Asymmetric Information and Contract Design for Payments for Environmental Services

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1. Introduction

In conservation programs that use payments for environmental services (PES), landowners are encouraged to use more environmentally beneficial practices in return for payments. PES programs generally have two common features. First, they are voluntary. Second, participation involves a contract between the conservation agent and the landowner. The landowner agrees to manage an ecosystem according to agreed-upon rules and receives a payment (in-kind or cash) conditional on compliance with the contract. In this paper, the word "landowner" denotes any entity that is in the position (de jure or de facto) to supply environmental services through its influence on an ecosystem (e.g., an individual, community, or firm). "Conservation agent" denotes any entity that wishes to encourage landowners to supply environmental services (e.g., a government agency, nongovernmental organization (NGO), private citizen, or firm).

PES contractual relationships are subject to asymmetric information between landowners and conservation agents. Information asymmetries can limit the effectiveness of PES schemes and make them expensive to implement. There is a well developed literature in "contract theory" that can provide abundant insights into the design of PES contracts (see, for example, Bolton and Dewatripont (2005) and references therein). In this paper, I highlight some of these insights.

There are two important information asymmetries in the design of contracts: hidden information and hidden action. Hidden information (adverse selection) arises when negotiating the contract. Landowners have better information than the conservation agent about the opportunity costs of supplying environmental services. Landowners can thus secure higher payments by claiming their costs are higher than they are. In other words, landowners attempt to extract informational rents from the conservation agent in the form of a higher than necessary payment to induce them to participate in the PES program.

Just as a monopolist gains rents from control of scarce resources, individuals with private information can also gain rents by using their private information as a form of market power. They may attempt to extract such rents by simply claiming to have higher opportunity costs, or by threatening to develop the land or actually beginning some development to make it look as if the land has high value. Hidden information has been the subject of almost a dozen theoretical analyses in the context of agri-environmental payment schemes, which have much in common with PES schemes (Spulber, 1988; Chambers 1992; Bourgeon et al. 1995; Wu and Babcock

1996; Fraser 1995, 1996; Latacz-Lohmann and Van der Hamsvoort 1997; Moxey et al. 1999; Ozanne et al. 2001).

Why should we care about these informational rents? Payments for environmental services are often funded by taxes, which involve inefficiencies (deadweight losses from the market distortions associated with taxation). Thus society benefits if the payments compensate the landowners' opportunity costs of contract compliance, but no more than these costs. When private agents are making the payments (e.g., firms interested in CO_2 sequestration or NGOs interested in biodiversity protection), they are likely to be budget-constrained and thus also wish to limit their expenditures per unit benefit obtained. Moreover, environmental services are generally public goods subject to free riding. Thus the available funds for PES contracts are generally inadequate to achieve the socially optimal level of these services. Maximizing the environmental services secured with available budgets is socially desirable.[1]

In contrast to hidden information, hidden action (moral hazard) arises after a contract has been negotiated. The conservation agent may find monitoring contract compliance costly and thus will be unwilling to verify compliance with certainty. Thus the landowner has an incentive to avoid fulfilling his or her contractual responsibilities. Once again the landowner attempts to extract informational rents from the conservation agent. In this case, the rents arise from payments for actions never taken. Noncompliance can also have a corrosive effect on the entire system of contracts if landowners are conditional cooperators and aware of the noncompliance of other landowners (see related literature on tax compliance). Hidden action in the context of agri-environmental payment schemes has also been the subject of theoretical analyses (Latacz-Lohmann (1998), Choe and Fraser (1998, 1999), Ozanne *et al.* (2001), and Fraser (2002), and Hart and Latacz-Lohman 2004).[2]

Hidden information is a problem in all PES contract settings. Hidden action is only a problem to the degree that the actions specified by the contract are costly to monitor. For contracts that simply specify payments based on forest cover or species abundance (as revealed

[1] I am therefore ignoring the case in which the PES program is an instrument for income redistribution as well as an instrument to supply environmental amenities. As we will see, however, reducing landowner informational rents is possible, but eliminating them for all landowners is not. Thus there will be income gains to landowners even in the best circumstances, but it may be that the conservation agent has a desire to share more of the available surplus with the landowners (in formal terms, this is akin to assuming that the participation constraint in a model of asymmetric information is not binding).

[2] Hogan (2002), White (2002) and Ozanne and White (2003) model the two types of information asymmetry simultaneously.

by satellite photos or biological surveys), hidden action may be a minor problem. In more complicated management contracts that require substantial investments by the landowner (e.g., tree planting and management), hidden action is likely to be a much more important problem.

In this paper, I focus on hidden information for three reasons: (1) spaces constraints prevent me from covering both topics in depth; (2) I believe that addressing hidden information is more important to achieving efficient outcomes in PES initiatives as they are currently designed; and (3) academics and practitioners are typically less familiar with methods available for addressing hidden information.

2. Hidden Information

To make clear what we mean by hidden information, consider a simple example. A conservation agent is interested in contracting with landowners for habitat quality, *h*, which can be represented by numbers ranging from 0 (completely converted) to 100 (pristine). There are two types of landowners: those with high-opportunity costs (H) and those with low-opportunity costs (L). A type H landowner has the cost function $2h^2$ and a type L landowner has the cost function $2h$. These cost functions are illustrated in Figure 1.

Assume that the conservation agent wishes to contract with a landowner to keep the landowner's habitat pristine, $h = 100$. Participation is voluntary and thus payments must at least cover the landowner's opportunity costs (in the theoretical jargon, the "participation constraints" are satisfied). In a perfect information world, the agent would offer \$200 if the landowner were type L and \$20,000 if the landowner were type H. However, if the conservation agent could not determine if a landowner is H or L, all landowners would claim they were type H in order to receive a larger payment.

As long as there is substantial heterogeneity in opportunity costs of supplying environmental services, hidden information will be a problem. For example, Shoemaker (1999) shows that the U.S Conservation Reserve Program, which pays farmers to set aside land for conservation, increased the average value of eligible land, which could only happen if landowners were receiving windfall gains as a result of their private information about opportunity costs. In an analysis of German agri-environmental payment program with fixed-price payments, Osterburg (1999) found that participation rates were highest in regions with poorer soils and lower land-use intensity (i.e., areas where environmental gains from contracts were small because land use intensity was reduced from a low level). In 1999, the state of California agreed to pay a timber company $480 million to protect 7500 acres of redwoods in the Headwater Forest (plus 50-year logging restrictions on another 8000 acres). Many conservationists, however, were outraged at the result of the bargaining. They pointed out that Pacific Lumber recently paid only $810 million for 211,000 acres of Headwater Forest and all of the capital equipment, which included a sawmill (The Economist, 1999).

Policy mechanisms for reducing informational rents can be broadly classified into three categories: (1) gathering more information on landowners in the form of costly-to-fake signals; (2) relying on screening contracts (self-selection mechanisms); or (3) harnessing competitive forces through procurement auctions. The basic idea of the latter two approaches is to design the contracting system to induce landowners to reveal their hidden information. A mechanism by which the landowner maximises his utility when he reports truthfully his type is called a revelation mechanism.

3. Gathering Information from Costly-to-Fake Signals.

The simplest, and coarsest, approach to addressing the hidden information of landowners is to gather information on observable landowner attributes that are correlated with opportunity costs and use these attributes to establish contract prices. With this information one can create eligibility requirements for receiving a given contract type and price. This approach is common in U.S. agri-environmental schemes where fixed contract prices often differ geographically to reflect regional differences in opportunity costs. Soil type, distance to roads and markets, and forest type are other examples of attributes that are often correlated with opportunity costs and, importantly, are impossible or costly for landowners to fake.

Regional and local intermediaries with better information about field conditions can facilitate the designation and collection of information on these attributes. If the gains to contracting are substantial, high-cost landowners may find other costly-to-fake signals to reveal their cost information (e.g., hiring a forester to certify the value of their timber). More sophisticated methods for categorizing cost types include using economic models of agricultural returns based on observable characteristics (i.e., each landowner receives a predicted opportunity cost from the model). Note, however, that collecting information about landowner characteristics is costly and the ability of this information to reduce information rents without distorting the conservation outcome will only be as good as the strength of the correlations between the characteristics and landowner types.

4. Screening Contracts.

An alternative approach to gathering information on landowner characteristics is to induce landowners to reveal their type by offering a contract for each of the different "types" of landowners believed to exist. The contracts are designed in a way that assures each type will pick the contract that is meant for that type.[3]

Consider the numerical example from above with type H and type L landowners. The essential insight of models of hidden information is that two types of contracts should be offered: a high-output contract for type L landowners and low-output for type H landowners. In addition to the requirement of designing payments to at least cover all landowners costs (i.e., "participation constraints" are satisfied), the contract design puts restrictions on the payments so that landowners pick the contract intended for their type (in the jargon, the "incentive compatibility constraints" are satisfied). Contracts are designed so that a landowner could never be better off choosing the contract intended for the other type.

If the conservation agent could not determine if a landowner is type H or type L, all landowners have an incentive to claim they are type H. The agent can instead offer two contracts that satisfy the landowners' participation constraints and incentive-compatibility constraints: (1) \$382 for $h = 100$; and (2) \$201 for $h = 10$.[4] A type H landowner prefers contract (2) and a type L landowner prefers contract (1). Thus their contract choices reveal their types.

Note that although landowners reveal their types, this revelation comes at a cost compared to the situation in which the conservation agent knows each landowner's type with certainty (in the jargon, it is a "second-best" rather than a "first-best" outcome). To encourage type L landowners to reveal their type, the conservation agent must compensate them at a level

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[3] In theory, screening contracts can induce information revelation in multiple dimensions (e.g., costs and biophysical attributes of ecosystem to be contracted). I am assuming, however, that the conservation agent has better information about the environmental attributes of a landowner's parcel and that the relevant hidden information is the reservation price of the landowner.

[4] These contracts are merely examples of two contracts that induce all landowners to sign a contract and choose the one appropriate for their type. To solve for a second-best set of contracts requires more information.

above their opportunity costs. This overcompensation is a rent from the private information held by the low-cost landowner. Through the use of screening contracts, the conservation agent has reduced the informational rents paid to the low-cost landowners, but has not eliminated them.

Moreover, reducing the informational rent comes at a cost of fewer environmental services supplied compared to the perfect information case. The low-cost landowner still supplies the same amount of habitat quality as in the perfect information context (in jargon, the "no-distortion-at-the-top rule" holds), but in order to reduce the attractiveness of low-cost landowners claiming to be high-cost, the contracts aimed at high-cost landowners require a lower level of habitat quality. This distortion in the contracted output of environmental services (and the informational rent paid to the low-cost landowners) grows with the difference in costs between the low-cost and high-cost landowners and the proportion of landowners who are low-cost. Under certain parameterizations, the best a conservation agent can do is offer a single contract aimed only at the low-cost landowner. Adding more landowner types does not change the basic result: inefficiently low supply of environmental services (except for the lowest-cost landowner) and positive informational rents (except for highest-cost landowner).

Thus the screening contracts are designed to reduce the costs of hidden information, but they cannot eliminate these costs. The basic idea is that the gain to the high-cost landowner must be reduced in order to reduce the incentive of the low-cost landowner to claim to be high-cost. The high-cost agent obtains little surplus (in the limit, zero), while the low-cost agent obtains surplus equal to the informational rent.

In addition to the standard attributes of screening contracts described above, PES contracts may require an additional constraint to ensure efficiency. In a theoretical model, Motte et al. (2002) show that informational rents obtained by low-cost landowners can relax the landowners' budget constraints and induce more cultivation, thereby lowering environmental benefits from PES contracts. In their model of payments for forested lands, Motte et al. suggest designing contracts with a "consistency constraint." This constraint requires landowners to set aside within the contract at least as much forested land as they would have without the contract.

Assuming a conservation agent could actually specify this consistency constraint in a contract (one must identify the counterfactual of future deforestation under no contract), it could ensure that ecosystem pressure is not displaced to other lands under the landowners' control. Unfortunately, the constraint leads to the undesirable outcome of paying some landowners to protect the exact same area that they would have protected in the absence of a contract (another form of informational rents). The greater the range of farmer types, the more likely there will be payments being made to landowners for not changing their behavior (along with the traditional informational rents associated with hidden information).[5]

Despite the appeal of screening contracts, their design is not straightforward in the field. Designing a menu of contracts that satisfy the participation constraints and the incentive compatibility constraints and maximize the conservation agent's objective function requires knowledge about the distribution of landowner types and sophisticated calculations by conservation practitioners. The administration of a large menu of contracts may also be expensive and unwieldy.

While there are many proposed incentive-compatible contract designs in the literature that might be adapted by practitioners to PES schemes, the ability of conservation practitioners to do so is questionable. Moreover, all such mechanisms depend on hyper-rational game-theoretic play by landowners who see the incentives hidden in the mechanisms. In experimental economic settings with North American college students, studies find that many do not understand the incentives in simple public good games (Ferraro and Vossler 2005), much less in environmental games with incentive-compatible mechanisms for achieving environmental goals (Spraggon; Oxby and Spraggon).[6] Despite much theoretical work on incentive-compatible contracts in the context of agri-environmental programs, I know of none offered by an existing agri-environmental payment scheme.

In the next section, I consider an alternative mechanism through which the conservation agent can reduce landowners' informational rents <u>and</u> move the allocation of contracts closer to the first-best outcome: procurement auctions for PES contracts.

5. Procurement Auctions for PES Contracts.

a. Why Use Them?

Procurement of goods and services for which there are no well-established markets is commonly performed using auctions. Procurement auctions are popular because competitive

[5] However, in a dynamic model with irreversible ecosystem change, such contracts may have additional value by preserving the option to contract on the land in the future

[6] In Oxby and Spraggon, individual play consistent with theory was only achieved through explicitly telling subjects what the payoff-maximizing strategy is through text and a payoff table. In a PES program, it is doubtful that landowners would believe the conservation agent is telling the truth about the optimal strategy.

bidding reduces seller's informational rents with smaller trade distortions, and because auctions use transparent rules that limit the influence of favoritism and political ties. Auctions use bidding rules and market competition to reduce the incentive for sellers to inflate their reservation prices for accepting a conservation contract (these reservation prices are a function of the alternative uses of the land, and landowner risk and time preferences).

Auctions as cost-revelation mechanisms are attractive because they do not require the conservation agent to specify the distribution of landowner types; landowners reveal this distribution. Moreover, if contracts are periodically purchased or renewed, auctions have the advantage of instantly revealing to the conservation agent any changes in the distribution. With more commonly used posted, take-it-or-leave-it prices in conservation initiatives, such changes can only be inferred indirectly by excess supply (e.g., U.S. Conservation Reserve Enhancement Program) or an excess demand for contracts (Costa Rica's ecosystem service payment program).

As with PES screening contracts, PES auctions will not eliminate the informational rents to landowners. They merely reduce these rents. However, in contrast to screening contracts, auctions reduce these rents with fewer distortions to the supply of environmental services, and they may be much easier for conservation practitioners to apply in the field. Whereas I could find no information about the application of screening contracts to conservation contracting, several well-known auctions for conservation contracts have been implemented.

The best-known conservation auction is that of the Conservation Reserve Program (CRP), which pays farmers to take land out of production in order to achieve agri-environmental objectives. Landowners make offers to receive payments in return for a contractual obligation to retire their land for a fixed period of time and, in many cases, to make environment-enhancing investments. The auctions from 1986 to 1990 were a standard procurement auction in which offers were tendered (sealed bid by mail) and ranked from lowest to highest price, and then contracts were signed until an acreage objective was achieved. More recent CRP auctions still solicit offers from landowners for contracts, but the contracts are ranked through an index that includes both costs and measures of environmental benefits.

In 2000, the Georgia legislature (United States) passed the Flint River Drought Protection Act, which mandates the state in drought years to pay farmers to suspend irrigation. The Director of the Environmental Protection Division (EPD) is required to announce if the upcoming summer will be characterized by severe drought and, if so, to determine the number of acres that must be taken out irrigation to maintain acceptable river flows. The Director then must use an "auction-like process" through which farmers submit offers to suspend irrigation of all lands covered by a specific water-use permit for the remainder of the calendar year.[7]

For reasons explained below, auction theory does not provide clear recommendations for the design of PES auctions. Thus, faculty at Georgia State University (Cummings et al. 2004) did what generally must be done for PES auction design: they used laboratory and field experiments as "test-beds" to determine which auction rules have more desirable properties on bidder behavior in the given context. In 2001, the Director of the EPD declared a severe drought and implemented an auction. At 8 sites around the state of Georgia, 194 farmers assembled to make offers for 347 permits (ranging from 4 to 1442 acres). They submitted their offers on paper to auction monitors (Georgia State University faculty and students, and EPD employees) and who then inputted the prices into a computer and sent them via the internet to a centralized site at which all offer prices could be compared and contracts accepted.

Note that farmers in Georgia have no ability to sell their irrigation rights to other landowners (the permit to use irrigation water could, however, be sold with the property). Thus, as will often be the case for suppliers of environmental services, farmers could not look to a competitive market to infer the value of giving up their irrigation activities for a year. Instead, they had to calculate the opportunity cost of not irrigating their fields for a year, which is the net benefits of foregone crop production that would result from forgoing irrigation for that year.

In Australia, auctions have been proposed to solicit voluntary landowner participation to achieve salinity control, nutrient control and biodiversity conservation (Stoneham et al.). A pilot auction, called Bush Tender, was conducted for biodiversity conservation contracts. A field ecologist visited landowners chosen to participate in the pilot. The ecologist assessed the quality of the native vegetation on the site and discussed management options with the landholder. This conversation ultimately lead to a management plan on which the landowners auction offer price would be based. Landowners submitted sealed proposals including their proposed conservation activities and their required payment. Each proposal was awarded an index score based on the environmental benefits expected from the management plan, and the offers were ranked based on

[7] In Georgia, farmers do not have a strong property right for irrigation. Their permits can legally be revoked at any time, but the government wanted to avoid the political conflict associated with revoking rights and decided to use a voluntary procurement auction. However, the EPD also made it known that if not enough landowners volunteered, the government reserved the right to force irrigation to stop. Such a regulatory threat may increase auction participation, but it also has unknown effects on bidding behavior.

the cost per unit of index score. Stoneham et al. argue that a fixed-price scheme would have cost seven times more than the auction to achieve the same level of biodiversity benefits (but given the auction was discriminative-price, it is difficult to make estimations about the counterfactual).

All three of these auctions use a sealed bid, discriminative-price auction format, in which each successful seller receives his own offer price. In two of the auctions (CRP and Georgia), the sellers can submit multiple units. In two of them (CRP and Bush Tender), the units offered are explicitly recognized as being heterogeneous in the environmental services they provide.[8] In one of the auctions (Georgia), landowners could revise their offers in repeated rounds in which offers are "provisionally" accepted, until a final round in which acceptance is binding (landowners do not know when this final round would occur).

Since an auction is no more than a set of rules for determining how resources will be allocated, it can easily be tailored to the specific objectives and characteristics of a PES program. Unfortunately many of the characteristics of PES auctions (e.g., multiple heterogeneous units, fixed buyer budgets or maximum acceptable offer prices) violate the standard assumptions in auction theory.[9] Therefore, extant theory will often not give unambiguous answers about the appropriate rules for a PES auction.

In one of the only theoretical treatments of an auction for environmental service contracts, Latacz-Lohman and van Hamsvoort (1997) develop a model of a discriminative-price, multiple-unit procurement auction in which the conservation agent has a maximum acceptable price per unit. They show that the optimal offer (from the landowners' perspectives) increase linearly with the landowner's opportunity costs and the landowner's expectation about the maximum acceptable price. Thus the offer reflects more than just opportunity costs, which implies that the auction is an imperfect revelation mechanism. However, the auction does appear to be an improvement over a fixed-price (take-it-or-leave-it) contracting program for two reasons: (1) although low-cost producers gain informational rents, they are smaller than in the fixed-price context; and (2) landowners with opportunity costs above the fixed payment level, who would not participate under the fixed-rate payment scheme, can now bid a value that covers their costs. With the same budget, the buyer can accept some of these high-cost farmers into the

[8] In the GA auction, the EPD recognized that water use varied by parcel, but without water meters, it could not differentiate the irrigation reductions afforded by each contract and thus the contracts were assumed homogenous.
[9] For example, when seller supply for multiple contracts is constant or increasing, there may be an incentive to bid above the opportunity cost of some units (see List and Lucking-Reiley 2000; Kagel and Levin 2001 for buyer's auction examples). With a fixed budget, the acquired quantity of environmental contracts is endogenous.

program via the cost savings provided by the low cost participants. The efficiency gains increase with the degree of heterogeneity of the landowners.

Because their model does not give clear answers about the size of the gains from using an auction over a fixed-price program, Latacz-Lohmann and van der Hamsvoort (1997) conduct simulations using parameters that represent stylized aspects of agri-environmental programs. The simulated gains in efficiency range from 16 to 29%, depending on the auction rules and simulation parameters. While such gains are substantial, they might easily be diminished by the administrative cost of an auction.

b. Pricing Rules

Like the three real-world auctions described above, the theoretical model and simulations used by Latacz-Lohmann and van der Hamsvoort assume a discriminative-price auction, in which landowners receive their offer prices. Revealing one's true reservation price is not in a landowner's best interest. Instead, one's offer price is represented by a function that is a best response to other landowners' bidding behavior. Therefore behavior in these auctions will be sensitive to the seller's risk preferences and beliefs about other sellers. In formulating their offers, landowners must trade off a higher net gain from a higher offer price with the reduced probability of securing a contract with a higher offer price (inflating your offer price may mean you lose a contract to a competitor). All else equal, heterogeneity of risk preferences across bidders implies that more risk-averse landowners, or landowners in more risky environments, will submit lower bids.

In contrast, all sellers in a uniform-price auction receive the same price. This price is typically determined by the highest rejected offer. In simple uniform-price auctions, this pricing rule increases the incentive to reveal opportunity costs compared to the discriminative-price auction: a seller can do no better than telling the truth because the price paid is not determined by an accepted offer.[10] Inflating one's offer only serves to decrease the probability of acceptance. However, in order to induce landowners to reveal their opportunity costs, the buyer must pay a price higher than the landowners' opportunity costs (i.e., information rents are required to induce the sellers to tell the truth).

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[10] In principle, a lower uniform price can be achieved if one uses the last accepted offer to determine the price, but inflating one's offer price on a unit can be desirable if one has good reason to believe this unit will set the price.

In some cases (e.g., Costa Rica's Programa de Pagos por Servicios Ambientales), paying everyone the same price may be considered fairer than discriminating by opportunity cost, which "punishes" public-spirited landowners who had managed their ecosystems for the public good in the absence of payments (less publicly-spirited landowners are "rewarded" with higher payments). The uniform-price auction can also be more forgiving to inexperienced bidders because bidding errors can often be costless. In other cases (e.g., Georgia irrigation auction), paying everyone the same price regardless of their opportunity costs might be considered unfair (or a waste of taxpayer funds) and thus the discriminative-price auction may be preferred.

To readers unfamiliar with these auctions, the discriminative auctions might appear to be the clear choice for a conservation buyer interested in achieving an environmental objective at least cost. However, a seller earns no surplus (profits) in the discriminative price auction if she submits an offer equal to her opportunity cost. Thus, as noted above, she has an incentive to inflate her offer. In the uniform-price auction, truth-telling is a weakly dominant strategy.[11] Thus, even though each landowner receives the same price in the uniform auction, overall expenditures can be lower. Which auction has lower expenditures for a given environmental objective will depend on the characteristics of the landowners and of the contracts.

Under standard assumptions, such as bidder risk-neutrality, the two auctions yield the same expenditures for the procurer. But with risk-averse bidders, Riley and Samuelson (1981) note that the discriminative-price auctions can yield lower expenditures because the conservation payment is a nonstochastic income component and therefore, were it secured, would lower the landowners income uncertainty. To obtain this decrease in uncertainty, the landowner has an incentive to reduce their offer price below what a risk-neutral landowner would offer.[12]

In the context of PES auctions, however, theory does not provide a clear prediction and thus economists have turned to experiments to explore the outcomes under different pricing rules. McKee and Berrens (2001) and Cason and Gangadharan (2005) find the discriminative auction to be less costly for a given environmental objective than the uniform price auction. Using a format that allows for bid revisions (see above), Cummings et al. find that average prices

[11] When multiple bids allowed, sophisticated bidders might not submit their offers independently, but rather submit them in a way that attempts to influence the uniform price.
[12] In low-income nations with common knowledge of corruption, the conservation payment may not be viewed as non-stochastic and thus these offer-reducing effects may not be observed

are initially lower in the discriminative auction, but the difference disappears as bidders are allowed to revise their offers.

Note that the (weak) superiority of the discriminative-price auction may not be general, but rather may depend on the parameterizations and rules used in the experiments, as well as the subject pools. For example, Cason and Gangadharan chose parameters that reflected conditions for two specific environmental problems in one area of Australia. They used a format that includes a fixed budget, allows only one unit per landowner sold, and recognizes heterogeneous contract quality across landowners. Their subjects bid truthfully on average in the uniform-price auction. McKee and Berrens chose parameters that reflect a government procurement auction for land acquisition that leads to biodiversity conservation. They used a single-shot format with a minimum quantity requirement and maximum accepted price, and allowed the land offered to be divisible. Their subjects did not bid truthfully in the uniform-price auction.

The auctions used in Cummings et al. (2004) and Cason et al. (2003) contain an additional twist: sellers can revise offers after learning whether any of their units are tentatively accepted. Both articles argue that announcing tentative acceptances and allowing offers to be revised provides useful information to auction participants and allows landowners to avoid costly mistakes from strategic bidding. A lot of auction theory assumes that bidders have independent private values, which means that each landowner know exactly the opportunity costs of accepting the conservation contract and these costs do not depend on the costs of the other landowners (i.e., learning the costs of other landowners may change one's bid, but not one's costs). In many PES auctions, landowners may have only a rough sense of what their reservation prices ought to be and thus would benefit from information provided through multiple rounds.

As noted by Cummings et al., reducing the likelihood of poor choices by the landowners reduces the likelihood that landowners will be angry about the auction process and that policymakers will be unhappy about higher-than-expected prices as well as participant anger. Cason et al. suggest that the chance to revise offers, as opposed to a single binding offer, may also be seen as "fairer" by the landowners. However, the advantages of allowing revisions have to be weighed against the administrative costs of evaluating offers each round and channeling information between the decisionmakers and the participants. Moreover, allowing for feedback and revision can make collusion easier (subjects in both experiments were allowed to communicate orally between auction rounds to verify that the institution was robust to collusion).

Finally, note that Cason et al. and Cummings et al. use repeated, sealed-bid auctions, in which landowners submit their offers privately. Repeated sealed-bid auctions are less susceptible to collusion and strategic gaming than repeated ascending (English), descending (Dutch) and uniform-price auctions (see Klemperer 2000), particularly when participants are risk-averse.

c. Targeted Auctions when Contracts Vary in Quality

Landowners are likely to vary not only in their opportunity costs, but also in the quality of the environmental services they can supply. This quality may depend on the landowner's actions[13] or the biophysical characteristics of the land. A targeted auction that recognizes the heterogeneity of contract quality will be more efficient than one that ignores such heterogeneity (Latacz-Lohman and van der Hamsvoort). How much more efficient depends on the nature of the heterogeneity. If opportunity costs and environmental benefits are strongly negatively correlated or if the relative spatial variability of costs is much higher than that of benefits, an auction that ignores benefits will secure much of the environmental benefits that could be secured through a targeted auction (Ferraro 2003a). When these conditions do not hold, there are gains to implementing a targeted auction.

The simplest way to target an auction is to separate bidders into different auctions where bidders are roughly homogenous with respect to the ecological values of their land. One can also establish minimum eligibility criteria to ensure low opportunity cost landowners cannot participate in auction (e.g., one cannot participate if located more than 5 km from a road).

A more sophisticated approach would be to assign an environmental benefit value to each contract. An auction solicits a wide range of bids simultaneously, thus reducing search costs for locating high-quality, low-cost suppliers. Given the difficulties associated with assigning a dollar value to environmental services, conservation agents are likely to use some kind of scoring rule to assign a value to each parcel. For example, the Conservation Reserve Program uses an Environmental Benefits Index, which assigns points to each land parcel's attributes. The total amount of points achievable for each attribute is determined by relative weights (e.g., up to 10 points can be awarded for proximity to wetlands and up to 15 points can be awarded for endangered species habitat). Scientists working with the Bush Tender auction created a

[13] Individual management plans can be more efficient, but can also substantially increase the administrative burden of contract writing and monitoring. They also imply more labor and cognitive investment by the landowner, which can reduce their incentives to participate in the auction.

Biodiversity Benefits Index (BBI) value for each site, which itself was a product of two other scores based on the current conservation value of the site and the quality and size of the site and the management plans. Contracts were then ranked by their BBI per dollar and awarded until budget exhausted. Ferraro (2004) describes a nonparametric method by which conservation investment opportunities can be ranked when the conservation agent cannot convert multiple biophysical attributes into a one-dimensional measure of environmental benefits. This method can be easily integrated into a targeted auction.

An important question is whether the benefit valuation rules should be shared with landowners. Announcing these rules can provide incentives for landowners to submit costly-to-fake signals of the environmental quality of their proposed activities about which the conservation agent may by uncertain or unaware (e.g., submitting a third-party certified management plan). However, quality differentiation may also offer landowners another source of rents that can be extracted from the conservation agent. Other analyses of auctions with quality-differentiated goods (e.g., Milgrom and Weber, 1982) show that heterogeneity of the auction items can influence the bid functions in a discriminatory auction.

In a laboratory auction experiment similar to Cason and Gangadharan (2004), Cason et al. (2003) find that revealing to the auction participants the environmental value of their land induces high-value landowners to substantially inflate their offers. This strategic behavior increases conservation expenditures. Note, however, laboratory subjects in the no-revelation treatment had absolutely no information about how the buyer valued their units. In reality, landowners have reasonably accurate prior beliefs about the attributes of their land that are valued and thus the cost of revealing information might not be as high as implied by Cason et al.

Even if revealing environmental benefit information did raise expenditures, it is unclear whether withholding such information is politically feasible (lacks transparency, increases actual or perceived corruption) or practical (over time landowners are bound to figure it out or local advocates will help them). Revealing such information may increase the perceived fairness of the auction because few people will publicly argue against the conservation agent seeking out the low-cost, high-quality contracts. As noted by Cason et al., revealing information about environmental benefits can also educate landowners about the most beneficial land use changes and encourage investment in conservation. Failure to reveal the environmental values publicly may also make it harder to use theory to guide design because auction theory generally assumes that the rules of the auction are common knowledge and are credible.

If value of a contract is determined not only by the landowner's ecosystem characteristics, but also by the characteristics of any contracted parcels nearby, one can consider a computer-assisted, combinatorial procedure to rank parcels. A combinatorial procedure can explicitly incorporate the value of contiguity (parcels are worth more when contiguous than fragmented) or the presence of thresholds (if a threshold level of ecosystems is not secured, few or no environmental benefits are secured). Such values and thresholds can be incorporated into the auction heuristically, by using Geographical Information Systems software to compare different portfolio arrangements (e.g., alternative paths for a biological corridor). More sophisticated methods for valuing contiguity or recognizing thresholds (e.g., threshold constraints in the targeting algorithm of Ferraro 2003b) can also be integrated directly with the offers arising from the PES auction (a true combinatorial auction; Banks et al. 2003). An even better approach would be to pay bonuses for parcels that are contiguous or meet a certain area threshold (see, for example, the agglomeration bonus of Parkhurst et al.). Auctions can also take into account substitutability among contracts through integration of the auction with maximum-coverage algorithms (e.g., Page (1997) and Solow et al. (1993)).[14]

Incorporating the benefits of contiguity and the presence of thresholds may not only increase environmental services; it may also decrease the costs of monitoring because contracts are spatially concentrated. Conservation agents may also be able to take advantage of group contracts that can reduce the rents arising from hidden action through peer pressures exerted on members. There may, however, be a disadvantage to publicly seeking contiguous lands or minimum areas in watersheds: collusion and holdouts are more likely.

d. Repeated Contracting

In PES programs, there will likely be periodic opportunities for landowners to contract with the conservation agent. Administrative and information constraints (not every landowner can be contacted and contracted in a year) and the use of limited duration contracts (subject to

[14] Another possible issue is that actions on landowner A's land may affect in a negative way the marginal productivity of actions taken on landowner B's land. For example, if landowners in riparian areas make substantial investments in large riparian buffers that stop most sediment before it reaches the water, the value of soil erosion reduction by upland landowners is reduced.

expiration and renewal) ensure that contracting must be considered a dynamic game. Thus, in PES auctions, repeated (periodic) auctions are likely to be the norm.

Depending on how much detail about past auction results are made public and how well participants are able to communicate, landowners can extract information from previous auctions to recapture their informational rents that were dissipated in early rounds of the auction. Useful information includes the auction's maximum accepted offer and the distribution of submitted offer prices. Say, for example, a landowner finds out that her offer is lower than most others in a discriminative-price auction. She loses nothing by raising her price in the next auction. In the limit, everyone below the maximum accepted offer (MAO) will raise their price to that level and everyone above it will not participate: the auction will collapse to a fixed-price scheme.[15] Of course, in a budget-constrained program the fixed-price to which the auction eventually collapses will be lower than the original MAO, but the collapse will nevertheless take place. If low-cost landowners knew of this potential outcome, many might refrain from participating in early rounds if contracts were of a greater duration than the auction cycle (in order to obtain a higher price in later rounds). A similar problem could arise in a uniform-price auction with multiple units because the marginal seller can exert some market power. With repeated auctions over time, the marginal sellers may be able to identify their position and power.[16]

Evidence of farmers learning MAOs in the Conservation Reserve Program (CRP) auctions date from the late 1980s (Shoemaker 1989 and references therein). During the initial sign-up, the average offer was lower than the MAO (bid caps) in all regions. By the fourth sign-up, the average offer approached or equaled the MAO in all regions. Shoemaker also showed that the CRP increased the average value of eligible land, which could only happen if landowners were receiving windfall gains as a result of their private information.

In the simulations based on their theoretical model, Latacz-Lohman and van der Hamsvoort show that neither complete uncertainty nor complete certainty about the maximum acceptable offer (MAO) is desirable in the discriminative-price auction. With high levels of uncertainty about the MAO, bidders tend to make high offers, while with high levels of certainty, low opportunity cost bidders make offers near the MAO and high opportunity cost bidders do not

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[15] Past experimental research has suggested that the price advantage of a monopolist can be neutralized in a double auction environment through buyer withholding of demand. In the PES context, the conservation agent often acts as a monopsonist and landowners can "withhold" supply by raising their offer prices until a uniform price is achieved.
[16] Despite this possibility, however, some authors (Cason and Plott 1996; Friedman 1991) argue that the uniform auction is more resistant to conspiracy and strategic manipulation than the discriminative auction.

participate. The authors suggest that, in the first auction, bidders should be given some guidance as to the range of realistic payments. In later auctions, however, the functional form of the bid acceptance mechanism should be concealed.

Note that the "informational" problem associated with repeated auctions does not mean an auction is less efficient than a fixed-price scheme, but rather that the auction's efficiency advantages may dissipate over time. This dissipation can be delayed or eliminated through the use of a targeted auction. In a targeted auction, there is no maximum accepted offer price, but rather a minimum benefit-cost ratio, which is much harder to infer from public information about offer prices and expenditures (particularly if the environmental scoring method is not fully disclosed to landowners or changed periodically). Even more difficult to strategically manipulate would be a targeted auction that uses distance functions to rank contracts (Ferraro 2004a) because a landowner would need to know (1) the distribution of offer prices, (2) the budget (if the program is budget constrained), (3) the distribution of contract attributes used in the distance function and (4) how to calculate the efficient frontier.

e. Other Issues in PES Auction Design

Many PES schemes are budget-constrained (others may use maximum acceptable bids or target numbers for contracts or hectares). The question then arises, should the budget be publicly revealed prior to the auction? No one has examined this issue experimentally, but I conjecture that the budget should not be revealed with until after the auction (if the budget was not binding, only expenditures should be reported). A range of potential expenditures can be announced before the auction (as was done in the Georgia irrigation auction), but if a precise value is announced, many landowners may choose their offer prices by dividing the budget by the expected number of participants.

Many PES auctions are likely to be sealed-bid auctions (in which each landowner submits an offer privately), but open-format auctions are also possible (e.g., ascending clock auctions). In such auctions, participants unsure about their own opportunity costs can gather information about other landowners' opportunity costs by observing their bidding behavior. Unfortunately, this same property makes open-format auctions more susceptible to collusion and a manipulation by local power structures (a "big-chief-and-his-family-wins-all" equilibrium). Moreover, open-format auctions (as well as sealed-bid auctions allowing revisions) require that all landowners assemble in a common location (although this location may be virtual via the internet or video-conferencing).

Much of the auction theory literature treats the units sold as indivisible, whereas in a PES auction, the unit sold will be contracts on divisible land units (in all the experiments except Berrens and McKee, the units sold were indivisible). A distinguishing feature of a divisible good auction is the very large strategy space available to bidders; bidders can submit, in effect, a supply schedule of price-quantity combinations. Unlike unit-demand auctions, in which bidders only choose among possible prices, divisible-good auctions allow bidders to choose from myriad upward sloping supply curves. Back and Zender (1993) have demonstrated that collusive strategies can be self-enforcing in uniform-price divisible-good auctions. The collusion leads to equilibria in which bidders increase their bids more than they would in the equilibria of a discriminatory auction. Recent work (Wang and Zender 1999), however, describes other equilibria in which the opposite is true with risk-averse bidders.[17]

Even if the good is not perfectly divisible, but multiple units can be sold, bidding behavior can be quite complex. Engelbrecht-Wiggans and Kahn (1999) suggest that strategic bidding can significantly raise prices in uniform price auctions. McCabe et al. (1989, 1990, 1991), however, show that in their uniform-price 'smart' auction for natural gas networks, the marginal unit cost is not under-revealed. Since it is the marginal unit that determines the uniform price, efficiency is achieved despite the strategic behavior. More experimental research is needed on the divisible and multiple unit nature of PES contract auctions.

Finally, in a PES auction, it is not correct to say that land parcels are being auctioned; more precisely, it is a contract for a particular land use that is being auctioned. Spulber (1990) introduced competition to the allocation of contracts and showed that, under asymmetric information about costs, incentives for performance determine contract terms, which then have a feedback effect on performance decisions. As Spulber has argued, bids for a contract to supply a service involve both a *price* and a *promise* to perform the service. Unlike in auctions that generate bids for the purchase of a good or service, the accuracy of cost information revealed in an auction that generates bids for a contracted service depends on the consequences of not carrying out contractual commitments. A conservation contract reflects a commitment to an

[17] Work by Chatterjea and Jarrow (1998) and Noussair (1995) also suggests that uniform-price auctions can be more resistant to price manipulation. Note that the auctions studied in these papers are buyer auctions (one seller, many buyers), but the results are symmetric for seller auctions.

ongoing relationship between buyer and seller, and thus issues of credible commitment and enforcement are essential to the performance of the auction institution. These issues are especially important in the context of less developed tropical nations (readers interested in designing contracts in the absence of a strong judicial system should explore research on self-enforcing contracts and private enforcement capital; e.g., Gow and Swinnen 2001).

f. Advantages and Disadvantages of PES Auctions

Auctions to procure PES contracts can be tailored to suit the characteristics of the land-use changes being procured, the political constraints affecting contract allocation, and the cognitive and institutional capacities of participants. Their main advantage lies in their ability to reduce the informational rents to landowners through competitive bidding. By reducing these rents, an auction mitigates the concern that many have about PES initiatives: namely, that the contracted lands are often lands that would not have been converted in the absence of payments (i.e., the opportunity costs of protecting these lands is zero). Auctions can also mitigate the concern that some have with regard to contracts for forest management: namely, these are ostensibly profitable enterprises that should not need additional payments to be adopted.[18]

An auction solicits a wide range of bids simultaneously, and thus can also be used in situations in which there are multiple buyers of environmental services who may want to coordinate their contracting activities. More research into the ways in which auctions can help or hinder multiple buyer-multiple seller transactions in the PES context (where environmental services are often jointly produced) is needed.

Because auctions use transparent rules, they can also reduce the influence of political power in the distribution of contracts. With a fixed take-it-or-leave-it payment, there may be more people eager to enroll than there is money to pay all of them. In these circumstances, other criteria are used to determine to whom the payments will go. In many cases, politically more powerful individuals and communities tend to receive the limited number of payments. With an auction, there is a transparent criterion for allocating payments from a fixed budget: payments are made to the lowest bidders. In many circumstances, these bidders are also the poorer, less powerful members of society (assuming they are allowed to participate).

[18] Note, however, that if landowners view the auction as part of a dynamic regulatory game in which the information acquired in the first-stage via the auction can be used against the landowners in the second stage, the rent-reducing powers of the auction will decrease.

In a PES program, conservation agents would like to encourage land-use innovations that can reduce the costs per unit of environmental benefit supplied (e.g., offering recreational access to tourists who pay for entry; finding cheaper ways to grow endangered species habitat). Screening contracts (section 3) encourage land-use innovation because the lowest-cost suppliers obtain the largest rents. Competitive auctions can encourage innovation in two ways: (1) by encouraging landowners with high per unit costs that are not winning contracts to innovate in order to win contracts (thus putting pressure on everyone else to reduce costs); and (2) in uniform-price auctions, by encouraging landowners to reduce costs to reap larger rents (in most auction theory – e.g., Latacz-Lohman and van der Hamsvoort - the size of a landowner's informational rents in discriminative auctions is not conditional on his opportunity costs).

Auction mechanisms can also be used as research tools to make ex ante estimates of the distribution of landowner willing-to-accept land use changes in return for payments (see Ferraro 2004b for a discussion of why such mechanisms can be superior to commonly used values from average agricultural returns or stated preference surveys). Such estimates can be used in simulations and laboratory experiments to test different PES program designs (regardless of whether auctions will be used in the final design). Stoneham (2004) noted that policymakers could use the information revealed during the Bush Tender pilot auction to improve policy decisions. Note, however, that the use of auction mechanisms in a research context to induce landowners to reveal their private information, which can then be used "against them," has ethical implications that have not yet been explored.

Of course, there are disadvantages to using auctions to allocate PES contracts. They are much more administratively complex than fixed take-it-or-leave contract schemes (but not more complex than bilateral bargaining with each landowner, as many land trusts do).[19] Auctions may reduce participation in the PES program because of the cognitive burden of coming up with offer (rather than deciding to take or leave the conservation agent's offer) or the mistrust associated

[19] Bilateral bargaining turns a game of one-side hidden information in which the uniformed party (conservation agent) has the bargaining power and thus can appropriate some of the informational rents of the informed party (landowner) at the expense of allocative efficiency (i.e., not all environmental services for which marginal benefits are greater than marginal costs will be supplied) into a two-sided hidden information game. In this case, each side will try to reduce the informational rents from the other side and trading will be inefficient. There is also the potential that no trades at all will take place (Myerson and Satterthwaite 1983). Furthermore, bilateral bargaining is highly decentralized and can generate significant transaction costs. When agents search out bargaining partners sequentially and the search process is costly, the most efficient exchanges may not be realized (Chamberlain 1948; Hong and Plott 1982).

with an unfamiliar institution. Furthermore, auctions require a large pool of potential bidders to maintain competitive pressures and to reduce opportunities and incentives to collude or otherwise behave strategically. How many participants constitute a "large" pool will depend on local conditions.

6. Conclusion

The two dominant forms of price setting for PES contracts are bilateral bargaining and posted prices (i.e., fixed take-it-or-leave-it prices). However, these two methods may result in highly inefficient outcomes in circumstances where a good or service is not commonly traded and where information between buyers and sellers is highly asymmetric. Such circumstances are pervasive in the contracting environment for environmental services.

In sections 2 through 5, I have highlighted three categories of policy mechanisms for addressing hidden information in the PES context: (1) gathering more information on landowners in the form of costly-to-fake signals; (2) relying on screening contracts (self-selection mechanisms); or (3) harnessing competitive forces through procurement auctions. Because of space constraints, I have ignored other important issues such as dynamic adverse selection (commitment problems when landowner types are constant, and tradeoffs between intraperiod risk sharing and intertemporal consumption when landowner types may change from exogenous shocks), adverse selection with multidimensional types (in particular the issue of bundling, which may be relevant to PES programs), and incomplete contracts (contracts that do not explicitly deal with all possible contingencies).

Because of space constraints, I have also ignored the problem of hidden action in the design of PES programs. When monitoring is imperfect, self-interested landowners have an incentive to avoid compliance with their contractual obligations. This incentive increases in the cost of compliance, and decreases in the probability of detection, probability of conviction given detection, and the penalty upon conviction. Risk preferences (higher risk aversion implies more compliance, particularly when payments are high), time preferences (higher discount rates imply less compliance) and social norms (an aversion to cheating implies more compliance) also affect the likelihood of non-compliance.

The problem of hidden action should not be ignored, but it is unclear just how much of a problem it will be in PES schemes as they are currently designed. Giannakas and Kaplan (2005) cite data on the U.S. "highly erodable lands" policy, which reveals that about 4% of 50,000 producers audited were found not to be actively applying conservation measures. In the case of wetland reconstruction, however, noncompliance rates were found to be much higher (Castelle et al.). The typical solution to the hidden action problem is to reward landowners most for outcomes that are most likely to arise when they put in the required effort and punishing them the most for outcomes that are most likely to occur when they shirk. Relevant literature on the role of hidden action in agri-environmental programs is listed in the Introduction.

In conclusion, contract theory offers many relevant insights into the design of PES programs, but it is worth remembering the simplified nature of the theory's models, the way in which results are dependent on parameters and institutional assumptions, and the complexity of the prescriptions that are often revealed by the models. Laboratory test-bed experiments with students and with actual landowners (to ensure they understand the language and rules in the same way that conservation agents do, and to observe the relevant social norms that may be invoked in the setting), followed by small-scale field experiments will continue to be necessary in PES contract design.

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