop investment strategy in period 1, that is, whether $d_1^* = 0$ or $d_1^* = 1$. In our comparison of the AFHH and DP option values we introduce a more general default value *D* that may represent any type of open-loop strategy with no investment in period 1. For comparison of the option values, the point is whether $V^*(1)$ exceeds *D* or not. We will compare the special cases of Dixit-Pindyck, $D = 0$, Mensink and Requate, $D = \bar{B}_0$, and Fisher, $D = V^*(0)$. Hence, we suggest that (3.1) is replaced by

(4.1) $$\Omega_0 = \max\{V_0 - I, D\}$$

where the default value *D* could be zero, reflecting that no investment takes place, or it could be a positive number reflecting the revenue from an old technology, or reflecting the environmental benefit if no investment takes place.

The comparison of the AFHH and the DP option values must distinguish between the three cases $\hat{d}_1 = d_1^* = 0$, $\hat{d}_1 = d_1^* = 1$ and $\hat{d}_1 = 0, d_1^* = 1$. It follows from the discussion of (2.13) that the option value is zero in the case of $\hat{d}_1 = d_1^* = 1$. In the following we consider the two other cases. For the open-loop strategy Ω_0 we have to distinguish between the two cases $d_1^* = 1$ and $d_1^* = 0$. We obtain

(4.2) $$\Omega_0 = \begin{cases} V_0 - I = V^*(1) & \text{if } d_1^* = 1 \\ D & \text{if } d_1^* = 0. \end{cases}$$

For the closed-loop strategy $F_0 = \max\left\{\hat{V}(0), \hat{V}(1)\right\}$ we obtain for $\hat{V}(0) > \hat{V}(1)$,

(4.3) $$F_0 = \hat{V}(0) \text{ if } \hat{d}_1 = 0.$$

Hence, we obtain

(4.4) $$OV^{DP} = \begin{cases} \hat{V}(0) - V^*(1) & \text{if } \hat{d}_1 = 0, d_1^* = 1 \\ \hat{V}(0) - D & \text{if } \hat{d}_1 = 0, d_1^* = 0. \end{cases}$$

By rewriting (4.4) we find the following expression for DP option value

(4.5) $$OV^{DP} = \begin{cases} \hat{V}(0) - V^*(0) + V^*(0) - V^*(1) = OV^{AFHH} + OV^{PP} & \text{if } \hat{d}_1 = 0, d_1^* = 1 \\ \hat{V}(0) - V^*(0) + V^*(0) - D = OV^{AFHH} + V^*(0) - D & \text{if } \hat{d}_1 = 0, d_1^* = 0. \end{cases}$$

From (4.5) it follows that the DP option value is different in the two situations $d_1^* = 1$ and $d_1^* = 0$. For $d_1^* = 1$, the DP option value equals the AFHH option value plus the pure postponement value, as shown by Hanemann and discussed by Mensink and Requate. The pure postponement value is negative in this case, hence, the DP option value is smaller than the AFHH option value. The interpretation of this difference is that part of the DP option value is lost when investment in period 1 is optimal in the open-loop strategy. The AFHH option value, however, is derived under the assumption that investment does not take place in period 1 in the open-loop strategy.

For $d_1^* = 0$, the DP option value equals the AFHH option value plus the correction term $V^*(0) - D$. If the default value *D* equals $V^*(0)$, it follows that the AFHH and DP option value concepts coincide when $\hat{d}_1 = d_1^* = 0$. Otherwise the difference between *D* and $V^*(0)$ creates a difference between the two option value concepts. As we will discuss below, our interpretation of Fisher is that he implicitly assumes that $\hat{d}_1 = d_1^* = 0$. In this model it thus obviously follows that the AFHH and DP option values coincide.

The AFHH and DP option values also coincide if $D = V^*(0) = 0$. Note that this special case corresponds to the Dixit-Pidyck model. In (3.1) they assume that $D = 0$, and the assumption $V^*(0) = 0$ corresponds to a situation where the default value of not investing in period 1 in the open-loop strategy is zero. If $V^*(0) = 0$, it follows from (4.5) that $OV^{DP} = OV^{AFHH}$ for $d_1^* = 0$ and $OV^{DP} = OV^{AFHH} - V^*(1)$ for $d_1^* = 1$. Hence, the option values coincide when the investment option is retained both in the closed-loop and the open-loop strategy, while in the case where investment in period 1 is optimal in the open-loop strategy, the DP option value equals the AFHH option value minus the present value of the investment project.

If $D = \overline{B}_0$, it follows from (4.5) that the AFHH and DP option values coincide if $\overline{B}_0 = V^*(0)$. While $\overline{B}_0$ and $V^*(0)$ refer to two different situations, namely, that investment takes place neither in period 1 nor in period 2, as compared to the possibility that investment may take place in period 2, what matters for the actual option values is the decision in period 1 that determines the actual level of the default values, as exemplifized with the default value *D* covering both $V^*(0)$ and $\overline{B}_0$ as special cases.

In the case where $D = \overline{B}_0 \neq V^*(0)$, it follows from (4.5) that

(4.6) $$OV^{DP} \lesseqgtr OV^{AFHH} \quad \text{if} \quad \overline{B}_0 \gtreqless V^*(0).$$

The DP option value exceeds the AFHH option value in the case where the default value of not investing in period 1 is smaller in the now-or-never context.

Finally, we will review Fisher's comparison of the AFHH and DP option values. In Fisher's comparison of the two option value concepts, he interprets Ω_0 in his equation (13´) as

(4.7) $$\Omega_0 = \max\left\{B_1(1) + E\left(B_2\left(1,\theta\right)\right), B_1(0) + \max\left\{E\left(B_2\left(0,\theta\right)\right), E\left(B_2\left(1,\theta\right)\right)\right\}\right\}.$$

Fisher says that the first part of the maximum expression equals $V_0 - I = V^*(1)$. However, he is somewhat unclear about the second part of the maximum expression. In the text after (13´) he first says that it is zero, corresponding to the default value in the Dixit-Pindyck framework. Then he proceeds to explain that in an environmental setting, the default value may be different from zero. We first interpret Fisher such that the default value is $V^*(0)$. Hence, (4.8) $$\Omega_0 = \max\left\{V^*(1), V^*(0)\right\}.$$

Fisher interprets F_0 in his equation (17´) as

(4.9) $$F_0 = \max\left\{B_1(1) + E\left(B_2\left(1,\theta\right)\right), B_1(0) + E\left(\max\left\{B_2\left(0,\theta\right), B_2\left(1,\theta\right)\right\}\right)\right\} = \max\left\{\hat{V}(1), \hat{V}(0)\right\}$$

where the latter equality follows from the definition of $\hat{V}(0)$. Fisher's explanation of his option value expression (18) is somewhat ambiguous. Mensink and Requate claim that Fisher makes an algebraic mistake in subtracting the two maximum expressions. In our view, Fisher may have tacitly assumed that the AFHH option value is only meaningful under the assumption that $\hat{d}_1 = d_1^* = 0$, that is, $\hat{V}(0) > \hat{V}(1)$ and $V^*(0) > V^*(1)$. In this case it follows from (4.7), (4.8) and (4.9) that $F_0 = E\left(\max\left\{B_2\left(0,\theta\right), B_2\left(1,\theta\right)\right\}\right) = \hat{V}(0)$ and $\Omega_0 = \max\left\{E\left(B_2\left(0,\theta\right)\right), E\left(B_2\left(1,\theta\right)\right)\right\} = V^*(0)$. With this interpretation Fisher correctly obtains in (18) that

(4.10) $$OV^{DP} = F_0 - \Omega_0 = \hat{V}(0) - V^*(0) = OV^{AFHH}.$$

Only when the open-loop and closed-loop strategies coincide, and investment does not take place in period 1, that is, $\hat{d}_1 = d_1^* = 0$, and the default value for not investing is $V^*(0)$, are the AFHH and DP option values equivalent.

Let us then interpret Fisher such that the default value of not investing in the first period in the open-loop strategy is zero. This case will illustrate the situation $V^*(1) \geq V^*(0)$ which Fisher disregarded in his analysis. Hence, (4.8) is replaced by

(4.11) $$\Omega_0 = \max\left\{V^*(1), 0\right\}$$

and (4.10) is replaced by

(4.12) $$OV^{DP} = F_0 - \Omega_0 = \begin{cases} \hat{V}(0) - V^*(1) = OV^{AFHH} + OV^{PP} & \text{if} \quad V^*(1) > V^*(0) > 0 \\ \hat{V}(0) = OV^{AFHH} + V^*(0) = OV^{AFHH} & \text{if} \quad V^*(1) = V^*(0) = 0. \end{cases}$$

As shown before, in the first case, corresponding to $\hat{d}_1 = 0$ and $d_1^* = 1$, the DP option value equals the AFHH option value plus the (negative) pure postponement value. This is the case where Mensink and Requate supplement Fisher's analysis. In the second case, where investment is not profitable in period 1 in the open-loop strategy, the DP option value equals the AFHH option value plus $V^*(0)$, and in the special case $V^*(0) = V^*(1) = 0$, that is, the pure postponement value is zero, the AFHH and DP option values coincide. For analysis of $\bar{B}_0$ as default value, we refer to the discussion above.

To summarize, we have shown that the default value $V^*(0)$ of not investing in period 1 in the open-loop strategy is a crucial parameter in the comparison of the AFHH and DP option values. The level of $V^*(0)$ relative to $V^*(1)$ determines whether $d_1^* = 0$ or $d_1^* = 1$. The distinction between the open-loop strategies $d_1^* = 0$ and $d_1^* = 1$ is the basis for finding the conditions for the AFHH and DP option values to coincide or not.

5. Concluding remarks

In their comparisons of the AFHH option value and the DP option value, neither Fisher nor Mensink and Requate recognize the crucial distinction between the open-loop strategies $d_1^* = 0$ and $d_1^* = 1$ for deriving the correct option value concepts. Fisher focuses on the environmental preservation context where $d_1^* = 0$ is the default investment decision in period 1 in the open-loop strategy, whereas Mensink and Requate focus on an investment context where $d_1^* = 1$ is the default investment decision in period 1 in the open-loop strategy. Hence, both articles fail to notice what Hanemann (1989) pointed out in the context of information, and what in our context implies a condition for the equivalence of the option values. The AFHH and DP option values are not equivalent for $\hat{d}_1 = 0$, $d_1^* = 1$, unless the pure postponement value is zero, whereas in the case $\hat{d}_1 = 0$, $d_1^* = 0$, the AFHH and DP option values are equivalent.

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