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## FINANCIAL OPTIONS FROM REGULATING REAL ESTATE FOR HABITAT CONSERVATION

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*This article offers an analysis of financial incentives for landowners, conservation bank managers, and land developers under habitat regulations for land use. A financial option theory approach is used with call and put options as contracts for habitat conservation and exchange. The market for habitat is modeled as a stochastic game to derive the option price on habitat that allows for arbitrage between land with and without permission to develop. This analysis applies to a variety of policies including transferable development rights, conservation, and mitigation banking to protect wetland and upland habitat and wildlife.*

### INTRODUCTION

Habitat loss is the largest threat to biodiversity (Wilcove et al., 1998). Current rates of biodiverse species extinction are estimated at several orders of magnitude above background or natural extinction rates (Lawton and May, 1995; Pimm et al., 1995). Habitat and biodiversity loss is currently addressed through several habitat policies at local, national, and international levels. Conserving habitat involves land management decisions including purchase of land or easements.

The following regulatory policies include incentive-based strategies on a national scale for habitat conservation in the United States: Transferable Development Rights, Safe Harbors Act, Conservation and Mitigation Banking, Candidate Conservation Agreements, Habitat Conservation Plans and Natural Community Conservation Plans of the Endangered Species Act (ESA). On an international scale, the Migratory Species Agreement has led to efforts to ensure that terrestrial and aquatic space is maintained in several countries, supporting the species as it moves between locations seasonally.

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What financial and economic incentives exist for landowners to support such policies for habitat? An analytical model is provided to study economic and environmental aspects of these conservation policies that act to give the landowner a financial call and put option. This article describes the sale of a land habitat option as a game to evaluate landowners' incentives and to provide an application of Ziegler's approach of option pricing in the environmental realm. Development results in permanent, irreversible destruction of habitat, with one chance for regulations to work. Irreversibility is another characteristic that is addressed using option theory.

The basic premise of conservation banking and transferable development rights is as follows. Conservation banks allow developers to develop if habitat that is threatened and protected is mitigated by ensuring the conservation in perpetuity of a compensating amount of equivalent habitat elsewhere. A landowner may conserve more habitat or hold more credits than is required and hold this surplus to sell to others who wish to develop and need to fulfill the mitigation requirements now or in the future. This ability to store or sell the surplus over the amount required by regulations is referred to as *mitigation banking*. The price of the credits is based on supply and demand (California Resources Agency, 1999).

The banker (landowner) has an economic incentive to encourage the wildlife species (perhaps endangered) through land management that increases either the quality of habitat, the ability of land to protect endangered species, or both, because they are saleable in land habitat form. The amount of credits the banker can sell depends upon the quality and type of habitat and the number of endangered species supported by the parcel of land. The success of International Paper Company's Southlands Mitigation Bank consists of maintaining pine tree habitat for red-cockaded woodpeckers (Environmental Defense Fund, 1999). There is potential to reduce the cost of compliance with the ESA to landowners and provide a financial incentive for conservation. Conservation banking compensates landowners for providing a public good and enables a market to determine the amount of compensation.

A Transferable Development Rights (TDR) program works by designating a zone where development is restricted in exchange for the right to transfer that development to a receiving zone where development is permitted. There is a maximum level of development within the development zone and rights are distributed to landowners within the region. Landowners who keep their actual development levels below their allotted development rights level can sell their surplus development rights to other landowners or they can use them to offset development on other properties (Boyd, 1999).

The value of a TDR and banked mitigation habitat is decided by a market and allows the regulator to implement habitat goals while maximizing

benefits of development. To facilitate trading and minimize transactions costs, regulators can establish a TDR bank or exchange, which brings together willing buyers and sellers such that each can find mutual gains through trade (Tripp and Dudek, 1989). Through promoting the growth of species and habitat on land that is not zoned for development and banking the growth increase, the owner of this land may allow the release for development of land otherwise encumbered by environmental laws and effectively transfer between land with and without permission to develop. The Pinelands in New Jersey contain 1.1 million acres arranged through a TDR program in place since 1983.

This article adds a formal link of land habitat policy with financial option transactions that contributes to the existing literature. There have been a few studies that apply option theory to natural resources rather than capital assets. A seminal paper by Arrow and Fisher (1974) noting irreversibility and uncertainty in natural resource preservation has preceded more recent efforts that model stochastic processes for resource decisions. For example, Chang (2005) examines forest rotation in an analytical model, whereas Yap (2004) investigates forest management with an empirical application in the Philippines. Li (1998) examines fish harvesting in an analytical rather than empirical model. Oil has been examined by several authors, including Paddock, Siegel, and Smith (1988), who evaluated prices from a real option model for offshore oil leases; Lund and Oksendal (1991), who examined stochastic specifications for oil; Gibson and Schwartz (1990), who focused on oil contingent claims prices; and Dixit and Pindyck (1994), who analyzed oil with option theory. There have been a few papers, by Bar-Illan and Strange (1992), Capozza and Li (2002), Majd and Pindyck (1987), and Williams (1993), that focus on the time of building without addressing habitat as an aspect of land use or policy aspects. In those articles, when resource exploitation is subject to irreversibility and uncertainty, extracting the resource becomes more conservative and the level of efficiency of effort increases.

The stochastic form in most applications is Brownian motion and geometric Brownian motion to depict both the price and resource evolution over time. The assumed stochastic form governs the decision to invest by a single decision-maker. In the case of Paddock et al. (1988) such an assumption leads to highly correlated values that cannot predict actual market prices and industry bids, which appear to be twice as large in magnitude (Quigg, 1993). Perhaps the offshore oil leases of Paddock et al. (1988) can be characterized as not readily observed like land-based oil wells, and that would be the reason for assumed stochastic processes not matching market transactions. The market price provides a comparison between real option values and transaction prices that occur due to more than one decision-maker involved in the market.

For a natural resource–like habitat without a readily observed commodity value, simply assuming an underlying stochastic functional form is only an assumption. There have not been papers formally addressing any attempt to model the nonmarket values of habitat through an option approach with a generic stochastic form. It would be better to allow for the market transaction of demand and supply for habitat on land to set the price.

Hence, the game structure of analysis proves useful for modeling a market setting involving exchange between more than one land market participant. Grenadier (1996, 2005) presents a game model expanding on Williams (1993) to focus on the equilibrium nature of sequential development with developers as leaders or followers where development decisions of each participant impact all other participants. The equilibrium structure is different from traditional option pricing that assumes that an asset can be replicated by instantaneously trading because the land market has transactions costs. However, the focus is on developed land rent rather than undeveloped parcels for environmental use of land and leaves room for more research.

The context of land management with actual applications to a policy that relates to habitat and environmental resource protection has not been addressed in the literature. This article adds to the literature by applying two lines of theory in a direct way to land management for environmental protection of habitat that relates to policies. In this context, land contains a real option to develop at later dates where the exercise price is the cost of development and option maturity is infinite. While the context is set in the United States, the principles apply elsewhere too. The few studies on TDRs cover the legal aspects in a qualitative way (Machemer and Kaplowitz, 2002; Miller, 1999). Metrick and Weitzman (1998) provide a summary of the types of species saved through the Endangered Species Act based on utility.

The finance literature contains approaches to investments as options from Merton (1973) and Black and Scholes (1973). The asset pricing model of Merton (1973) does not depend on solving an optimization decision problem. Rather, for the financial assets evaluated (bonds and options rather than real assets like land), their value is defined according to an underlying stochastic process and no arbitrage condition. A second-order partial differential equation is solved where the total return on value equals the risk-free return plus a risk adjustment term that is an additional rate of return required for each unit of volatility. The no-arbitrage condition provides a framework for pricing assets and indicating how the asset and interest rate depend on the state for a state-dependent return at a terminal date. Merton (1973) uses boundary conditions for the Ito process.

Ziegler (1975) defines option pricing as a game between buyer and seller, drawing on Merton's price options results. The game theoretic aspect of

his analysis is that the players are rational and the bank anticipates that the investor will exercise an optimal strategy. While Merton (1973) relied on the stochastic process to prove the price of a call option, the present article proves the price through the sale of an option with game theory parallel to Ziegler (1975) but applied to habitat conservation of land. This game structure has an advantage of a greater simplicity, both conceptually and computationally, that does not depend on hedging and includes information on the part of each player. Referencing Aumann's theorem of information of the players helps the transaction and market clearing price (Aumann, 1976). One innovation of the current article's method relates to the interpretation of the fair price of an option as an equilibrium price for the solution to the game that describes the sale of the option in the game. The Nash equilibrium of the game is conditional on the firm's exercise strategy and other players' strategies.

## **MODEL**

First, a static problem of the landowner involved with habitat on land is presented. Then dynamics and uncertainty are added into a market specification.

### ***Deterministic Landowner's Problem***

Assume there is an area  $Z_0$  of habitat that is valuable and should be protected. The environmental regulator determines from demand for development that an amount  $\bar{Z}$  must be conserved through one of the policies described in the introduction and that the difference  $[Z_0 - \bar{Z}]$  can be sold for development. In addition, more of the initial area  $Z_0$  can be sold if an equivalent amount of currently unpreserved similar habitat is put irreversibly into preservation as part of the policies described in the introduction as mitigation banking and transferable development rights.

An index for determining the amount of acreage to be compensated between habitats is the compensation ratio. The compensation ratio contains the compensating amount of equivalent habitat for the amount of acreage used in development. The units of measure are in number of acres of restored or preserved habitat in the numerator and the number of acres affected by development in the denominator. The compensation ratio is set by the environmental regulator on the basis of ecological considerations such as similarity between sites of soil, vegetation, and species supported. Assume that the compensation ratio is constant and for simplicity equal to 1. This regulator then has the power to control use, location, and timing of land for development.

There is demand for land for development in the original area. The demand curve is  $P = f(L)$  where  $L$  is the amount supplied and  $P$  is what developers are willing to pay for an extra acre (unit of area). Clearly,  $P$  is decreasing in  $L$ . Absent any mitigation, the supply of land for development would be  $[Z_0 - \bar{Z}]$  and the market price would be  $P = f[Z_0 - \bar{Z}]$ . Habitat policy allows the supply of land for development to be increased by the amount of land available for conserving or mitigating habitat.

The cost of conservation or the TDR is the purchase of land to be set aside and banked. As more equivalent land is purchased and set aside, the cost of finding such land will rise. Assume that the cost curve of land for conservation is  $C(M)$ , where  $C$  is the cost of an extra unit and  $M$  is the amount used for conservation. So at a market price of  $P$  per unit of land, the total supply is the amount of the initial area allowed to be used for development  $[Z_0 - \bar{Z}]$  plus the amount supplied for conservation at a market price  $P$ , which is the value of  $M$  given by  $C(M) = P$ . Hence, market equilibrium with conservation when the price is such that demand and supply are equal shows

$$f(Z_0 - \bar{Z} + M) = C(M) \quad (1)$$

This means supplying  $Z_0 - \bar{Z}$  inelastically and  $C(M)$  from mitigation banking at a lower price than where the market would clear in absence of mitigation banking. The impact of the banking provision is to lower the cost of development and to increase the supply of land for development, without the target habitat falling below  $\bar{Z}$ , assuming that the land is readily available to conserve. The precise amount by which these changes occur will depend on the slope of  $C(M)$ , which in turn depends on the amount of equivalent land available, its cost, and the compensation ratio. Any value greater than 1 will increase the cost of mitigation and raise the slope of  $C(M)$ . Ecological factors will affect the equilibrium price and the amount of development that occurs, and the final equilibrium is a function of both economic and ecological aspects such as flora and fauna species.

Suppose that there is a recognized population of species  $W_0$  that must be preserved. It might be that  $W_0$  can grow on  $Z_0$  or more land, where  $W_0$  is clearly an increasing function of  $Z$ . If the population rises above  $W_0$ , then the excess over  $W_0$  entitles the landowner to release more land for development or, through TDRs, transfer to another landowner the right to use previously restricted land for development. If land is used for development on the basis of a population increase, then the higher population has to be maintained; otherwise, the landowner is not obligated to maintain the larger population. This feature is known as a Safe Harbor provision (under the Endangered Species Act) and assures the landowner that he cannot be made worse off by promoting the growth of wildlife habitat. This provision

gives an option-like structure to the landowner. A stochastic process may characterize the uncertainty of population of species in terms of its correspondence to  $Z$ . Such uncertainty may lead one to allocate more land as habitat just to guarantee enough wildlife somewhere on the land to meet policy requirements.

By allocating more land as habitat and increasing the wildlife population, the developer would have a larger bankable surplus. The banking of habitat and species becomes a vehicle for trade between two different land markets. The spontaneous increase in population of species means that some land can be released for development. There is an assumption of diminishing marginal productivity as the marginal product of habitat decreases as land increases.

The landowner will presumably support the extra population if the value of the land released for development exceeds the cost of land and resources needed to support the wildlife population increase. The amount of land needed to support a population of  $W$  is  $Z_0(W_0)$  when no additional habitat is allocated for preservation,  $W = f(Z_0, 0)$ . The amount of land released from ESA regulations when one new population unit is increased is  $Q$ . The market value of the land that can be released as a result of banking and what the banked population is worth is  $PQ$ .

There is a cost to supporting a higher population because more resources and land are needed. The minimum cost of supporting a population of  $W$  is given by the cost function

$$C(W, P) = \min_{f(Z)} [PZ] \quad (2)$$

The profit  $\pi$  that a landowner makes from the sale of land when the population rises by one unit is therefore

$$\pi = P \cdot Q - \frac{\partial C(W, P)}{\partial W} \quad (3)$$

where the second term of the right-hand side is the marginal cost of the population increase. The Safe Harbor provision provides the incentive for the landowner to support a population increase since it is the maximum of profit. The landowner does not have the incentive without the provision. The maximization with and without the Safe Harbor provision is depicted as the maximum and zero, respectively.

$$\max \pi = P \cdot Q - \frac{\partial C(W, P)}{\partial W}, 0 \quad (4)$$

The Safe Harbor provisions give the landowner a call and put option on the profits from population growth that can be uncertain in terms of the amount of  $W$  corresponding to  $Z$ . A call option on a good conveys the right but not the obligation to purchase (call) or sell (put) the good at the exercise price at any time up to the expiration date. The option has value if the market price exceeds the exercise price. An option is a contract giving its buyer the right to buy (call) or sell (put) a share of a stock (of habitat, land) on specified terms either at a fixed time of maturity or during a certain period of time in the future. An option is perpetual if there is no expiration date. Depending on the type of option (call, put, European, American, etc.), there are different boundary conditions that characterize the option and transactions associated with it.

Using the Merton (1973) approach, a stochastic process would be specified for the evolution of  $Z$  and habitat quality in terms of how much  $W$  it has. The ecological process of habitat is stochastic due to complex biological, chemical, and physical factors affecting evolution of an ecosystem (Castelle, Connelly, and Emers, 1992). The option value described above would then be specified from a second-order partial differential equation with boundary conditions for the Ito process to determine value. The mean growth rate of  $W$  in relation to  $Z$  could provide the drift term and the instantaneous standard deviation could gauge the variance for the Brownian motion form. The boundary conditions may not be precisely defined for habitat that has no formal market without the environmental policy. As Quigg (1993) and Brennan and Schwartz (1985) found, it is hard to gauge the threshold levels for entering and exiting investment (in copper or oil, as examples) or not if the expectations do not match the actual values.

Habitat is not a readily transacted commodity without an observable price. Thus, it would be difficult to peg the actual option price without accounting for the actual exchange between players in a market with derived demand for habitat from the development requirement to conserve habitat in exchange for development rights. A real-world example of a missing market for values on habitat is park fees (at state or national parks). Park fees are set arbitrarily, without the true demand or consumer surplus measures for aesthetics and recreation of nature. Empirical evidence from a wetlands mitigation bank set up in California indicates the value per acre was \$6000 and then jumped to \$7000 once there was a market for habitat credits associated with each acre (Eliot and Holderman, 1988). The suggestion below Equation (1) that the price for land set aside for habitat with the presence of a formal market would be lower than without the market may not be true if the full values of aesthetics, existence, and recreation that habitat provides are expressed in market demand.



The presence of the policies such as Transferable Development Rights or Conservation Banks creates a formal market to transact the habitat. The conclusion to draw from this section is that simply relying on a stochastic process to gauge the value of a form of capital that is not readily transacted without a market is difficult to do. Thus, the Merton (1973) approach may not lead to the right interpretation of value of habitat in the context that would help with the policies devoted to conservation. The next section focuses on the market context of habitat value in a game structure to convey both demand and supply players in the exchange.

### *Stochastic Process of Habitat and the Market for Conservation*

For modeling the habitat market created through the TDR and conservation banking policies, there is one financial intermediary, such as the conservation bank manager on the supply side; one private investor (land developer) on the demand side; one riskless asset (bond), yielding interest at rate  $r$ ; and the stock of mitigated land  $M$  supporting  $W$  whose value follows a geometric Brownian motion (GBM). GBM is justified to represent the variability of value as a function of the ecological uncertainty.

The market sale of the habitat option as a game has the specification of payoffs emphasizing expectations according to GBM with the drift equal to the interest rate. The game helps define the price of the option without hinging on hedging concepts and accounts for supply and demand of a typically nonmarket commodity: nature. Both parties have prior information about the GBM. Some private information may differ in terms of knowledge of habitat amenities that are not readily sold commodities. Perhaps more scientific information is needed (a bank manager may have available more than the investor or not) regarding the drift term of the GBM. Once the sale of the option is arranged, the agents implicitly make their posterior belief common knowledge, and hence they end up with a common value for the drift,  $\mu$ .

A conservation bank manager or landowner wants to sell a perpetual American option with an exercise price of  $E$  to a land investor (developer). The option is referred to as American because the option to sell is in the future and the option is perpetual because it has no expiration. The option is issued on a habitat asset  $Z$  whose value  $S_t$ , the price process, satisfies the stochastic differential equation

$$dS_t = \mu S_t dt + \sigma S_t dK_t; \quad S_0 = S \quad (5)$$

where  $K = (K_t)_{t \geq 0}$  is a standard Brownian motion. Note that  $S$  depends on the habitat and  $W$ ;  $S(Z, M, W)$ . Let  $r$  be the rate of interest. A pseudo price process  $X$  is also presented parallel to Merton (1973) and Black and Scholes

(1973) where an option is evaluated according to the equivalent Martingale measure, whose existence and uniqueness in a complete market is related to absence of arbitrage by the fundamental theorems of asset pricing. The geometric Brownian motion form of  $X$ , depicted in Equation (6), has a standard normal cumulative density function. Recall that a market is said to be complete with respect to time if each bounded measurable non-negative payoff function  $f_T$  can be replicated; i.e., there exists an admissible self-financing portfolio  $\Pi$  such that  $X^\Pi = f_T$ , where  $X^\Pi$  indicates the value of the portfolio  $\Pi$  at time  $T$ . So, the price process  $X$  that will help in the analysis satisfies the stochastic differential equation

$$dX_t = rX_t dt + \sigma X_t dK_t; \quad X_0 = S \quad (6)$$

Replicating an option—i.e., trading continuously the stock and the bond to guarantee for any time  $t$  the random value of the option, with probability one—has game theoretic aspects embedded in it. Which price should the conservation manager or landowner ask for the option? The possible equilibrium price  $P$  of the option depends on the initial value of the share  $S_0$ , on the number of years before expiration  $\infty$ , and on the exercise price  $E$ .

The method for option pricing in this game has three steps:

1. A game is defined with players, actions, preferences, and payoffs.
2. The Nash equilibria of the game are found and a unique one implies a financial transaction.
3. The price of this unique equilibrium is the fair price with an explicit calculation.

The set of players is  $N =$  player I, player II = conservation bank manager, land investor. The value of the option in time  $t$  is  $v(S_t, E)$  and the discounted value is  $e^{-rt}v(S_t, E)$ . An upper bound,  $H$ , is the largest value of the habitat stock. The strategies for the option holder are a put  $[0, H]$  or a call  $[H, \infty]$  and can be indexed by  $H \geq 0$ . The stopping time is defined as  $\tau_H$ , of first entry of a GBM in  $[0, H]$  for put options and the time of first entry in  $[H, \infty]$  for call options.

Initially, the conservation bank manager can choose whether or not to sell the option at price  $P$ . Price equals  $\infty$  if the option is not sold. Simultaneously, the land investor can decide a maximum price  $\bar{P}$  at which he is willing to buy the option, and he can choose a random stopping time,  $\tau_H$ . In Equations (7) and (8), the set of actions  $A_i$  available to the players is based on optimal range for both the bank manager and the investor between the

exercise price and the current value of the option

$$A_I = \{P | P \in \mathfrak{R}^+\} \cup \{\infty\} \quad (7)$$

$$A_{II} = \tau \times \{\bar{P} | \bar{P} \in \mathfrak{R}^+\} \quad (8)$$

where  $\tau$  refers to stopping times with respect to the natural GBM of habitat value.

Assume that both the conservation bank manager and the land investor are risk neutral. The interest rate  $r$  and the habitat volatility coefficient  $\sigma^2$  are common knowledge for those in the habitat market. The price of the underlying stock is  $S_0$ . At this price, both players are ready to act and are indifferent between the amount of cash  $S_0$  and any Martingale  $J$  with expected value  $S_0$  from the price process. The discounted pseudo price process is  $J_t := e^{-rt} X_t$  that they are indifferent to with  $S_0$ . The assumptions stated in this paragraph imply a relationship with Merton's (1973) logic of obtaining the value of an option. However, through the game model, the role of information and game actions affect rewards of players on the demand and supply sides. Hence, the derivation of the option value is different and the game model approaches a real market transaction of habitat.

The solutions of (5) and (6) are given by the formulas related to GBM as a tractable stochastic process

$$X_t = \exp \left\{ \left( r - \frac{1}{2} \sigma^2 \right) t + \sigma K_t \right\} S_0 \quad (9)$$

$$S_t = \exp\{(\mu - r)t\} X_t = \exp \left\{ \left( \mu - \frac{1}{2} \sigma^2 \right) t + \sigma K_t \right\} S_0 \quad (10)$$

Hence the discounted price process is

$$e^{-rt} S_t = e^{(\mu-r)t} J_t \quad (11)$$

There cannot be a consensus on a value if  $\mu \neq r$ . In fact, if both players agree on a value  $\mu > r$  for the drift, then the conservation bank manager would not sell the stock, and if  $\mu < r$  the land investor would not buy.

The two players could have different opinions about the drift term since the conservation bank manager has more experience than the land investor with habitat and wildlife influencing  $S$ . The drift term  $\mu$  is viewed as a random variable whose distribution may be perceived differently by the two players before the sale. By offering the stock for sale, the bank reveals common knowledge that its posterior estimate of the drift  $\mu$  is less than or equal to  $r$ . On the other hand, by showing an interest in purchasing

the stock, the land investor reveals common knowledge that its posterior estimate is greater or equal to  $r$ .

Aumann's (1976) theorem states that if the prior is the same, and the posteriors are common knowledge, then the posteriors must coincide. Thus, the conservation bank manager and the land investor will end up with a common opinion on the drift  $\mu$ , and necessarily the value agreed upon for  $\mu$  must equal  $r$ .

The expected utility payoffs  $p_i$  that represent them: for every pair a,b of profiles of actions are  $p_i(a) \geq p_i(b)$ . Since the transaction is being carried out in a formal market for habitat, this leads the players to assess the value of the drift  $\mu$  as  $r$ , and hence the take into account what is noted at the pseudo price process  $X$ . Therefore,  $\mu$  becomes  $r$ , and  $S$  can be identified with  $X$ .

In view of the previous steps, the players' preferences can be represented according to the theory of Von Neumann Morgenstern expectations of the utility functions

$$u_I : (P, (\tau_H, \bar{P})) \rightarrow P - e^{-r\tau_H} v(X_{\tau_H}, E) \tag{12}$$

$$u_{II} : (P, (\tau_H, \bar{P})) \rightarrow e^{-r\tau_H} v(X_{\tau_H}, E) - P \tag{13}$$

if  $P \leq \bar{P}$ ; i.e., in case a transaction is carried out, and  $u_I = u_{II} = 0$  otherwise. The maximization of the value of an option in this game that gives an arbitrage-free value of the payoff to the player can be considered a proxy for expected utility. And, over the expected utility approach, the option pricing approach has the advantage that it automatically takes into account the time value of money and the price of risk (Ziegler, 1975). Observe that  $\tau_H$  is a first entrance time for the process  $X$ . In fact, player I (conservation bank manager) receives  $P$  and will pay at the random strike time  $\tau_H$  the amount  $v(X_{\tau_H}, E)$ . What player I receives, player II (land investor) pays, and vice versa.

From these considerations, the payoffs of the players are clearly equal to zero if there is no habitat market transaction and are

$$p_I(P, (\tau_H, \bar{P})) := \mathbf{E}[P - e^{-r\tau_H} v(X_{\tau_H}, E)] \tag{14}$$

$$p_{II}(P, (\tau_H, \bar{P})) := \mathbf{E}[e^{-r\tau_H} v(X_{\tau_H}, E) - P] \tag{15}$$

in case of a habitat market transaction.

The second step of determining the habitat option price is solving for the Nash equilibria that will show how the fair price of an option is an equilibrium price of the game described above for both players to optimize in the habitat market transaction.

PROPOSITION 1: *The fair price of a perpetual American option with strike price  $E$  is*

$$P^* = \sup_{H \in \mathfrak{R}_+} \mathbf{E}[\exp\{-r\tau_H\}v(X_{\tau_H}, E)], \quad (16)$$

where  $\tau_H$  is the first entrance time of the pseudo price process  $X$  in  $[0, H]$ , for a put, or in  $[H, \infty]$ , for a call, and  $\mathbf{E}$  is the expectation operator.

The price  $P^*$  is an equilibrium price for the game described above, as follows:

*If there exists an optimal exercise policy, namely, if there exists  $H^*$  such that*

$$P^* = \mathbf{E}[\exp\{-r\tau_{H^*}\}v(X_{\tau_{H^*}}, E)]$$

then

$$(P^*, (\tau_{H^*}, P^*)) \quad (17)$$

*is a Nash equilibrium. If there exists no optimal exercise policy, then for every  $\varepsilon > 0$  there exists  $H_\varepsilon$  such that*

$$(P^* - \varepsilon, (\tau_{H_\varepsilon}, P^* - \varepsilon)) \quad (18)$$

*is an  $\varepsilon$ -equilibrium, where  $H_\varepsilon$  is such that*

$$\mathbf{E}[\exp\{-r\tau_{H_\varepsilon}\}v(X_{\tau_{H_\varepsilon}}, E)] \geq P^* - \varepsilon$$

PROOF: *In order to prove that Equation (17) is a Nash equilibrium, Player I gets zero with the strategy, and also if he raises the price, since the transaction would be cancelled. He gets less than zero if he lowers the price, and hence he has no unilateral deviations. Player II gets zero with the strategy, and also if he lowers the bid, since the transaction would be cancelled. Obviously, he has no interest in bidding more. Once the purchase is carried out, he has no interest in not exercising optimally.*

Suppose now that the supremum in (16) is not achieved. Similar arguments yield that Equation (17) is an  $\varepsilon$ -equilibrium. In fact, let  $H_\varepsilon$  be such that exercising at  $\tau_{H_\varepsilon}$  yields an expected discounted value of the option greater or equal to  $P^* - \varepsilon$  (for simplicity, assume it gives exactly  $P^* - \varepsilon$ ). The strategy in Equation (17) yields zero to both players, and no player has an interest in deviating unilaterally from the stated price. Furthermore, once player II has acquired the option, the exercise strategy indicated is  $\varepsilon$ -optimal, and no strategy can guarantee to increase his payoff by more than  $\varepsilon$ .

The proposition and the proof are a formal representation of the market interaction for habitat where supply and demand sides transact. The proof corresponds to that case of a price that is reasonable for both sides trying to optimize, given the information they have about the habitat. The formal presentation enables the price to reflect supply and demand rather than a park fee price arbitrarily set without any tie to true supply and demand for the natural resources in the park such as habitat.

The third step of determining the habitat option price is computation of equilibrium prices of the game for the market exchange of habitat. The option price follows the definition of fair price,  $\mathbf{E}[e^{-r\tau_H} v(X_{\tau_H}; E)]|_{H=H^*}$ , that will be agreeable according to the optimization by both players.

For a perpetual American put option  $v(X_t, E) = \max\{0, E - X_t\}$  and  $\tau_H = \inf\{t \geq 0 : X_t \leq H\}$ ,  $H^*$  exists and it is finite where the demand side believes the price of the underlying habitat will not decrease and has the right to sell the asset at the strike price.

Consider  $H \in [0, E]$  because a put is never exercised if  $X_t > E$  and recall that  $X_0 = S_0$ . If  $S_0 \leq H$  then  $\tau_H = 0$  and  $G^* = E - S_0$ , where  $G^*$  is the price of the put option on habitat. For that reason, consider  $S_0 > H$ . According to Proposition 1,  $(G^*, (\tau_{H^*}, G^*))$  with  $G^* = \mathbf{E}[e^{-r\tau_H} \max\{0, E - X_{\tau_H}\}]|_{H=H^*}$  is a Nash equilibrium. Then

$$\begin{aligned} \mathbf{E}[e^{-r\tau_H} \max\{0, E - X_{\tau_H}\}] &= \mathbf{E}[e^{-r\tau_H} \max\{0, E - X_{\tau_H}\}(\mathbf{1}_{(\tau_H < +\infty)} \\ &+ \mathbf{1}_{(\tau_H = +\infty)})] = \mathbf{E}[e^{-r\tau_H} \max\{0, E - X_{\tau_H}\} \mathbf{1}_{(\tau_H < +\infty)}] = (E - H)\mathbf{E}[e^{-r\tau_H}] \end{aligned} \tag{19}$$

because if  $\tau_H$  is finite,  $X_{\tau_H} = H$  and  $H \leq E$ , so  $(E - H) \geq 0$ . The previous paragraph and Equation (19) are based on both players optimizing while gauging habitat value with the actions they are taking. For the developer, the derived demand for habitat is from his demand for development and the corresponding amount of habitat he needs to meet the TDR or conservation bank policy requirements. The conservation bank supplier is expected to anticipate that the developer will exercise when it is optimal for development plans and the amount of habitat he needs as a result. The put and call options simply provide context of a financial agreement (contract) between demand and supply sides in the habitat market.

Making use of the Laplace transform formula for the times of first exit from an open set for a Brownian motion leads to

$$(E - H)\mathbf{E}[e^{-r\tau_H}] = (E - H) \left(\frac{H}{S_0}\right)^{\frac{2r}{\sigma^2}} \tag{20}$$

Equation (20) indicates that the optimal exercise strategy for the developer is one that maximizes the difference between the strike price and the current value of the underlying habitat asset.

$H^*$  is the maximum of this expression indicating an upper bound threshold for investing in habitat with GBM structure:

$$H^* = \frac{2r}{\sigma^2 + 2r} E \tag{21}$$

so that the equilibrium price of the habitat option is  $E - S_0$  if  $S_0 \leq H$  and

$$\frac{\sigma^2}{\sigma^2 + 2r} E \left( \frac{2r}{\sigma^2 + 2r} \frac{E}{S} \right)^{\frac{2r}{\sigma^2}} \tag{22}$$

if  $S_0 > H$ . Instead of asserting this form through boundary conditions that may not be defined for habitat that is not readily transacted outside of the habitat policy framework, Equations (21) and (22) draw on the position of each player and their optimal strategies in a market transaction based on development and bank objectives and information. The equilibrium is where supply and demand clear the market in a manner of call and put options as the format for involving more than one party in the market exchange of the habitat asset. Therefore, while it is similar in form to Merton (1973), it is not derived through smooth pasting and value-matching assertions without the market interaction.

For a perpetual American call option on habitat  $v(X_t, E) = \max\{0, X_t - E\}$  and  $\tau_H = \inf\{t \geq 0 : X_t \geq H\}$ ,  $H^*$  does not exist since the developer wants the price of the underlying asset to rise in the future and  $\mathbf{E}[\exp\{-r\tau_H\}v(X_{\tau_H}, E)]$  is increasing in  $H$  ( $H^* = +\infty$ ). Consider  $H \in [E, +\infty]$  because a call is never exercised if  $X_t < E$  because that implies that profit is maximized and the landowner could hold onto the habitat option and retain the option to make a gain up to the exercise price. The following equations relate market exchanges to call and put options in the habitat market where the underlying asset transacted at any time is influenced by supply and demand for habitat as a derived demand to meet habitat requirements for development plans. According to Proposition 1, for every  $\varepsilon > 0$  there exists  $H_\varepsilon$  such that

$$(F^* - \varepsilon, (\tau_{H_\varepsilon}, F^* - \varepsilon)) \tag{23}$$

is an  $\varepsilon$ -equilibrium where  $F^*$  is the price of call option on habitat expressed as follows

$$F^* = \lim_{H \rightarrow \infty} \mathbf{E}[\exp\{-r\tau_H\}v(X_{\tau_H}, E)] \tag{24}$$

and the value  $H_\varepsilon$  is such that

$$\mathbf{E}[\exp\{-r\tau_{H_\varepsilon}\}v(X_{\tau_{H_\varepsilon}}, E)] \geq F^* - \varepsilon \quad (25)$$

We have

$$\begin{aligned} \mathbf{E}[e^{-r\tau_H} \max\{0, X_{\tau_H} - E\}] &= \mathbf{E}[e^{-r\tau_H} \max\{0, X_{\tau_H} - E\}] \\ &\cdot \mathbf{1}_{(\tau_H < +\infty)} = (H - E)\mathbf{E}[e^{-r\tau_H}] \end{aligned} \quad (26)$$

The previous equations characterize how the transaction would take place, in terms of the difference between the strike price and underlying habitat asset value as a call option relates to the buyer wanting the price of the underlying asset to rise and a put option where the price may fall, based on variation in supply and demand for habitat. The Laplace transform formula for the times of first exit from an open set for a Brownian motion helps characterize the put option for the transaction with the following:

$$(H - E)\mathbf{E}[e^{-r\tau_H}] = S_0 \left(1 - \frac{E}{H}\right) \rightarrow_{H \rightarrow +\infty} S_0 \quad (27)$$

where the asset price is expressed with the relationship between discounted and current value. Thus,  $\forall \varepsilon > 0$ , we can find  $H_\varepsilon$  such that

$$(S_0 - \varepsilon, (\tau_{H_\varepsilon}, S_0 - \varepsilon)) \quad (28)$$

is an  $\varepsilon$ -equilibrium of the game. According to Proposition 1, the value  $H_\varepsilon$  must be such that  $\mathbf{E}[\exp\{-r\tau_H\}v(X_{\tau_H}, E)] \geq P^* - \varepsilon$ . In this case  $H_\varepsilon$  must be such that

$$S_0 \left(1 - \frac{E}{H_\varepsilon}\right) \geq S_0 - \varepsilon \quad (29)$$

and hence  $H_\varepsilon = \frac{S_0 E}{\varepsilon}$ .

The price of a call option on habitat  $F^* = S_0$  has been proven here through game theory utilizing demand and supply side interaction and the role of information for an asset does not usually have an observable price in the absence of the market created by the habitat policies. The market context can offer a direct way of viewing how the price would be derived rather than the assumptions that would have to be made through the option pricing method of Merton (1973) for assets that have observable prices.



## **CONCLUSIONS**

The habitat regulatory policies for land appear capable of attaining conservation goals and providing compensation for the removal of land from the development market. Such policies can reduce the impact of habitat conservation on market prices while still maintaining the amount of land targeted by conservationists.

The analytics show a release of land for development while preserving the initial habitat intact can provide an incentive for a landowner to invest in increasing the wildlife population. This incentive is particularly strong in the case in which the opportunity cost to the landowner of allocating land to wildlife is below the market price of land zoned for development. Conservation banking and TDRs effectively allow the landowner to arbitrage between these markets and provides the landowner with an economic opportunity that is otherwise completely absent. Finding an endangered species on his land may in this case be in the landowner's interest. If none of his land is zoned for development, then he can nevertheless earn some of the premium from development by others with derived demand for habitat to meet development requirements of the policies.

The option value conveyed by the Safe Harbor provisions introduced under the ESA allows a landowner to support and bank an increased population only if advantageous to do so. Thus, the landowner has a free call option on the increased population, as another advantage of conservation banking. The TDR, together with conservation banking, acts to redistribute gains away from owners of land that can be developed and whose development is restricted by the ESA or other habitat policy toward owners of land not so zoned. The recipient landowners who support and bank the habitat for wildlife can sell credits to others for their development potential in a formal habitat market. The interpretation of the fair price of a habitat option as an equilibrium price is the solution to the game that describes the sale of the option in the habitat market.

There is an important irreversibility associated with releasing land for development, as developed land cannot be restored or reverted to its original habitat, and in particular to a condition where it can support endangered species. The seminar article by Arrow and Fisher (1974) with a qualitative discussion of irreversibility and uncertainty in natural resource preservation still applies. Policy-makers therefore need to ensure that conserved acreage for habitat is committed in perpetuity if land is developed in exchange through TDR and conservation banking.

Without such policies, there has not been a formal market for habitat and therefore it is not a transacted commodity with an observable price. Therefore, it is difficult to observe a trend of prices to base financial forecasting of a stochastic process. Hence, the framework for financial assets (stocks,

bonds, and options) with their value defined according to an underlying stochastic process and no arbitrage condition may be difficult to apply to habitat where boundary conditions for the Ito process as Merton (1973) outlines are hard to pin down without a price trend.

The presence of the policies such Transferable Development Rights or a Conservation Bank creates a formal market to transact the habitat between players in a market with derived demand for habitat from the development requirement to conserve habitat in exchange for development rights. The game option pricing method directly represents market exchange between supply and demand sides, enabling some additional interpretations beyond other option pricing methods. Whatever asymmetric information exists between the conservation banker/landowner and land investor, the game setup helps derive the habitat option price.

Ziegler (1975) defines option pricing as a game between buyer and seller, drawing on Merton's price options results. The game theoretic aspect of Ziegler's analysis is that the players are rational and the bank anticipates that the investor will exercise an optimal strategy. Whereas Merton (1973) relied on the stochastic process to prove the price of a call option, the present article proves the price through the sale of an option with game theory parallel to Ziegler (1975) but applied to habitat conservation of land. The game theoretic aspect of his analysis is that the players are rational and the bank anticipates that the investor will exercise an optimal strategy. This game structure has an advantage of a greater simplicity, both conceptually and computationally, that does not depend on hedging and includes information on the part of each player. Referencing Aumann's (1976) theorem of information of the players helps the transaction and market clearing price. One innovation of this article's method relates to the interpretation of the fair price of an option as an equilibrium price for the solution to the game that describes the sale of the option in the game.

## REFERENCES

- Arrow, K., and Fisher, A. (1974) Environmental preservation, uncertainty, and irreversibility. *Quarterly Journal of Economics*, 88, 312–319.
- Aumann, R. (1976) Agreeing to disagree. *Annals of Statistics*, 4, 1236–1239.
- Bar-Illan, A., and Strange, W. (1992) Investment lags. Working Paper, Tel-Aviv University and University of British Columbia.
- Black, F., and Scholes, M. (1973) The pricing of options and corporate liabilities. *Journal of Political Economy*, 81, 637–659.
- Boyd, J. (1999) The law and economics of habitat conservation: Lessons from an analysis of easement acquisitions. Discussion Paper 99-32, Washington, DC: Resources for the Future.

- Brennan, M., and Schwartz, E. (1985) Evaluating Natural Resource Investments. *Journal of Business*, 58(2), 135–157.
- Capozza, D., and Li, Y. (2002) Optimal land development decisions. *Journal of Urban Economics*, 51(1), 123–142.
- Castelle, A., Connelly, C., and Emers, M. (1992) Wetland mitigation replacement ratios. Olympia, WA: Washington State Department of Ecology.
- Chang, F. (2005) On elasticities of harvesting rules. *Journal of Economic Dynamics and Control*, 29(3), 469–485.
- California Resources Agency, (2002) Private land programs and incentives. Available at: <http://www.dfg.ca.gov/habitats/archive/private.html> (accessed June 2006).
- Dixit, A., and Pindyck, R. (1994) *Investment under uncertainty*. Princeton, NJ: Princeton University Press.
- Eliot, W., and Holderman, R. (1988) Pickleweed or parking lot? *California Coast and Ocean*, 4(1), 5–9.
- Environmental Defense Fund. (1999) Mitigation banking as an endangered species conservation tool, appendix 1: Case studies of selected endangered species. Available at: <http://www.environmentaldefense.org/documents/146mb%2EPDF> (accessed June 2006).
- Gibson, R., and Schwartz, E. (1990) Stochastic convenience yield and the pricing of oil contingent claims. *Journal of Finance*, 45, 959–976.
- Grenadier, S. (1996) The strategic exercises of options: Development cascades and overbuilding in real estate markets. *Journal of Finance*, 51(4), 1653–1679.
- Grenadier, S. (2005) An equilibrium analysis of real estate leases. *Journal of Business*, 78(4), 1173–1213.
- Lawton, J., and May, R. (1995) *Extinction rates*. Oxford, U.K.: University Press.
- Li, E. (1998) Option value of harvesting: Theory and evidence. *Marine Resource Economics*, 13(2), 135–142.
- Lund, D., and Oksendal, B. (1991) *Stochastic models and option values: Applications to resources, environment and investment problems, contributions to economic analysis*. North Holland, Amsterdam.
- Machemer, P., and Kaplowitz, M. (2002) A framework for evaluating transferable development programs. *Journal of Environmental Planning and Management*, 45(5), 773–795.
- Majd, S., and Pindyck, R. (1987) Time to build, option value and investment decisions. *Journal of Financial Economics*, 18, 7–27.
- Merton, R. (1973) Theory of rational option pricing. *Bell Journal of Economics*, 4(1), 141–183.
- Metrick, A., and Weitzman, M. (1998) Conflicts and choices in biodiversity preservation. *Journal of Economic Perspectives*, 12(3), 21–34.
- Miller, A. (1999) Transferable development rights in the constitutional landscape: Has Penn Central failed to weather the storm? *Natural Resources Journal*, 39(3), 459–516.
- Paddock, J., Siegel, D., and Smith, J. (1988) Option valuation of claims on real assets: The case of offshore petroleum leases. *Quarterly Journal of Economics*, 103, 479–508.
- Pimm, S., Russell, G., Gittleman, J., and Brooks, T. (1995) The future of biodiversity. *Science*, 269, 347–350.

- Quigg, L. (1993) Empirical testing of real option-pricing models. *Journal of Finance*, 48, 621–639.
- Tripp, J., and Dudek, D. (1989) Institutional guidelines for developing transferable rights programs. *Yale Journal on Regulation*, 369, 372–373.
- Wilcove, P., Rothstein, D., Dubov, J., Phillips, A., and Losos, E. (1998) Quantifying threats to imperiled species in U.S. *Bioscience*, 48, 607–615.
- Williams, E. (1993) Investment, capital and finance: Corporate and entrepreneurial theories of the firm. In *Can the free market pick winners? What determines investment*, ed. P. Davidson. Armonk, New York.
- Yap, R. (2004) Option valuation of Philippine forest plantation leases. *Environment and Development Economics*, 9(3), 315–333.
- Ziegler, A. (1999) *A game theory analysis of options, contributions to the theory of financial intermediation in continuous time*. Berlin: Springer Verlag.

### **BIOGRAPHICAL SKETCH**

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