An auction mechanism for optimal conservation under asymmetric information[1]

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Main finding: This paper derives an optimal solution to the provision of habitat conservation on private land overcoming the asymmetric information problems when landowners have private information about opportunity cost and environmental benefits, through an *N*+1 price auction with a participation fee. The proposed mechanism gives incentives for landowners to truthfully reveal their break even bid price, incorporating information about opportunity cost and habitat quality. It extends prior results on truth-telling in uniform price auctions when landowners have private information about costs and public benefits of the item at auction.

Abstract: In this paper we address the design of a mechanism to provide conservation through voluntary agreements with private landowners who have better information about both the opportunity cost of conservation and the conservation value of their land. We describe an auction mechanism that induces landowners to reveal information about habitat quality and opportunity cost. The auction mechanism is an *N*+1 price auction in which the conservation contract price for the *N* winning bids is set by the lowest non-winning bid. Landowners with winning bid must pay a fee for a biological survey that verifies whether or not the land contains high quality habitat. Only lands with high quality habitat are enrolled in the conservation program and paid the conservation contract price. We show that this auction mechanism can attain an optimal solution even though landowners have private information about both opportunity cost and conservation value.

Key words: Biodiversity, conservation, habitat protection, asymmetric information, auctions, truth-telling.

JEL codes: D440, Q570, Q230, L140

1. Introduction

Conserving biodiversity generates a range of public goods, but its successful accomplishment often depends on actions of private landowners. For example, a landowner may decide to harvest timber that generates a financial return for the landowner but results in habitat destruction that negatively affects the provision of public goods. The loss of habitat can lead to population declines and increased probability of extinction for species, with potential loss of existence value, recreation value (e.g., birdwatching), or contribution to ecological functions associated with the provision of ecosystem services. Most species depend at least in part on habitat that occurs on private land and private land makes up the majority of habitat for many species (Brown and Shogren 1998, Innes *et al.* 1998). Private landowners typically have better information about the opportunity cost of conservation on private land. In addition, private landowners may also have better information about habitat value because of their close contact with and knowledge of the land. The question that we address in this paper is the design of a mechanism to provide an optimal conservation solution through voluntary agreements with private landowners who have better information about both the opportunity cost and the conservation value of their land.

Initiatives for conserving biodiversity on private land include both mandatory regulatory approaches that restrict what private landowners can legally do as well as voluntary approaches involving payments to landowners who enroll in conservation programs or who agree to sell land or conservation easements. In the U.S., the Endangered Species Act (ESA) prohibits landowners from otherwise legal actions if such actions would result in harm to endangered species. Under the ESA, compensation is not required to be paid to landowners for the cost of restrictions on land use. The lack of compensation sets up an adversarial relationship between landowners and conservation organizations that sometimes gives landowners an incentive to take actions detrimental to conservation (e.g., Mann and Plummer 1995, Polasky and Doremus 1998). Lueck and Michael (2005) document evidence of landowner decisions to shorten the rotation time for timber harvest in North Carolina to prevent habitation by the red-cockaded woodpecker, an endangered species that nests in mature forest stands.

Voluntary approaches can overcome the type of perverse incentive problems that can occur with mandatory regulatory approaches, but they must also be designed carefully to overcome their own set of incentive problems. When landowners have better information about opportunity cost or habitat value, it is desirable to design voluntary programs so that landowners truthfully reveal their information. Without truthful revelation, a conservation agency may enroll land in a conservation program that has higher opportunity cost or lower habitat value than is optimal. The conservation agency may also end up spending resources to uncover information that is already known by landowners. In addition, payments must be sufficiently high to induce participation by landowners, but excess payments unnecessarily raise program costs.

In this paper we develop a conservation auction with several desirable incentive properties. A key feature of our model is asymmetric information between private landowners and a conservation agency. Each landowner is assumed to have better, but not necessarily perfect, information about habitat quality on her own land as compared to the information of the conservation agency. In addition, each landowner has better information about the opportunity cost of conservation of her land. The conservation agency can gain information about habitat quality of a particular site by undertaking a survey, but doing so entails some cost. The conservation agency would like to target surveys for lands that are likely to contain high quality habitat and have low opportunity cost. We use a Vickrey style auction in which the N winning bids are paid a contract price equal to the *N*+1st bid. This auction gives landowners an incentive to truthfully reveal information about cost. A novel feature of our auction specification mechanism is that it requires landowners to pay a fee to cover the costs of a biological survey in the case of winning bids where the conservation agency chooses to survey her land. By sequentially surveying starting from the lowest bids, the conservation agency can reduce survey costs and enroll high quality, low opportunity cost lands. By only enrolling land that the survey shows has high quality habitat, there is an incentive to landowners with signals of low quality habitat to increase their bid in order to compensate them for the risk that they will have to pay for a survey but not be rewarded with a conservation contract. We show that this type of auction will get landowners to truthfully reveal their information about both habitat quality and opportunity cost. Further, we show that this auction mechanism will achieve an optimal outcome under certain conditions. The main necessary condition for this auction mechanism to achieve an optimal result is that it is efficient for the conservation agency to do a biological survey of a site prior to choosing to whether to enroll the site in the conservation program. This condition will hold when the value of information about habitat quality exceeds the cost of the survey.

In the next section, we present a brief overview of the literature on habitat conservation programs and auctions. The third section presents a conservation auction model. We analyze the equilibrium strategy of landowners in section 4. Section 5 analyzes an auction design that can achieve a socially optimal result under certain conditions. The paper ends with a discussion on implications for policy design and future research.

2. Habitat conservation and auction schemes

2.1 Habitat conservation schemes

Habitat loss and fragmentation is widely thought to be the primary cause of biodiversity decline (e.g., Wilcove *et al.* 1998, Wilson 1992). The primary response to the rapid loss of natural habitat has been focused on establishing formal protected areas in parks and biological reserves. There is a large literature in conservation biology on systematic conservation planning that analyzes the question of what areas are best to protect to provide habitat for conserving biodiversity (Margules and Pressey 2000). Though this literature implicitly recognizes resource constraints, typically by limiting the amount of area included in the biological reserve network, much of it ignores considerations of cost. Several papers have combined biological information on species ranges and habitat needs with economic information on opportunity cost of reserve designation to find cost-effective conservation strategies (e.g., Ando *et al.* 1998; see Naidoo *et al.* 2006 for a summary). More recent work has expanded the combined ecological-economic analysis to include biological objectives and economic returns for a range of land uses including agricultural production, forestry, housing development and nature reserves (e.g., Polasky *et al.* 2005, 2008), and a range of ecosystem services in addition to conserving biodiversity (e.g., Naidoo and Ricketts 2006, Nelson *et al.* 2008).

For the most part the literature on systematic conservation planning assumes that a planner has complete information and the objective is to find the optimal conservation strategy. But trying to secure conservation on private land where such conservation generates public benefits but private costs to landowners, and where landowners have private information about either benefits or costs, requires moving beyond the systematic conservation planning literature to an explicit consideration of incentives. For conservation on private land, the central issue is the design of mechanisms for voluntary agreements that maximize the net benefits of conservation given asymmetric information. A number of papers have analyzed the problem of providing incentives to private landowners to enhance the provision of environmental benefits from agricultural land (e.g., Wu and Babcock 1995, 1996, Feng 2007) or conservation (e.g., Polasky and Doremus 1998, Smith and Shogren 2002). Here we explore the use of an auction mechanism to achieve conservation on private land.

2.2 Auctions and their use in biodiversity conservation

Achieving voluntary provision of public benefits on private lands typically involves some form of payments for ecosystem services (PES). PES schemes often involve setting a fixed contract price and enrolling landowners willing to accept that price in exchange for managing land in a manner compatible with the provision of a public good. Fixed contract price mechanisms do not tend to work as well as auction mechanisms when the conservation agency has limited information about landowners' willingness to accept (Latacz-Lohmann and Van der Hamsvoort 1997, Cason and Gangadharan 2004, Schillizzi and Latacz-Lohmann 2007). Auctions can be designed to help the agency discover information about willingness to accept. Auctions for conservation or other environmental benefits have been implemented in the Australian Bush Tender Scheme (Stoneham *et al.* 2003) and the U.S. Conservation Reserve Program.

In a conservation auction, each landowner bids an amount they would accept in exchange for enrolling in the conservation program. Most conservation auction schemes use discriminatory pricing, i.e., each bidder is paid according to her posted bid. One difficulty with discriminatory price auctions is that bidders have an incentive to bid strategically (Vickrey 1961). In the context of a conservation auction, a landowner may inflate her bid above her true willingness to accept in order to gain a higher contract price. This problem with discriminatory price auctions led Vickrey to propose a second price auction scheme (Vickrey 1961). In the context of a conservation auction, a second price auction gives a conservation contract to the lowest bidder but pays that bidder a price equal to the second lowest bid. By removing the link between the bid and the payment, the second price auction mechanisms makes bidding the willingness to accept a dominant strategy. In other words, second price auctions give incentives for truthful revelation of bidder values ("truth telling").

For biodiversity conservation, it will typically be the case that the conservation agency wishes to auction multiple contracts rather than a single contract (Latacz-Lohmann and Van der Hamsvoort 1997). The Vickrey auction for multiple contracts entails paying the same price to all bidders who are awarded the contract. This contract price is determined by the first non-accepted bid. This auction mechanism is called a *uniform price auction* or *N*+1 *price auction* (Milgrom 2004). Figure 1 provides an illustration of how the *N*+1 price auction works in the context of a conservation auction where the five lowest bids are awarded a contract at a price equal to the sixth lowest bid.

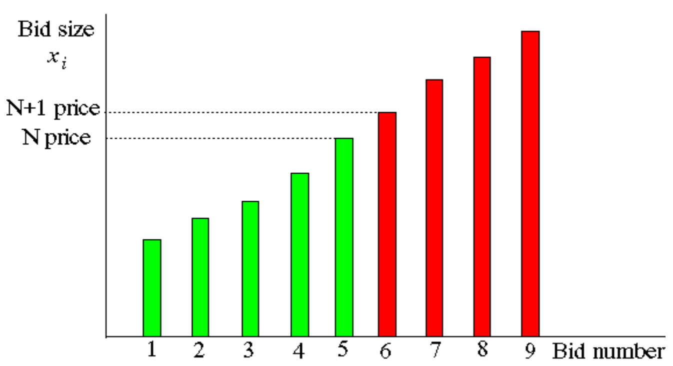

Figure 1: An N+1 price conservation auction with five contracts.

The revenue equivalence theorem states that the expected cost to the conservation agency should be the same under both discriminatory price and uniform (*N*+1) price auctions. The revenue equivalence theorem assumes that certain conditions, such as risk neutral bidders, which may not hold in practice. Evidence from experiment finds that contract payments tend to be lower on average with discriminatory price auctions than with uniform price auctions (McKee and Berrens 2001, Cason and Gangadharan 2005). Bidders in discriminatory price auctions do not inflate their bids above willingness to accept as much as the theory suggests they should in order to maximize expected returns. The performance of discriminatory price auctions appears to diminish as bidders gain more information and act more strategically. When bidders are given information about the environmental benefits of their land, bidders with high benefit sites that are desirable to enroll in the conservation program raise their bids above willingness to accept by more than when they are not given such information (Cason *et al.* 2003). There is an extensive literature on the (relative) performance of various auction formats (see Lusk *et al.* 2004, Rosseau and Moon 2007, and Ferraro 2008 for useful summaries).

2.3 Our approach in comparison with existing work

Here we use a uniform (*N*+1) price auction because of the desirable incentive properties because it gives incentives to accurately reveal bidder information. Cason and Gangadharan (2005) find that under the uniform price auction that bids are within 2% of costs, while bids are more than 8% above costs in the discriminatory price auction. Even though evidence suggests that the uniform price auction may result in higher program costs than a discriminatory price, the performance of the two types of auctions on this dimension may be closer than in a typical auction because we assume that landowners are informed about environmental quality of their land in our model. Further, higher than necessary payments to landowners are transfers not pure inefficiency. Of greater concern for efficiency is enrolling the right set of landowners in the program, which are those with high environmental benefits relative to costs.

A key issue in our model in which landowners have better but not perfect information about habitat quality is to accurately reflect landowner information about habitat quality, as well as opportunity cost, in the bidding. The conservation agency would like to target sites likely to have high quality habitat. Doing so prevents wasting resources on biological surveys for sites that ultimately will be rejected from inclusion in the conservation program. In order to give proper incentives to reveal information about habitat quality, we propose that that landowner for each winning bid has to pay a fee to cover the cost of a biological survey. The proposed fee and biological survey has two beneficial effects. First, doing a biological survey gives the conservation agency the best possible information about habitat quality and reduces the number of errors of either enrolling low quality habitat land or missing the chance to enroll high quality habitat land. Second, surveying sites sequentially starting from the lowest bid reduces the expected number of sites surveyed, and hence the expected cost of surveying, compared mechanisms without incentives to truthfully reveal information about habitat quality. The next section formally describes the auction mechanism.

3. The conservation auction model

Each site i, $i = 1, 2, \ldots, M$, is owned by a single landowner and each landowner owns one site. Each site is either a high quality site containing habitat for a species of interest, $b_i = b^h$, or a low quality site that does not, $b_i = b^l$. Each site may be either developed, which generates a private return to the landowner but destroys habitat, or conserved, which maintains habitat but generates no returns to the landowner.

The landowner of site *i* is assumed to have better information than the conservation agency about the quality of habitat in site *i* for the species. One example of a species where landowners probably have better information about the quality of habitat than regulators is the forest grouse (*Tetrao urogallus*), whose mating grounds are frequently known by locals but not by outside experts or government officials. In the first stage of the model, we assume that the landowner of site *i* receives a signal about the quality of habitat of site *i*, q_i^h or q_i^l. Let the probability that the site has high quality given a high quality signal be α_i^h : $\alpha_i^h = \Pr(b_i = b^h \mid q_i^h)$. Let the probability that the site has high quality given a low quality signal be α_i^l : $\alpha_i^l = \Pr(b_i = b^h \mid q_i^l)$. Let the conservation agency's probability that the site is of high quality be α_i^R. Consistent with the landowner having better information, we assume that:

$$\alpha_i^h = \Pr(b_i = b^h \mid q_i^h) > \alpha_i^R > \Pr(b_i = b^h \mid q_i^l) = \alpha_i^l. \qquad (1)$$

The conservation agency provides incentives for habitat conservation by providing payments to landowners that agree to conserve their land. Voluntary provision of habitat is achieved through means of an *N*+1 price auction (described above). After receiving a signal about habitat quality for their site, each landowner simultaneously chooses whether or not to enter a bid in the auction, and the amount of the bid (x_i) if a bid is entered. If a landowner does not enter a bid they do not participate in the auction. For those landowners participating in the auction, we order the bids $\{x_1, x_2, \ldots, x_m\}$ with the lowest bid labeled as site 1, the next lowest as site 2, and so on up to site *m*, where *m* is the number of landowners that bid, $m \leq M$.

Before deciding which landowners should be offered a conservation contract, the conservation agency can undertake a biological survey of a site at a cost φ. The survey generates a signal that the site is high quality, s_i^h, or low quality, s_i^l. For simplicity, we assume that the survey generates full information about site quality:

$$\Pr(b_i = b^h \mid s_i^h) = 1, \Pr(b_i = b^h \mid s_i^l) = 0) . \qquad (2)$$

The model can also be analyzed with improved but still imperfect information after the biological survey without substantive change to the results.

After the bids are made, the conservation agency sequentially surveys sites in ascending order of bids starting from site 1. If the conservation agency decides to survey site *i*, the landowner of site *i* is required to pay a fee, φ. Landowners who do not bid or who bid but whose sites are not surveyed do not pay the fee. If the survey reveals that the site has high quality habitat, the conservation agency offers a payment of *y* to a landowner if the landowner will conserve the site. If the survey reveals low quality habitat then no payment is offered. The survey and offer process continues until the conservation agency exhausts the conservation budget or achieves a point at which the expected cost of continued surveying and contracting exceeds the expected benefit. The contract payment amount *y* is set equal to the lowest bid on a site for which the conservation agency does not survey as in the *N*+1 price auction.

In the final stage of the model, the landowner of site *i* chooses whether to conserve or develop the site. Conserving the site maintains the habitat value of the site, which is a public good only a portion of whose value is realized by the landowner. Developing the site generates a market return for the landowner. The net cost to the landowner of maintaining habitat and foregoing development is $c_i > 0$. We assume that c_i is known by the landowner, but not known by the conservation agency. Figure 2 summarizes the timing of the moves, strategies and payoffs to the landowner in the auction model.

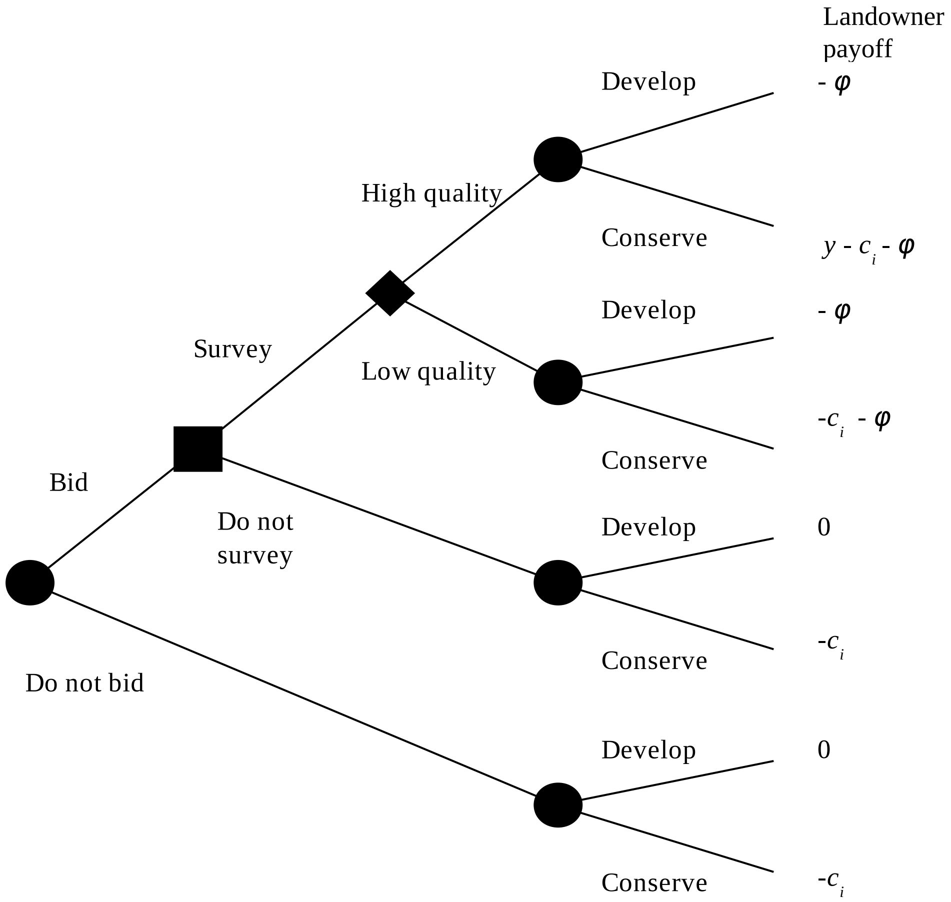

Figure 2: The decision tree summarizing the order of moves and landowner payoffs. A circle indicates landowner choice, a square indicates conservation agency choice, and a diamond indicates the outcome is due to chance. The initial move of nature that generates a high or low signal to the landowner is not shown.

We report payoffs to the landowner as being the difference between the realized outcome and the status quo with no conservation policy where the landowner chooses to develop the property. Therefore, a landowner who does not bid earns a payoff of 0 with development, and $-c_i$ with conservation. Similarly, a landowner that bids but owns a site where the conservation agency does not choose to survey also earns a payoff of 0 with development, and $-c_i$ with conservation. If the landowner bids and the conservation agency surveys and reveals low quality habitat, then the landowner earns a payoff of $-\varphi$ with development, and $-\varphi - c_i$ with conservation. If the landowner bids and the conservation agency surveys and reveals high quality habitat, then the landowner earns a payoff of $-\varphi$ with development and $y - c_i - \varphi$ with conservation.

At the time that the landowner chooses whether or not to bid, the landowner does not know the amount the conservation agency will pay for a conservation contract. Let landowner *i*'s expectation of the payment upon being awarded a conservation contract, contingent on $y \geq c_i$, be $\hat{y}_i$. Note that if $y < c_i$ the landowner would find it advantageous to reject the conservation payment and develop the property. Also, the landowner doesn't know whether the conservation agency will choose to survey the site or not. Let $\beta_i(x_i)$ be the probability that the conservation agency will choose to survey site *i* given bid x_i. Higher bids make it less likely that the property will be surveyed, $\beta_i'(x_i) \leq 0$. The expected payoff for a landowner who has received signal q_i^j ($j = h$ or l), and who bids x_i is:

$$\beta_i(x_i)[\alpha_i^j(\hat{y}_i - c_i) - \varphi]. \tag{3}$$

We assume that each landowner is risk neutral.

4. Equilibrium strategy for landowners

Because landowners have better information about the quality of habitat and their own opportunity cost of foregoing development, the auction mechanism is designed to give landowners an incentive to bid based on their information about habitat quality and cost. Landowners have an incentive to reveal information about habitat quality and cost because high cost and high likelihood of low quality habitat make bidding less profitable for the landowner. Incentives to reveal information about habitat quality are further enhanced by introducing a fee, φ, that the landowner must pay if the conservation agency decides to survey the site. The existence of the fee discourages landowners who have a signal of low quality from entering a low bid. Landowners who have a signal of low quality who enter a bid and have their land surveyed have to pay the fee but are unlikely to get a payment to preserve habitat.

For the landowner, the optimal choice of whether to conserve or not is straightforward once the choices of whether to bid and to survey are made, and survey results (if there is a survey) are determined. The landowner will choose to conserve when a survey has revealed high quality and the contract price is sufficiently high to induce the landowner to accept it, $y \geq c_i$, otherwise the landowner will choose to develop.

For the landowner to choose to submit a bid and participate in the auction, the expected benefits of bidding must be higher than from not bidding ("the participation constraint"). Note that the expected benefits of submitting a bid must be non-negative because the landowner can earn a payoff of 0 by not bidding and choosing to develop. Therefore, a landowner who has observed signal q_i^j will submit a bid if and only if:

$$\beta_i(x_i)[\alpha_i^j(\hat{y}_i - c_i) - \varphi] \geq 0 . \tag{4}$$

Since $\beta_i(x_i) \geq 0$, a landowner will submit a bid if and only if:

$$\alpha_i^j(\hat{y}_i - c_i) - \varphi \geq 0 ,$$

$$\hat{y}_i \geq \frac{\varphi}{\alpha_i^j} + c_i . \tag{5}$$

Define the break even contract price as

$$\bar{y}_i \equiv \frac{\varphi}{\alpha_i^j} + c_i . \tag{6}$$

The landowner should bid as long as $\hat{y}_i \geq \bar{y}_i$.

Note that the bid of landowner i, x_i, does not affect any term inside the brackets in equation (4), which represents the expected payoff to the landowner if a survey occurs. The only thing that x_i affects is the probability of a survey occurring, $\beta_i(x_i)$. As long as term inside the brackets in equation (4) remains non-negative, the landowner would like to choose as low a bid as possible in order to increase the chance that a survey will occur ($\beta_i'(x_i) \leq 0$). In an N+1 price auction, we know that $y \geq x_i$ for any landowner being surveyed. Therefore, as long as $x_i \geq \bar{y}_i$, the landowner will be guaranteed non-negative returns, $y \geq \bar{y}_i$. If the landowner lowers the bid below $\bar{y}_i$ there is a risk that the conservation agency will choose to survey and set a contract price so low that the expected payoff becomes negative. We use these facts to show that having each landowner will set their bid equal to their break even price, $x_i = \bar{y}_i$, in equilibrium given that certain conditions specified below are met.

Consider landowner i with break even contract price $\bar{y}_i$. Label x_{N+1} as the lowest bid for which the conservation agency does not survey. In the N+1 price auction, the contract price will be $y = x_{N+1}$. First suppose that $\bar{y}_i < x_{N+1}$. Any bid $x_i \leq x_{N+1}$ triggers the conservation agency to survey and offer a contract price of $y = x_{N+1}$ if the survey reveals high quality habitat, which gives the landowner a positive expected payoff since $x_{N+1} > \bar{y}_i$. In a standard N+1 price auction, any bid $x_i > x_{N+1}$ would mean that the landowner not be offered a contract and would earn a payoff of 0. Here, however, there is some chance that by bidding higher than x_{N+1} the final contract price will go higher than x_{N+1} and landowner i can still be offered a contract at the higher price. Setting $x_i > x_{N+1}$ means that x_{N+1} is now the N^{th} highest bid and would be surveyed. If site N+1 turns out to have low quality, which occurs with probability $(1-\alpha_{N+1}^{j})$, then additional sites will be surveyed and the eventual contract price could end up higher. Suppose that by choosing $x_i = x_i^z > x_{N+1}$ the contract price becomes $x_{N+z} > x_{N+1}$ and that the probability that site i would still be surveyed is $\beta_i(x_i^z)$. In order for landowner i to find it profitable to bid $x_i \leq x_{N+1}$ rather than x_i^z it must be the case that:

$$\alpha_i^j (x_{N+1} - c_i) - \varphi \geq \beta_i(x_i^z)[\alpha_i^j (x_{N+z} - c_i) - \varphi] \tag{7}$$

Equation (7) will hold when the probability of being surveyed at the higher bid, $\beta_i(x_i^z)$, is low enough to offset any potential increase in returns from the increase in contract price. As long as equation (7) is satisfied for all $x_i^z > x_{N+1}$, bidding $x_i = \bar{y}_i$, is an equilibrium strategy for landowner i when $\bar{y}_i < x_{N+1}$.

Next, suppose that $\bar{y}_i \geq x_{N+1}$. By setting $x_i = \bar{y}_i \geq x_{N+1}$, landowner i would receive a payoff of 0. If, however, landowner i sets $x_i < x_{N+1}$ then landowner i would expect to earn $\alpha_i^j (x_{N+1} - c_i) - \varphi \leq 0$, because $\bar{y}_i \geq x_{N+1}$. Bidding $x_i = \bar{y}_i$, is an equilibrium strategy for landowner i when $\bar{y}_i \geq x_{N+1}$.

We summarize this discussion in the following proposition.

Proposition 1: The equilibrium strategy for landowner i, i = 1, 2, …, N, is to bid $x_i = \bar{y}_i \equiv \frac{\varphi}{\alpha_i^j} + c_i$, the break even bid price, as long as equation (7) is satisfied for all bids $x_i^z > x_{N+1}$ when $\bar{y}_i < x_{N+1}$.

Proposition 1 states that landowners will truthfully reveal information about their break even bid, which contains their information about habitat quality (α_i^j) and opportunity cost of conservation (c_i), in the N+1 price auction with the survey fee φ. The break even bid price $\bar{y}_i \equiv \frac{\varphi}{\alpha_i^j} + c_i$, is composed of two components. The first component, $\frac{\varphi}{\alpha_i^j}$, reflects the cost of surveying site *i* adjusted by the probability of finding high quality habitat in the survey. This term reflects the expected survey cost associated with getting a high quality site for conservation. The second term, c_i, reflects the opportunity cost of conservation from foregoing development. The landowner's bid, therefore, reflects both the private information about cost as well as the private signal about habitat quality.

5. Social optimum

We assume a benevolent conservation agency whose objective is to maximize social welfare. Let *B* represent the social value of habitat conservation on high quality habitat sites. Assume there is no habitat conservation value for conserving low quality habitat sites. Let *j* be the number of sites that are surveyed and *K* be the set of sites that are conserved. Then, the measure of social welfare relative to a status quo of no surveying and conservation is:

$$W = \sum_{i \in K} (\alpha_i B - c_i) - j\mu \tag{8}$$

where α_i is the probability that site *i* contains high quality habitat (which may be equal to 1 if a survey has been done and shown the site to have high quality). The first term in equation (8) represents the expected net benefits of conservation and the second term represents the cost of surveying.

With complete information, the optimal solution would be to choose to conserve all sites for which $B \geq c_i$, and not do any surveying. With only imperfect signals of habitat quality, however, not surveying will lead to mistakes either by conserving sites with low quality habitat or not conserving sites with relatively low opportunity costs and high quality habitat. When the probability that site *i* contains high quality habitat is α_i, conserving site *i* without surveying gives expected social welfare benefits of $\alpha_i B - c_i$. With a survey of site *i*, and conservation only if the survey reveals high quality habitat, the expected social welfare benefits are $\alpha_i (B - c_i) - \mu$. Note that by surveying, one can avoid the opportunity cost of conserving land when there is low habitat quality, which is equal to (1-α_i)c_i.

Suppose the conservation agency had the best available *ex ante* information for site *i*, which is contained in the signal of habitat quality to landowner *i*. In this case, it will be optimal to survey site *i*, with the choice of conservation if high quality habitat is revealed and the choice of development if low quality habitat is revealed, if and only if the following two conditions hold:

$$\begin{aligned} &\alpha_i^j (B - c_i) - \mu \geq 0 \\ &\Rightarrow B \geq \frac{\mu}{\alpha_i^j} + c_i \end{aligned} \tag{9}$$

and

$$\begin{aligned} &\alpha_i^j (B - c_i) - \mu \geq \alpha_i^j B - c_i \\ &\Rightarrow (1 - \alpha_i^j) c_i \geq \mu. \end{aligned} \tag{10}$$

Equations (9) and (10) show when the expected social welfare with a survey and an informed decision on whether or not to conserve exceed social welfare with no survey and a decision to develop (equation 9) or conserve (equation 10). Equation (9) will be satisfied when the benefits of conservation exceed the costs of surveying (including surveying sites that do not have high quality habitat) plus the opportunity cost of foregone development. Equation (10) will be satisfied when the benefits of informed choice, which avoids paying the opportunity cost of conservation for sites with low quality habitat, exceed the costs of surveying.

Assuming that equation (10) holds, i.e., that the value of information from a survey exceeds the cost of the survey, then the conservation agency can implement the optimal solution through the N+1 price auction by setting the conservation contract payment equal to the social benefits of habitat conservation, $y = B$, and the fee charged to landowners equal to the cost of a survey, $\varphi = \mu$. By doing so, the landowner will bid

$$x_i = \bar{y}_i \equiv \frac{\varphi}{\alpha_i^j} + c_i = \frac{\mu}{\alpha_i^j} + c_i \ . \tag{11}$$

The conservation agency should then survey all sites whose bids satisfy $x_i \leq y = B$ and offer contracts to those sites where high quality habitat is found. Landowners receiving a conservation contract with price $y \geq x_i$ will accept the contract and choose to conserve. This outcome yields the optimal solution. We summarize this discussion in Proposition 2.

Proposition 2: An optimal solution can be implemented under asymmetric information where landowners have better information about habitat quality and opportunity cost of conservation through the use of an N+1 price auction assuming that both equation (7), which ensures truth-telling by landowners, and equation (10), which ensures that surveying potential conservation sites is efficient, are satisfied.

An N+1 price auction induces landowners to reveal information both about habitat quality and opportunity cost. The N+1 price auction with a fee allocates contracts to the least cost providers, where cost is made up of both opportunity cost of foregoing development and information costs associated with surveys (including survey costs for low quality habitat not selected for conservation). By setting the contract price equal to the public benefits of conservation and the auction fee equal to survey costs the conservation agency generates an optimal solution in the N+1 price auction.

6. Discussion

In this paper we have shown that an optimal solution to the provision of habitat conservation on private land can be obtained, overcoming problems introduced by asymmetric information even when landowners have private information about both opportunity cost and environmental benefits, through the use of an *N*+1 price auction with a participation fee (when a survey occurs). An *N*+1 price auction with a fee to pay for biological surveys gives incentives for landowners to bid their break even bid price, which incorporates information about both opportunity cost and information about habitat quality. This result extends prior results on truth-telling through uniform price auctions to cases where sellers have private information about both cost and public benefit of the item at auction. Though we have cast the discussion in terms of conserving biodiversity, the model is general and will apply to any cases of pollution regulation in which firms have better information about the toxicity of their emissions or other cases where private agents are likely to be better informed than regulators.

Our optimality results for the *N*+1 price auction with the fee required two conditions to hold. The first condition is that no landowner would find it advantageous to try to manipulate the contract price by raising her bid. Such manipulation is not possible in a standard uniform price auction. It is theoretically possible in our auction mechanism because some sites can be surveyed and rejected. If by changing the ordering of bids more sites end up being surveyed and rejected, then the *N*+1 price can end up being higher. Though theoretically possible, in practice it is extremely unlikely that any landowner would find it profitable to try to do this type of manipulation, as it requires moving the bid only beyond sites that will fail the survey, which is something that is difficult to predict ahead of time.

The second condition that must hold is that it is optimal to survey sites rather than just offer conservation contracts to landowners who have signals of high quality without verifying that the habitat really is high quality. This condition will hold when a survey is fairly cheap to do or where the survey offers a significantly improved signal of habitat quality compared to what the landowner knows and the costs of incorrectly enrolling a site are high. When landowner information about benefits is very good or a survey is quite expensive this condition may not hold. Then it would be optimal to just have landowners with a signal of high quality enroll in the program. However, unless there is some type of penalty for enrolling in the program and turning out to have low quality, too many landowners will enroll and the conservation program will be stuck paying for land that does not deliver conservation benefits. In this case, there will be some unavoidable verification costs required to make it unprofitable for landowners with low quality habitat to claim to have high quality habitat. The existence of such costs is a standard result in the literature on adverse selection.

There are likely to be additional political economy advantages of type of auction mechanism we propose beyond the efficiency results demonstrated here. First, the program is relatively simple and easy to administer. The auction mechanism proposed here only differs from a standard uniform price auction in that it includes a survey fee for those landowners whose land is chosen to be surveyed. The non-discriminatory aspect of the auction mechanism, where all landowners who end up with contracts end up receiving the same contract, is likely to be viewed as "fair" by participants. Such uniform price auctions are less likely to give rise to concerns over horizontal equity than are auctions with price discrimination. It is also the case that having the lowest cost (of such quality) habitats enrolled in the program will mean that enrolled landowners have less incentive to cheat on the contract than the average landowner, thereby reducing the need to strictly monitor and enforce compliance.

One aspect of the auction mechanism that could generate opposition from landowners is the requirement that a landowner pays for a survey of her land even when the survey shows that the site does not contain suitable habitat. In this case, a landowner will pay a cost but will not receive any of the benefits of enrolling in the conservation program. This aspect of the program may give rise to pressures on surveyors to "find" high quality habitat even where none exists. Careful auditing of biological survey results may be necessary. Further, if landowners are risk averse, the potential for loss might keep some landowners from bidding even though they would have positive expected value from entering a bid in the auction. Having the possibility of paying without getting program rewards, however, is necessary to dissuade landowners who are less likely to have high quality lands from entering winning bids.

The N+1 price auction gives some rents to landowners. In the case where there is some cost to the use of public funds, the existence of excess payments to landowners will generate an inefficient result. A well known result in mechanism design is that Pareto optimality is not possible under asymmetric information with both incentive compatibility and rent extraction concerns (Campbell 1987). A discriminatory price auction gives landowners an incentive to inflate their bid rather that truthfully revealing their information, and will therefore also give landowners some rents. Discriminatory price auctions have been shown to generate lower rents to landowners in experiments (e.g., Cason and Gangadharan 2005). Hence, if rent extraction is a major concern then there is some grounds for preferring a discriminatory price auction over uniform price auctions. The cost advantage of discriminatory price auctions, however, may decline when landowners become more experienced in auctions or where they have good information about environmental benefits (Cason *et al.* 2003). Landowners who perceive that they are low cost or high quality providers may therefore seek to increase their compensation by bidding more. The relative performance of discriminatory and uniform price auctions hinges on what are the most important policy objectives to achieve, to reduce rents to landowners (and thereby public expenditures) or to provide incentives for truthful revelation of information.

Conservation outcomes are typically a function of the spatial pattern of habitat across a landscape. An important complication that we did not consider in this paper is to the importance of coordinating conservation planning across many landowners. For example, having a landowner enroll an isolated parcel in a conservation program may not contribute much to species conservation. The same amount (and quality) of habitat may contribute far more to species conservation when it is added to neighboring habitat. Trying to coordinate across multiple landowners with private information to get an optimal pattern of conservation is a difficult, and as yet, unsolved problem. Nelson *et al.* (2008) show that voluntary payments programs that pay a uniform rate generate far fewer environmental benefits for a given size budget than does the optimal (full information) solution, both because the "wrong landowners" are enrolled and because of the inability to price discriminate. Empirical studies and simulations show that using biological information to target incentives can improve performance (e.g., Connor *et al.* 2008, Lewis *et al.* 2008). A series of papers, have investigated improving conservation solutions by making payments to an individual landowner a function of the responses of neighboring landowners (Drechsler *et al.* 2007, Lewis and Plantinga 2007, Lewis *et al.* 2008, Parkhurst *et al.* 2002, Parkhurst and Shogren 2007, 2008, Warziniack, Shogren, and Parkhurst 2007). This literature shows that it is possible to coordinate landowner decisions by making payoffs contingent on neighbors' decisions. A topic for future research is whether the auction mechanism developed here can be usefully extended to situations where coordination across landowners is needed, and whether this type of auction mechanism or other mechanisms can generate an optimal or near-optimal solution.

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