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Arrow–Fisher–Hanemann–Henry and Dixit–Pindyck Option Values Under Strategic Interactions*

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ABSTRACT

We extend the Arrow–Fisher–Hanemann–Henry (AFHH) and Dixit–Pindyck (DP) option values to a game situation. By reinterpreting the AFHH option value as a change in the surplus from conservation because of the prospect of future information, we deal with a conceptual difficulty associated with the AFHH option value in the presence of strategic interactions. We then introduce the DP option value into a game situation. We show that the equivalence between the expected value of information and the DP option value in the standard model does not hold under strategic interactions.

Keywords: Irreversibility; quasi-option value; uncertainty; value of information.

JEL Codes: C72, H43, Q50

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Introduction

The value of the prospect of future information is often ignored in the standard analysis of net present value. Ignoring it, however, tends to bias decisions. In private investment analysis, future information may allow the investors to make state-contingent decisions and thereby avoid unnecessary sunk costs. As Dixit and Pindyck (1994) emphasize, the opportunity cost due to the forgone opportunity to delay the investment, or the Dixit–Pindyck (DP) option value, must be included in the cost of immediate investment in addition to direct investment costs.

The prospect of future information also plays an important role in the analysis of public projects. Suppose, for example, that a policy maker has to choose whether to develop or conserve a forest. The forest may (or may not) contain economically valuable plants, but such plants may be discovered only in the future (say, by independent scientific research), if they exist in the forest at all. Then, ignoring the possibility of the future discovery of plants will bias the current decision toward development. Therefore, the Arrow–Fisher–Hanemann–Henry (AFHH) option value due to Arrow and Fisher (1974), Henry (1974), Fisher and Hanemann (1987), and Hanemann (1989), also called the quasi-option value, must be incorporated into the cost-benefit analysis. The AFHH option value is particularly relevant to those issues in which future information and irreversibility play an important role, including climate change and conservation of biodiversity. This concept has also been extended to a situation where the decision maker faces hard uncertainty represented by a nonadditive measure over events (Basili, 1998).

The AFHH option value is related to the option value in the private investment analysis. Lund (1991) compares the AFHH option value with valuation of financial options as represented by Black and Scholes (1973) and Merton (1973). The AFHH option value is closely related to but generally different from the expected value of information (EVI) (Conrad, 1980; Hanemann, 1989). Fisher (2000) claimed that the AFHH and DP option values are identical, although Mensink and Requate (2005) subsequently found this argument incorrect.

In the previous studies of option values mentioned above, presence of a single decision-maker is assumed. It is indeed sufficient to have only one decision maker in the model, for example, when there is a social planner who can stipulate the action of each player in the society. Even if this is not the case, when the market is competitive and each player has negligible impacts on other players, a single decision-maker model would still be appropriate.

However, in many practical situations, the single decision-maker model is not appropriate. The policy-maker may have to take the competition among firms or different public entities as given. A firm may compete with only a few other firms in the same industry and its decision may have non-negligible impacts on other firms.

This is important, because the AFHH option value is conceptually problematic in the presence of strategic interactions. To see this, first note that the AFHH option value in the standard model is defined as the difference between the payoff from conservation relative to development with the prospect of future information and the corresponding payoff without the prospect of future information. Therefore, we need to be able to define the payoff in each outcome (i.e., conservation or development). However, as pointed out by Fujii and Ishikawa (2012), this definition is problematic in the presence of strategic interactions, because not all outcomes can be supported as an equilibrium. Therefore, the AFHH option value does not have an obvious definition under strategic interactions.

Furthermore, the EVI for the society critically depends on how the information is held and released. Fujii and Ishikawa (2012) have shown that the prospect of future information could even be harmful to everyone in the society, a situation that never happens in a single decision-maker model. Therefore, we cannot appropriately take the prospect of future information into account without considering the strategic interactions in the society.

In this study, we extend Fujii and Ishikawa (2012) in two ways. First, we provide an alternative interpretation to the AFHH option value. In this interpretation, the AFHH option value is taken as the change in a surplus measure for conservation because of the prospect of future information. This allows us to overcome the conceptual difficulties pointed out by Fujii and Ishikawa (2012) and to define the AFHH option value even in the presence of strategic interactions. However, unlike the case of a single decision-maker studied by Hanemann (1989), our AFHH option value cannot be interpreted as the conditional value of information.

Second, we also extend the discussion on the relationship between the AFHH and DP option values by Fisher (2000) and Mensink and Requate (2005) to a game situation. We argue that whether or not the AFHH option value is more relevant than the DP option value would depend on the degree of control that the regulator has on the strategic interactions in the society. We also show that the DP option value in the single decision-maker case is identical to the EVI, but this equivalence does not hold in the presence of strategic interactions. These points reinforce the finding of Fujii and Ishikawa (2012) that social cost-benefit analyses require a careful assessment of strategic interactions in the society.

This paper is organized as follows. In section "Setup," we set up a simple model of an irreversible decision under strategic interactions first proposed by Fujii and Ishikawa (2012). This model is a straightforward extension of the single decision-maker model widely used in the literature. Because we adopt the same model and notations as Fujii and Ishikawa (2012), we only provide a brief summary below and omit a detailed discussion on the motivation of the way the model is formulated. In section "Case (I): Social Optimum," we introduce the AFHH and DP option values in the standard single decision-maker case. Most of the results in this section, except for Proposition 1, are not new, but they serve as a reference case. We then extend the AFHH and DP option values to a game situation in section "Case (II): Strategic Interactions." The last section provides some discussion.

Setup

There are two time periods: period 1 (current period) and period 2 (future period). The future state is uncertain. The state s takes a good state s_1 with probability π and a bad state s_2 with probability $1-\pi$. There are two risk-neutral players α and β, each of both cares only about their own payoff, and a regulator. In each period $t \in \{1,2\}$, each player $i \in \{\alpha,\beta\}$ takes an action $d_t^i \in \{0,1\}$, where $d_t^i = 0$ represents conservation (or no immediate investment in the context of the DP option value) and $d_t^i = 1$ represents development (or immediate investment). The decision to develop is irreversible and thus $d_1^i \leq d_2^i$. We denote the sequence of actions taken by player i by $d^i \equiv (d_1^i, d_2^i)$. For the simplicity of argument, we assume that each player always chooses to develop if the player is indifferent between conservation and development.

We normalize the payoffs so that the player receives a payoff of zero in each period he chooses conservation. We assume that the total payoff from development for the two players in present value is a in period 1 and $b \cdot \mathrm{Ind}(s = s_1) - c \cdot \mathrm{Ind}(s = s_2)$ in period 2 for positive constants a, b, and c, where $\mathrm{Ind}(\cdot)$ is an indicator function that takes one if the argument is true and zero otherwise. Therefore, development is beneficial to the society in the good state and harmful in the bad state. We assume that the total payoff is shared equally by the two players when they take the same sequence of actions. When one player chooses a sequence $(1,1)$ (i.e., development in both periods) and the opponent chooses a sequence $(0,1)$ (i.e., conservation in period 1 and development in period 2), the leader [follower] of development, who chooses the sequence $(1,1)$ $[(0,1)]$, takes a share k $[1-k]$ of the total payoff from the development in period 2 for some constant $k \in (0,1)$.

We assume that new information becomes available to the regulator so that the regulator knows the true state after period 1 but before actions are taken by players in period 2. We use the hat (ˆ) and the asterisk (*) notations to denote the cases with and without the prospect of future information, respectively. Furthermore, we use the tilde (˜) notation to denote the case where the option to delay the decision to develop is not available, which corresponds to the case where the sequence $(0,1)$ is not allowed. We also assume that the game structure and probability distribution of the states are common knowledge and that the regulator tries to maximize the expected total payoffs in the society (i.e., the sum of the payoffs for players α and β) for the two periods, which we refer to as the social welfare. The latter assumption can be justified when the regulator can transfer the payoffs between the players in a lump-sum manner.

Case (I): Social Optimum

As with Fujii and Ishikawa (2012), we start with studying the social optimal choice, i.e., a social planner can stipulate the action of each player. This is *de facto* a single decision-maker case. Because the social welfare is determined only by the timing of development and not by who chooses to develop, we simply impose $d^{\alpha} = d^{\beta}$ in this section. This allows us to avoid unnecessary complications and treat the action of player α as the action of a representative player. Given the setup presented in the ‘‘Setup’’ section and assuming a rational choice in period 2, we can write the value functions, or the social welfare, as a function of the current action d_1^{α}, in the following manner[1]:

$$\hat{V}(d_1^{\alpha}) = B + (a - C) \cdot \mathrm{Ind}(d_1^{\alpha} = 1); \tag{1}$$

$$V^*(d_1^{\alpha}) = \max(B - C, 0) \cdot \mathrm{Ind}(d_1^{\alpha} = 0) + (a + B - C) \cdot \mathrm{Ind}(d_1^{\alpha} = 1), \tag{2}$$

[1] See Fujii and Ishikawa (2012) for the derivation of this result.

where $B \equiv \pi b$ and $C \equiv (1-\pi)c$ denote the expected gross benefit and cost in period 2, respectively. Thus, the social planner chooses d_1^α to maximize $\hat{V}$ [V^*] in the presence [absence] of the prospect of future information. Using these value functions, the AFHH option value can be found as follows:[2]

$$\begin{aligned}\mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}} &\equiv (\hat{V}(0) - \hat{V}(1)) - (V^*(0) - V^*(1)) \\ &= \hat{V}(0) - V^*(0) = \min(B, C). \end{aligned} \tag{3}$$

The AFHH option value can be interpreted as the correction term that must be added to the net present value of conservation relative to development when the net present value is calculated ignoring the prospect of future information. The third expression shows that the AFHH option value is the change in the expected total payoff for the society from the prospect of future information, given that conservation is chosen in period 1. Thus, the AFHH option value can be interpreted as the conditional value of information (Hanemann, 1989).

It is also possible to give the AFHH option value an alternative interpretation. We can interpret $\hat{\theta}_{\mathrm{I}} \equiv \hat{V}(0) - \hat{V}(1)$ as a surplus measure of conservation relative to development when future information is available. This is the minimum transfer of payoff that must be given to the social planner to ensure development takes place in period 1. In the current setup, this is the smallest number that has to be added to a to make the social planner indifferent between conservation and development in period 1. This number is negative if the social planner prefers development to conservation. We similarly define $\theta_{\mathrm{I}}^* \equiv V^*(0) - V^*(1)$ for the case without the prospect of future information. Given these definitions, we have $\mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}} = \hat{\theta}_{\mathrm{I}} - \theta_{\mathrm{I}}^*$. As we argue in the next section, this alternative interpretation allows us to define the AFHH option value in a game situation.

Mensink and Requate (2005) argue that the DP option value can be defined as follows:

$$\mathrm{OV}_{\mathrm{I}}^{\mathrm{DP}} \equiv \max(\hat{V}(0), \hat{V}(1)) - \max(\bar{B}_0, V^*(1)), \tag{4}$$

where $\bar{B}_0$ is the default value, which is the present value of the stream of payoffs that would emerge if no investment decision is made at all times.

[2] We use subscripts I and II to clearly distinguish between Cases (I) and (II). To maintain the consistency with Fujii and Ishikawa (2012), we also use the subscript S in the next section to emphasize the social value of the option.

In our model, this is equal to choosing conservation in both periods, which implies that $\bar{B}_0 = 0$. In this definition, the social planner is assumed to commit in period 1 to either conservation or development for both periods under the net present value decision rule (See also, Mensink and Requate, 2005). Thus, the DP option value can be thought of as the value arising from the flexibility to delay the decision to develop (or invest).

A concept related to the AFHH and DP option values is the EVI, which is defined as follows:

$$\mathrm{EVI_I} \equiv \max(\hat{V}(0), \hat{V}(1)) - \max(V^*(0), V^*(1)). \tag{5}$$

The EVI is the additional expected total payoff from the future information. If we define $\hat{W}_\mathrm{I} \equiv \max(\hat{V}(0), \hat{V}(1))$ and $W_\mathrm{I}^* \equiv \max(V^*(0), V^*(1))$, they can be interpreted as the social welfare when the social planner behaves rationally given the availability of future information. Thus, $\mathrm{EVI_I} = \hat{W}_\mathrm{I} - W_\mathrm{I}^*$ is the change in the social welfare from future information. Similarly, if we define $\tilde{W}_\mathrm{I}^* \equiv \max(\bar{B}_0, V^*(1))$, we have $\mathrm{OV_I^{DP}} = \hat{W}_\mathrm{I} - \tilde{W}_\mathrm{I}^*$. It turns out, however, that the DP option value is identical to the EVI in the current setup:

Proposition 1 *Given the setup in the second section, we have the following*:

$$\mathrm{OV_I^{DP}} = \mathrm{EVI_I} = (C - a) \cdot \mathrm{Ind}(a \leq C < a + B) + B \cdot \mathrm{Ind}(a + B \leq C). \tag{6}$$

We omit the formal proof because it is straightforward. Intuitively, the result can be understood in the following manner. When there is no prospect of future information, the social planner simply loses the opportunity cost a, if he chooses to conserve in period 1. Thus, a rational social planner chooses either $(0, 0)$ or $(1, 1)$; he never chooses $(0, 1)$. Therefore, even though $V^*(0) \neq 0$ in general, this occurs only when $V^*(1) = \hat{V}(1) > V^*(0) > 0$, in which case we have $\max(V^*(0), V^*(1)) = \max(0, V^*(1)) = V^*(1) = \hat{V}(1)$, equating $\mathrm{OV_I^{DP}}$ with $\mathrm{EVI_I}$.

Put differently, in the absence of future information, if development is more attractive than conservation in period 2, development is certainly more attractive in period 1. Therefore, in the absence of future information, the flexibility to delay the decision (i.e., the possibility to take a sequence of action $(0, 1)$) is not valuable for the social planner. This in turn means that the welfare that social planner gains from the option to delay comes only from the expected value of information.

By comparing Equation (3) with Equation (6), we have the following proposition:

Proposition 2 $\mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}}$, $\mathrm{OV}_{\mathrm{I}}^{\mathrm{DP}}$, *and* $\mathrm{EVI}_{\mathrm{I}}$ *satisfy the following relationship:*

$$\begin{aligned}\mathrm{EVI}_{\mathrm{I}} &= \mathrm{OV}_{\mathrm{I}}^{\mathrm{DP}} \\ &= \mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}} \cdot \mathrm{Ind}(C > a) + \mathrm{PPV} \cdot \mathrm{Ind}(a + B > C > a) \quad (\geq 0),\end{aligned} \tag{7}$$

where $\mathrm{PPV} \equiv V^*(0) - V^*(1) = -a + \max(0, C - B)$ is what Mensink and Requate (2005) call the pure postponement value. Clearly, $\mathrm{EVI}_{\mathrm{I}} = \mathrm{OV}_{\mathrm{I}}^{\mathrm{DP}} = \mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}}$ when $a + B < C$. However, as Hanemann (1989) has shown, $\mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}} \neq \mathrm{EVI}_{\mathrm{I}}(= \mathrm{OV}_{\mathrm{I}}^{\mathrm{DP}})$ in general. In fact, Equation (7) is simply a restatement of Equation (17) in his paper and the generalization of the results presented by Mensink and Requate (2005). Thus, Proposition 2 is simply a summary of the results of previous studies. However, the social optimum case discussed in this section serves as a reference case.

Case (II): Strategic Interactions

In this section, we let the players interact strategically with each other. That is, each player chooses his action so as to maximize his payoff for the two periods. Unlike the previous section, the regulator is unable to stipulate the players' actions. As with Fujii and Ishikawa (2012), we take the efficient subgame perfect Nash equilibrium as the relevant solution concept. The subgame played in period 2 is determined by the action profile $(d_1^{\alpha}, d_1^{\beta})$ in period 1.

Given the setup in the "Setup" section, each player $i \in \{\alpha, \beta\}$ has three possible pure strategies $d^i \in \{(0,0), (0,1), (1,1)\}$ when future information is not available. When information is available in period 2, each player can take a state-contingent action. Therefore, if conservation is chosen in period 1, the set of strategies for player i in the subgame in period 2 is $\{0, \mathrm{Ind}(s = s_1), \mathrm{Ind}(s = s_2), 1\}$. However, because $\mathrm{Ind}(s = s_1)$ dominates the other strategies, we only need to consider the following two strategies $d^i \in \{(0, \mathrm{Ind}(s = s_1)), (1,1)\}$. The payoff matrices for these cases are given in Table 1.

With some slight abuse of terminology, we shall use the cell index in Table 1 to specify a profile of the sequence of actions. For example, b*)

Table 1. The *ex ante* expected payoff matrix for two periods when no information is available in period 2 (top) and the corresponding matrix when information is available in period 2 (bottom). The borders define the subgame to be played in period 2.

d^α \ d^β		$(0,0)$		$(0,1)$		$(1,1)$
$(0,0)$	a*)	$(0,0)$	b*)	$(0,B-C)$	c*)	$(0,a+B-C)$
$(0,1)$	d*)	$(B-C,0)$	e*)	$\left(\frac{(B-C)}{2},\frac{(B-C)}{2}\right)$	f*)	$((1-k)(B-C),a+k(B-C))$
$(1,1)$	g*)	$(a+B-C,0)$	h*)	$(a+k(B-C),(1-k)(B-C))$	i*)	$(\frac{a+B-C}{2},\frac{a+B-C}{2})$

$d_2^\alpha(s)$ \ $d_2^\beta(s)$		$(0,\mathrm{Ind}(s=s_1))$		$(1,1)$
$(0,\mathrm{Ind}(s=s_1))$	â)	$(B/2,B/2)$	$\hat{\text{b}}$)	$((1-k)B,a+kB-C)$
$(1,1)$	ĉ)	$(a+kB-C,(1-k)B)$	$\hat{\text{d}}$)	$((a+B-C)/2,(a+B-C)/2)$

refers to the profile $(d^\alpha, d^\beta) = ((0,0),(0,1))$. The equilibrium profile in the absence of future information is: a*) if $C - B > a$; e*) if $a < (1/2-k)(B-C)$ and $k < 1/2$; i*) if $a \geq C - B \geq 0$ or $a \geq (1-2k)(B-C) \geq 0$; and f*) or h*) otherwise. In the presence of future information, the equilibrium is: (â) if $a < (1 + \mathrm{Ind}(k \geq 1/2))(k - 1/2)B + C$; $\hat{\mathrm{d}}$) if $a \geq (1-2k)B + C$; and ($\hat{\mathrm{b}}$) or (ĉ) otherwise.[3]

We can now introduce the EVI and the AFHH and DP option values for the society in the current context. As Fujii and Ishikawa (2012) argue, the EVI in this case is simply the change in the expected total payoff for the two periods due to the information. Let $\hat{W}_{\mathrm{II}}$ and W^*_{II} be the equilibrium social welfare (i.e., the expected total payoff in the equilibrium for the two players summed over the two periods).[4] For example, when $C - B > a$, the equilibrium is $\hat{a}$) and a^*) with and without information in period 2, respectively, and thus we have $\hat{W}_{\mathrm{II}} = B$ and $W^*_{\mathrm{II}} = 0$. Using $\hat{W}_{\mathrm{II}}$ and W^*_{II}, we can define and compute the EVI for the current case as follows:

$$\mathrm{EVI_S} \equiv \hat{W}_{\mathrm{II}} - W^*_{\mathrm{II}} \tag{8}$$

$$= \begin{cases} C - a & \text{if } a + (k - \frac{1}{2})B < C \leq a + B \quad \text{and} \quad k \geq \frac{1}{2}, \\ & \text{or if } \max\left(a + (k-\frac{1}{2})B, B - \frac{2a}{1-2k}\right) < C < B + a \\ & \text{and} \quad k < \frac{1}{2} \\ B & \text{if } C > B + a \\ C & \text{if } C < B - \frac{2a}{1-2k} \quad \text{and} \quad k < \frac{1}{2} \\ 0 & \text{otherwise.} \end{cases} \tag{9}$$

To apply the DP option value in the current case, we need to consider the change in the social welfare due to the flexibility to delay the decision. When the players can choose a state-contingent action, the social welfare is clearly $\hat{W}_{\mathrm{II}}$. The question is, therefore, what the relevant social welfare is under the net present value decision rule when the flexibility is ignored. We argue that the regulator in this case would be able to distribute a development right for free to the players in period 1. This right can be exercised only in period 1. Thus, the player has to commit to development or conservation in period 1. They cannot choose the sequence $(0,1)$. Therefore, the equilibrium in the

[3] When we have multiple asymmetric equilibria, we can choose an arbitrary equilibrium because the choice does not affect the social welfare (Fujii and Ishikawa 2012).

[4] The formal definition of these variables are given in Definition 1 in Fujii and Ishikawa (2012).

absence of future information is a*) if $C > a + B$ and i*) otherwise. We denote the equilibrium social welfare by $\tilde{W}^*_{\mathrm{II}} (= \max(0, a + B - C))$. With these considerations, we can now define the DP option value for the current case:

Definition 1 *The DP option value* $\mathrm{OV}^{\mathrm{DP}}_{\mathrm{S}}$ *in a game situation is defined as follows:*

$$\mathrm{OV}^{\mathrm{DP}}_{\mathrm{S}} \equiv \hat{W}_{\mathrm{II}} - \tilde{W}^*_{\mathrm{II}}. \tag{10}$$

Notice that the definition will coincide with $\mathrm{OV}^{\mathrm{DP}}_{\mathrm{I}}$, if the regulator is able to stipulate the action of each player. It is straightforward to show the following:

Proposition 3 *Given the setup in the "Setup" section, we obtain the following from Equations* (8) *and* (10):

$$\mathrm{EVI}_{\mathrm{S}} = \mathrm{OV}^{\mathrm{DP}}_{\mathrm{S}} + a \cdot \mathrm{Ind}(a < (1/2 - k)(B - C) \quad \text{and} \quad k < 1/2). \tag{11}$$

Proposition 3 shows that the equivalence between the EVI and DP option value holds when either $a < (1/2 - k)(B - C)$ or $k < 1/2$ is violated. When the conditions in the indicator function hold, EVI is larger than the DP option value by a, a result that is not expected from Case (I). Under these conditions, each player chooses the sequence of action $(0, 1)$, if allowed, in the absence of future information.

However, in the calculation of the DP option value, each player is required to commit to either conservation or development without the option to delay the decision to develop, i.e., $(0, 1)$ is not allowed. This constraint, in turn, improves the efficiency in the absence of future information because it prevents the players from simultaneously choosing $(0, 1)$, which is an inefficient equilibrium. The second term of Equation (11) reflects this welfare difference between W^*_{II} and $\tilde{W}^*_{\mathrm{II}}$.

Another notable point in Proposition 3 is that both EVI and the DP option value can be negative. Fujii and Ishikawa (2012) have shown that EVI is negative if and only if $k < 1/2$, $C < a$, and $2(a - C)/(1 - 2k) < B < C + 2a/(1 - 2k)$. By these conditions and Proposition 3, we can show the following corollary:

Corollary 1 *The DP option value in a game situation is negative if and only if* $0 > C - a > (k - 1/2)B$ *and* $k < 1/2$.

This corollary shows that the flexibility to delay the decision can harm the social welfare. This happens because the prospect of information encourages the players to wait until period 2 to develop even when immediate development (i.e., development in period 1) is socially efficient.

Now, let us turn to the AFHH option value in the current case. Fujii and Ishikawa (2012) have shown that the AFHH option value has a conceptual difficulty in the presence of strategic interactions because the value function is not meaningful when a particular outcome (i.e., development or conservation) is not supported as an equilibrium. To circumvent this problem, we adopt the alternative interpretation of the AFHH option value and extend it to a game situation by considering surplus measures $\hat{\theta}$ and θ^* of conservation for the cases with and without the prospect of future information, respectively.

We first consider the surplus measure $\hat{\theta}_{\mathrm{II}}$, which can be defined as the difference in the individual payoffs between conservation and development when the opponent is choosing conservation. When the information about the state becomes available in period 2, this can be done by taking the difference of the payoff for player α [player β] between cells â) and ĉ) [cells â) and $\hat{\text{b}}$)].

$$\hat{\theta}_{\mathrm{II}} = \frac{B}{2} - (a + kB - C) = \left(\frac{1}{2} - k\right) B + C - a. \tag{12}$$

When the information is not available, we can compute θ^*_{II} in the following manner. Using the backward induction, the reduced payoff matrix consists of e*), f*), h*), and i*) when $B > C$, and a*), c*), g*), and i*) when $B \leq C$. Therefore, we have:

$$\theta^*_{\mathrm{II}} = ((1/2 - k)(B - C) - a) \cdot \mathrm{Ind}(B > C) - (a + B - C)\,\mathrm{Ind}(B \leq C). \tag{13}$$

Using Equations (12) and (13), we can define the AFHH option value for the current case as follows:

Definition 2 *The AFHH option value* $\mathrm{OV}_{\mathrm{S}}^{\mathrm{AFHH}}$ *in a game situation is defined as follows:*

$$\mathrm{OV}_{\mathrm{S}}^{\mathrm{AFHH}} \equiv \hat{\theta}_{\mathrm{II}} - \theta^*_{\mathrm{II}}.$$

This definition is based on the reinterpretation of the AFHH option value presented in section "Case (I): Social Optimum," i.e., the change in the surplus from conservation because of the future information.

Proposition 4 *Given the setup in the "Setup" section and Definition 2, the following relationship between* $\mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}}$ *and* $\mathrm{OV}_{\mathrm{S}}^{\mathrm{AFHH}}$ *follows from Equations* (3), (12), *and* (13):

$$\mathrm{OV}_{\mathrm{S}}^{\mathrm{AFHH}} = \left(\frac{3}{2} - k\right) \min(B, C) = \left(\frac{3}{2} - k\right) \mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}}. \tag{14}$$

By comparing Equation (14) with Equations (9) and (11), it is clear that the AFHH option value is different from the DP option value and the EVI, which should not be surprising given Proposition 2. There are five additional points to note here. First, our definition of $\mathrm{OV}_{\mathrm{S}}^{\mathrm{AFHH}}$ is a direct extension of $\mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}}$. If the regulator can stipulate the actions of the two players, $\mathrm{OV}_{\mathrm{S}}^{\mathrm{AFHH}}$ coincides with $\mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}}$.

Second, Equation (14) clearly shows that the change in the surplus measure of conservation depends on k. This is because information influences the way players interact with each other. It also shows that $\mathrm{OV}_{\mathrm{S}}^{\mathrm{AFHH}} = \mathrm{OV}_{\mathrm{I}}^{\mathrm{AFHH}}$ if and only if $k = 1/2$. This is because the strategy taken by the opponent does not change the incentive structure when $k = 1/2$. For example, in the absence of the prospect of future information, each player chooses to develop in this case if and only if $a + B - C \geq 0$ regardless of the opponent's strategy.

Third, the point made by Fujii and Ishikawa (2012) is still valid, even though we have successfully extended the definition of AFHH option value. That is, since some outcomes are not supported as an equilibrium, it is not possible to interpret $\mathrm{OV}_{\mathrm{S}}^{\mathrm{AFHH}}$ as the conditional value of information, unlike the single decision-maker case studied by Hanemann (1989).

Fourth, Equation (14) shows that the AFHH option value is positive even in the presence of strategic interactions. The AFHH option value in the current case is the change of payoff needed to induce development in light of the prospect of future information. Since the prospect of future information makes conservation more attractive in period 1, the results are intuitive.

Fifth, Equation (14) also shows that the parameter k affects the option value. Because the follower develops only when the state is good ($s = s_1$) in the presence of information in period 2, the temptation to conserve in period 1 is higher when the follower's share $1 - k$ of the benefits from development in period 2 is higher. As a result, the AFHH option value in a game situation tends to be higher when k is lower.

Discussion

In this study, we have extended the AFHH and DP option values to a game situation. One novelty of this study is that, by reinterpreting the AFHH option value as the change in the surplus of conservation because of future information, we have overcome the conceptual difficulty of the AFHH option value pointed by Fujii and Ishikawa (2012). While the AFHH and DP option values and the EVI discussed above are related to each other, the appropriate choice of these measures in a practical application of cost-benefit analysis would depend on the policy instruments that are available to the regulator. For example, if the regulator simply passes information to the players with no additional policy instruments, the EVI would be the measure that the regulator would ultimately be interested in. The regulator can choose to pass on the information if and only if EVI is positive.

The AFHH option value is relevant if the cost-benefit analyst wants to measure the value of conservation. Unlike the single decision-maker case, this measurement may be complicated in a game situation because the regulator can directly implement neither conservation nor development. Our approach is to use a minimum hypothetical transfer to induce development to measure the surplus of conservation. We chose the parameter a for this transfer because this parameter directly changes the net present value of development. However, under some circumstances, the regulator may be able to make, for example, state-contingent transfers. In such a case, the AFHH option value may be altered.

The DP option value is most relevant in a situation where the regulator can make the players commit to either conservation or development in period 1. This can be done, for example, by distributing free development rights in period 1, which can be exercised only immediately. Such a situation may arise in practice because the regulator may be short-lived, in the sense that the opportunity to develop is lost for ever when the person in charge in the regulating body changes.

This study has highlighted the fact that the AFHH and DP option values and the EVI all depend on the way players interact with each other, a point that has largely been neglected in the literature. Therefore, social cost-benefit analyses under strategic interactions require a careful assessment of the information and policy instruments that may be available to the regulator in the future.

References

Arrow, K. J., and A. C. Fisher. 1974. "Environmental Preservation, Uncertainty, and Irreversibility." *Quarterly Journal of Economics* 88: 312–319.
Basili, M. 1998. "Quasi-option Value and Hard Uncertainty." *Environment and Development Economics* 3: 417–423.
Black, F., and M. Scholes. 1973. "The Pricing of Options and Corporate Liabilities." *Journal of Political Economy* 81: 637–659.
Conrad, J. M. 1980. "Quasi-option Value and the Expected Value of Information." *Quarterly Journal of Economics* 95: 813–820.
Dixit, A. K. and R. S. Pindyck. 1994. *Investment Under Uncertainty.* (Princeton University Press).
Fisher, A. C. and W. M. Hanemann. 1987. "Quasi-option Value: Some Misconceptions Dispelled." *Journal of Environmental Economics and Management* 14: 183–190.
Fisher, A. C. 2000. "Investment Under Uncertainty and Option Value in Environmental Economics." *Resource and Energy Economics* 22: 197–204.
Fujii, T. and R. Ishikawa. 2012. "Quasi-option Value under Strategic Interactions." *Resource and Energy Economics* 34: 36–54.
Hanemann, W. M. 1989. "Information and the Concept of Option Value." *Journal of Environmental Economics and Management* 16: 23–37.
Henry, C. 1974. "Investment Decisions Under Uncertainty: The Irreversibility Effect." *American Economic Review* 64: 1006–1012.
Lund, D. 1991. "Financial and Non-financial Option Valuation." In *Stochastic Models and Option Values*, eds. D. Lund and B. Oksendal, North-Holland, pp. 143–163.
Mensink, P. and T. Requate. 2005. "The Dixit–Pindyck and Arrow–Fisher–Hanemann–Henry Option Values are Not Equivalent: A Note on Fisher (2000)." *Resource and Energy Economics* 27: 83–88.
Merton, R. C. 1973. "Theory of Rational Option Pricing." *Bell Journal of Economics and Management Science* 4(1): 141–183.