Auctions:
Theoretical background and empirical applications in natural resources[1]

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1 Paper (revised version) presented at the 2nd EAAE workshop on Valuation methods in agro-food and environmental economics "Experimental auctions: theoretical background and empirical applications" July 2-3, 2009. Large parts of this paper builds on a report that is under preparation for the Expert Group on Environmental Studies under the Swedish Ministry of Finance (Romstad *et al*., 2012).

Abstract

In recent years auctions have gained increased attention in public procurement. This attention is gradually moving into the area of environmental economics, both on the demand side through various stated preference methods, and more recently also on the supply side. Here, a central issue is that for many environmental goods and services multiple contracts will be offered, making multi unit auctions particularly relevant.

In this paper I argue that the possibilities of strategic behavior in multi unit discriminatory price auctions calls for caution in the auction design. Arguments and findings in the literature suggest that multi unit uniform price auctions will lead to higher outlays on behalf of the regulatory agency compared to discriminatory price auctions. However, truth telling is important for legitimacy of the auction and to know what the size of the strategical biases are. I therefore propose using the uniform auction format.

A possible variation of the multi unit uniform price auctions is also presented to elicit willingness-to-pay for environmental goods and services.

The implications on the bidding behavior from noncompliance in contract terms are also addressed.

Key words: multi unit auctions, discriminatory price auctions, uniform price auctions, procurement, willingness-to-pay, economic experiments.

1 Introduction

This paper deals with auction theory applied to natural resource problems and issues of which there are two main strands: (i) procurement of private supply of environmental goods and services, and (ii) non-market valuation. The use of auctions mechanisms in these areas have grown immensely in the last decade or so, partly because auctions have seen increasing use in the economy at large. Milgrom (2004) is a fairly recent summary of auction theory and applications spanning conventional applications like Sotheby's art auctions to public procurement auctions and bidding contests for natural resources.

The increased use of auctions has also drawn attention to auctions at a more general level. With Mirrlees and Vickrey being awarded the “Nobel prize in economics”[2] for their “for their fundamental contributions to the economic theory of incentives under asymmetric information” (Nobel Foundation, undated) incentive problems received more public attention. Vickrey's primary contributions were on auctions, and the so-called Vickrey auctions (Vickrey, 1961) is probably the auction mechanism that has intrigued the most. It has also inspired other researchers to think more seriously about the incentive issues of auctions. In the line of Vickrey auctions, the Becker-de Groot-Marschack (1964) mechanism is a well known extension.

Many environmental and natural resource economics issues are partly characterized by the public goods nature, i.e., non-rivalry and non-exclusiveness in consumption (Randall, 1982), of the goods and services in question. This is particularly an issue on the the demand side, which again relates to non-market valuation and the problems associated with stated preference elicitation.

2 The *Nobel prize in economics* is not among the original Nobel prizes set forth by Alfred Nobel. Its proper name is *The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel*, and it was instigated in 1969 by the Swedish National Bank to enhance the recognition of economics as a science. More information about the prize can be found at *http://nobelprize.org/nobel_prizes/economics/* .

The public goods dimension also has implications for market allocation of many environmental goods and services. Because there will be no observable market price for many these goods and services, market allocation will not take place. Environmental goods and services are still of value to society. This is the rationale for state or regional agencies to represent citizens' demand by offering various forms of contracts. These contracts have many similar features with ordinary public procurement in the sense that there is one buyer of the services, and many possible suppliers. In some cases public procurement involves finding one supplier, like when building a bridge, or many providers, like when allocating mobile phone licenses. Again, Milgrom (2004) is a key reference for providing examples that have parallels for procurement of management contracts related to the environment.

This paper does not deal that much with the design of experimental auctions for two reasons: First, there are rather few successful experiments that have been conducted related to the environment, and second because for experiments to provide the insights we seek, they need to match the problem at hand. Here it should be noted that those having performed an unsuccessful experiment rarely seek to publish their experiences (that in many cases would constitute improved learning on how to avoid the pitfalls). The wider experience of auctions from public procurement therefore provides a better background than dwelling on the few environmental auctions experiments that have been performed.

The next section provides some further background related to public procurement of environmental management contracts. Section three deals with auction theory in general, while section four looks at some issues related to procurement auctions and the environment. Section five briefly addresses non-market valuation, and section six concludes.

2 Background

The most noteworthy experiences on using auctions for environmental goods and services are the US conservation reserve program (USDA Economic Research Service 2009) that was started in 1985, and the Australian Bush tender scheme (Stoneham *et al.* 2003). Both these programs have used auctions or menu pricing to induce land owners to undertake desired management practices on how to design payment schemes have been reasonably successful. These programs have also partly succeeded in resolving some of the information asymmetries on costs, although the auctions have not been of the uniform price kind that theory suggests for truthful revelation to take place.

Auction like approaches pertaining to the environment has also been used in developing countries. The FAO Roles of agriculture project provides a nice overview on payment for environmental services in developing counties (FAO 2009).

Public procurement for supplying environmental goods and services must be seen in light of two additional aspects: (i) society's means are limited, and the alternate value of these resources may be high, and (ii) the regulatory agency has limited experience and knowledge of the cost of providing the requested service. While (i) points to strong emphasis on lowering costs, (ii) increases the temptation for potential providers to inflate bids. As such transactions are performed quite seldom, and the regulatory setting often is unique, the scope is large for providers' (agents') to utilize their informational advantage. Often multiple conservation or management contracts are to be awarded at once. This limits the scope for learning by the agency.

Physical targets, like a certain acreage under conservation, combined with or a known public budget further increases the information advantage of potential providers. The ability to identify low cost providers is often linked to the choice of policy instruments. Low cost policies reduce the strain on scarce resources and public funds. Figure 1 shows the cost savings of a low versus more costly policy for reaching a fixed target.

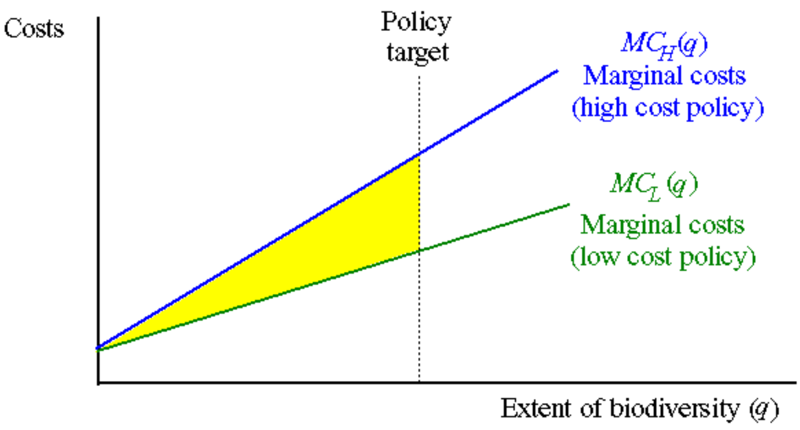

Figure 1: Cost savings of low cost policies.

The yellow shaded area in Figure 1 shows the cost savings from applying the low cost rather than a higher cost policy. Suppose that the environmental target is not fixed but determined by what is efficient. This implies that the marginal costs should be set equal to the marginal benefits of the policy, providing q_H for the high cost policy, and q_L for the low cost policy as illustrated in Figure 2.

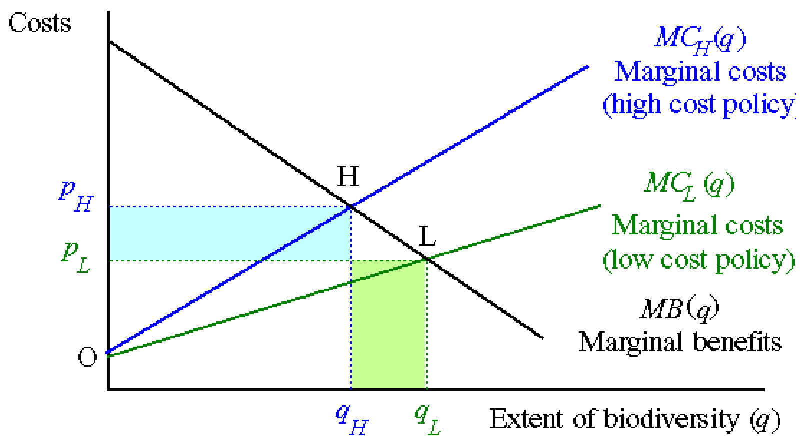

Figure 2: Low cost policies and optimal target setting.

If the policy agency is unable to undertake discriminatory pricing, and has to pay a uniform price to all suppliers of *q*, it may actually end up paying more for less services supplied, q_H, under the high cost policy than for more services provided, q_L, under the low cost policy. Whether this is the case depends on the relative sizes of the light blue and light green rectangles, which in turn depends on the relative elasticities of the marginal cost and marginal benefit schedules. Moreover, there are efficiency gains from applying the the low cost policy given by the triangle OHL.

The ability to identify low cost policies may provide substantial efficiency cost savings depending on the distance between the marginal cost schedules and the slope of marginal benefit curve. In cases where government has to pay for securing these services, public expenditures from a least cost policy will always be lower compared to alternate (higher cost) policies if the policy target is fixed (as in Figure 1).

Viewing the provision of non-market goods and services as any other production with some associated costs has some virtues, of which the interaction with the demand side and the resulting "price" is the most important (Romstad, 2008). This opens for using the economics toolbox to a larger extent, and it becomes easier to see to what extent troublesome issues like monopolies and information rents can be controlled.

2.1 Identifying the least cost policies

An inherent problem with any regulation that seeks to alter agent behavior is that affected agents seek to exaggerate their costs/forgone profits from the proposed regulation to influence the regulatory agency to reduce the extent of the policy from the efficient level (i.e., regulatory capture; Stigler, 1971). In the case that government is to pay for biodiversity, experiences from public procurement in other sectors of the economy suggests that forest owners will overstate their costs of providing biodiversity. By not truthfully revealing their costs forest owners may increase the compensation paid. In turn, that augments the toll on public expenditures above what would have been necessary.

We therefore need some mechanism to induce land owners to truthfully reveal their costs of incorporating environmental aspects in their land management. N-price procurement contract auctions (after Vickrey, 1961) is one mechanism that achieves truthful revelation under certain conditions. For auctions to work there needs to be some competition among bidders. This implies that not all bidders for environmental management contracts will get a contract, i.e., auctions will only work as long as it suffices to undertake special management for environmental purposes on parts of the acreage.

2.2 Decentralized decision making and spatial considerations

One difficulty with auctions or any other decentralized decision making system is that the spatial coordination may be insufficient. This is clearly an issue for biodiversity in forests, where habitats for some species need to be quite large for the species to be viable. This implies that in many cases habitats will span over several properties. For auctions to work properly in this setting one also needs to give forest owners incentives to post bids including more than one property. Experiences on this issue is limited, but the experimental economics literature suggests that spatial coordination can be achieved without complicating the policy too much (Parkhurst and Shogren, 2005).

The issues related to spatial coordination are not unique to decentralized decision making schemes like auctions. In the case of top-down management from an (environmental) agency, the distribution of the compensation paid to various forest owners may cause other problems of dissatisfied forest owners who are likely to sabotage the regulation, thereby reducing its intended impacts.

2.3 Conducting experiments

The main reasons for running economic experiments are in my mind to:

(1) Be able to test policies *ex ante,* i.e., before observed data on agent behavior is available.

(2) To establish a more controlled environment with less "noise" in the data. This implies making the experiment as "clean cut" as possible to avoid unobserved variables to influence experiment outcomes.

One implication of the second aspect is that one must have a clear understanding of what is it one wants to test. That means that the experiment is solidly anchored in the theoretical analysis preceding the experiment. The few experiments I have conducted relate to multi unit uniform price auctions. When I conduct such experiments I heavily rely on my colleague, Frode Alfnes.[3] We assign some value (or cost) to all participants. These values are private information on behalf of the participants, and we can choose how much information we provide to participants on the distribution of values, which then becomes public information.

After some coaching and tests, the first (base) experiment is always to run a few iterations on the standard multi unit uniform price auction. Results are revealed to participants after each experiment, and serve as further coaching of the participants before the research question that is at the center of the analysis. One advantage of this is that we also have a base with which to compare results from the extended analyses as results between sessions may be sensitive to the group composition, while results usually are quite consistent with each experimental session. To make results less sensitive of group participants, experiments are always repeated, preferably three or more times.

3 Auction theory

Adverse selection (hidden type) issues in principal-agent frameworks (Stiglitz 1989) means that the agent – the best informed party on the issue at hand – is able to benefit (to reap information rents) by not fully revealing his type to the principal (the policy agency). This corresponds to meeting the participation constraint for truthful revelation in the mechanism design literature (Campbell 1987).

For any trade to take place or a contract to be signed, all parties involved must be at least as well off as they were before, i.e., the participation constraint is met for all parties. This is required since entering the agreement is voluntary. Preferably, a trade or a contract is signed to generate some surplus.

In our setting of full compensation schemes only the agent knows the true value of the compensation he needs in order to be indifferent between getting and not getting a contract. That is, the agent is the best informed party, and society at large, paying the compensation for environmental management, is the least informed party. Consequently, agents may capture excessive information rents unless care is taken in the policy design. This is a typical case of *adverse selection*.

There exists three ways of inducing agents to reveal their true cost type, self selection mechanisms, auctions, and the Becker-de Groot-Marschak (BDM) mechanism. BDM (Becker *et al*. 1964) has many similarities with uniform price auctions.

In *self selection mechanisms*, like menu pricing[4], the regulator offers a fixed payment for the contract. Forest owners who have lower costs than the payment would accept the contract, while high cost providers would refuse. Menu pricing schemes therefore satisfy the truth telling condition, but it provides little information on the distribution of the payment forest owners request to be indifferent between getting and not getting a contract. Latacz-Lohmann and Schilizzi (2005) discuss self selection mechanisms in more detail. They also note that such contracts have not been very widely used.

3 Frode Alfnes, Department of Economics and Resource Management, Norwegian University of Life Sciences (*http://www.umb.no/ior/ansatte/frode.alfnes*). It is great to have a colleague like Frode, who always is very helpful and entusiastic.

4 Menu pricing involves forest owners who are offered several choice alternative. Each alternative has two attributes, a payment and a set of requirements the agent must satisfy to collect the payment. Through their choice of alternative (menu item) forest owners reveal their type.

The *Becker-de Groot-Marschak* (1964) mechanism is a weakly incentive-compatible procedure for truthful revelation of bidders' willingness-to-pay. It has been used quite frequently in experimental economics. There are several variations of the BDM mechanism. Common features of BDM are that agents formulate their bids, and if an agent's bid exceeds or equals a randomly drawn cutoff price, the agent pays the price and receives the item being auctioned. Otherwise, the agent pays nothing and receives nothing. Several works have established the conditions under which truthful revelation is not guaranteed under the BDM (see Horowitz, 2006).

Auctions have gained increased attention, recently also for allocating environmental management contracts. There are essentially four basic auction forms: English, Dutch, first-price sealed-bid and Vickrey (Chan *et al.*, 2003). All these auctions were originally designed for sales of goods and items, but in principle there is no difference if they are run as procurement auctions, i.e., one seeks the lowest bidders for delivering a service. Section 3.1 contains a brief summary of the four auction formats.

3.1 A brief summary of auction formats

There are four main auction formats: English auctions, Dutch auctions, first-price sealed-bid auctions and second-price sealed-bid auctions.

(1) *English auctions* are open auctions with an ascending outcry format, where the price is successively increased until only one bidder remains. A bidder bids as long as the current price remains below his own valuation of the auctioned good. As bids increase, bidders successively withdraw from the auction in order of their relative valuations. The good is sold to the bidder with the highest valuation who is the last remaining person in the auction for a price above what makes the second last bidder withdraw from the auction. The dominant strategy is to stop bidding once the bid price exceeds one’s own valuation. Bidding more than the subjective valuation involves the risk of winning the auction and having to pay more than one’s subjective valuation. Bidding below the subjective valuation reduces the chance of winning. Bids in the English auction therefore reveal bidders’ valuations.

(2) In *Dutch auctions* bids are announced in a descending order. A bidder wins by being the first to accept an announced bid and pays that price. The term “Dutch auction” originates from the use of this auction format in the Netherlands’ flower markets.

(3) *First-price sealed-bid auctions* require bidders to submit confidential bids to the seller. As the name reveals, bidders cannot observe the size of the competing bids when placing his bid. This is in contrast to the English auction where other bids are observable. The bidder with the highest bid wins and pays that bid.

(4) *Second-price sealed-bid auctions* (Vickrey 1961), also denoted Vickrey auctions, differs from the first-price sealed-bid auctions as the highest bidder wins the auction, but only pays the price of the second-highest bidder. This separation between the bid and the price paid makes it a dominant strategy to bid the subjective valuation. Bidding above the subjective valuation increases the risk of having to pay more for the auctioned item than what the bidder perceives it is worth. Contrary, bidding below the subjective valuation increases the risk of loosing out on a good where one would have been willing to pay more.

All these four commonly used auction formats have two desirable properties under rational bidding behavior. First, the winner is the person with the highest subjective valuation. However, only the sealed bid formats provide incentives that bidders will bid their maximum willingness-to-pay. Second, under the following assumptions the revenues collected under these auctions are on average the same (Chan *et al.* 2003 for full details, summarized by Latacz-Lohmann and Schilizzi 2005:18):

- *The auction sells a single item.*
- *Independent private values*: Each bidder has a valuation of the traded good that is unknown to the seller and rival bidders and that is not influenced by others' views (in particular, no resale value). The seller does not know each bidder's exact valuation and perceives this valuation to be drawn randomly from some probability distribution. Likewise, bidders have prior knowledge about the probability distribution of rival bidders' valuations, but not about competitors' exact valuations.
- *Symmetric bidding*: The probability distribution of valuations is identical for all bidders.
- *Competitive bidding*: All bidders enter the auction with the intent to win and know the number of rival bidders. There is no collusion and bidders do not have the ability to influence market demand.

This is known as the *Revenue equivalence theorem* that Vickrey (1961) also pointed to.

3.2 Multi unit auctions

In the case of auctioning off environmental management contracts, the regulator frequently would like to auction off more than one contract. Here, the regulator may choose to between two auction formats, discriminatory and uniform price auctions. In *discriminatory price auctions* bidders are paid an amount equal to their bid, i.e., the compensation is lower for low bidders who are selected first. Discriminatory price auctions belong to the wider class of *first-price sealed-bid auctions*. By adjusting their bids upward in a contract procurement auction, bidders may extract information rents. However, this strategic adjustment entails some risk of not getting a contract the forest owner would have benefited from. To see this, consider some bidder who feels reasonably certain he is a low cost supplier. By overstating his requested compensation by bidding more, the risks of not getting one of the contracts is minor compared to the expected gains of strategic bidding. This is an essential weakness of all *discriminatory price auctions*.

In *uniform price auctions* all bidders are paid the same compensation, for example the bid size of the N+1 bidder, i.e., the first bidder who does not get a contract. Uniform price auctions belong to the wider class of Vickrey style (second price) auctions, and is the only auction format that induces truthful revelation of bidders' opportunity value. This separation of the bid size and the compensation paid is the driving force for truthful revelation – bidders gain nothing by bidding anything different from their opportunity costs: If they bid more, they risk to loose out on a contract that would have increased their profits, and by bidding less, they risk getting a contract where fulfilling contract terms implies loosing money.

The Becker-de Groot-Marschak (BDM) mechanism and uniform price auctions share the property of separation off the bid size and the compensation paid, which makes it a weakly dominant strategy for bidders to equate their bids with their opportunity value or costs. BDM and uniform price auctions only differs in the way the price is determined: in BDM the price is randomly drawn, while in uniform price auctions the price is usually set by the first non-winning bid. The critique of BDM therefore also applies to N+1 price auctions.

Figure 3 provides an illustration of two versions of uniform price procurement auctions, an *N* and an *N*+1 uniform price auction involving nine forest owners and five management contracts that are auctioned off.

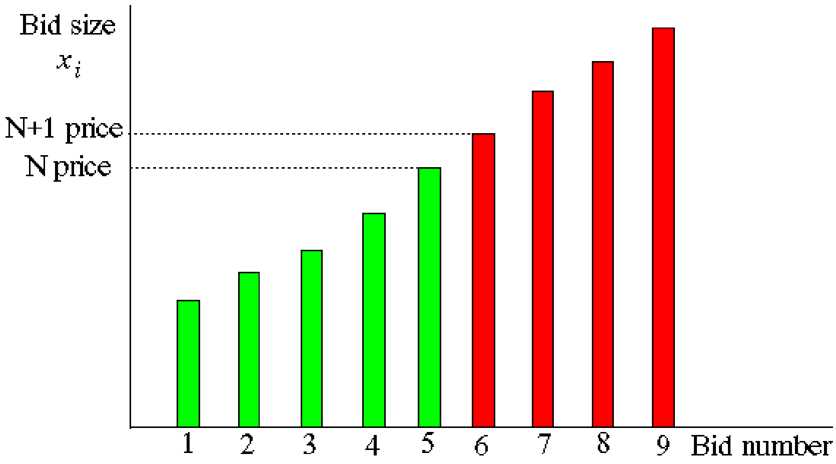

Figure 3: Multi contract reverse procurement auctions

The green bars represent the five lowest bidders in the auction, whereas the red bars represent the four highest bidders. In the *N*+1 price version of the uniform price auction bidders 1-5 all get a contract., and they are each paid an amount equal to the bid of bidder number 6. The difference between the contract price and the bid is the information rent the landowner enjoys under a uniform price procurement auction. It is possible to reduce the information rents to bidders in uniform price auctions by using an *N* price setting rule as long as no bidder knows if he has the N^{th} ranked bid. In the above figure this corresponds to all agents being paid an amount equal to the 5^{th} lowest bid. Therefore, using the *N price* format, bidders extract less information rents. However, in auctions with many bidders (and an implicit assumption that bids are not too different, the reductions in information rents from using the *N* price compared to the *N*+1 price format is expected to be minor. The benefits of reducing the information rents by the *N* price setting rule must be compared with the risk of loosing truth telling if some bidders are well informed about the bidding behavior of others.

It should also be noted that the *Revenue Equivalence Theorem* does not hold in multiple unit (contract) auctions (Chan *et al.* 2003). Therefore one could expect the expenditures paid to bidders in uniform price procurement auctions to exceed those under discriminatory price procurement auctions.

While truth telling is a desirable property of uniform price auctions it does not come without costs. It is like the famous “there is no free lunch” saying, or put in mechanism design terms: “incentives (for securing truth telling) cost” (Campbell 1987). If truth telling is worth less than the information rents given up, it would be optimal for the regulator to sacrifice truth telling. However, this only holds when the size of the information rents, i.e., the extent of strategic bidding, is known. In our setting we know there will be some strategic bidding taking place under discriminatory pricing, but one is unable *a priori* to know the magnitude of the upward strategic adjustments of the bids. Hence, the adjustment may be smaller or larger than the size of the verifiable information rents given to bidders under a uniform price auction.

Consider a situation where the regulator has a certain budget at his disposal, that is once the sum of the contract payments offered reach the budget limit, no further contracts are awarded. Then by construction the revenues of the two auction formats will be the same, and the only difference is the number of contracts awarded. Figure 4 provides an illustration.

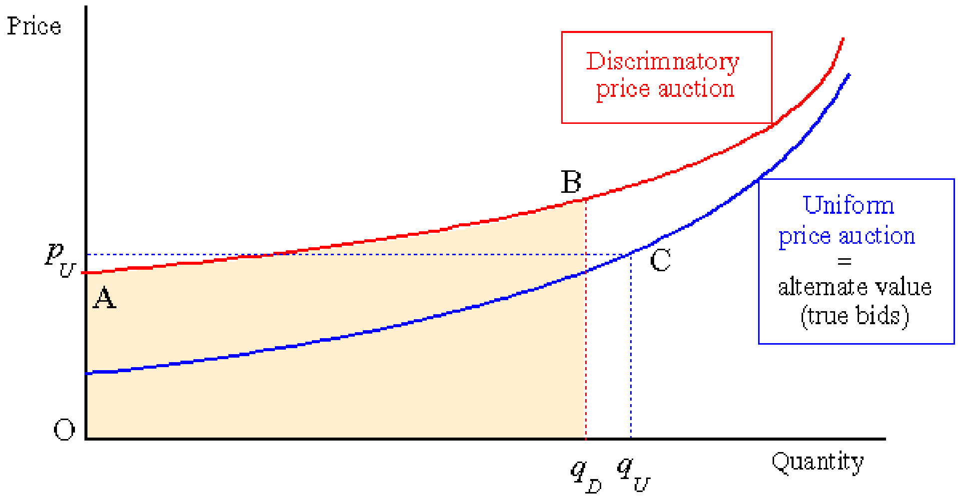

Figure 4: Auction revenues under budget constraints
(after Latacz-Lohmann and Schilizzi 2005:24)

Because the auctioneer has a given budget the total expenditures under the discriminatory price procurement auction (the shaded area OABq_D) and under the uniform price auction (the square Op_UCq_U) are the same. However, in Figure 4 more contracts are awarded under the uniform price auction, indicating that the auctioneer gets more value for his money. The opposite result, i.e., more contracts are awarded under the discriminatory procurement auctions, may however also appear if the strategic adjustments of the bids in the discriminatory price auction are minor.

Irrespective of which auction design that is used, quantity restricted procurement auctions are more common. Here, the supplied quantity will be the same (by construction). Depending on the strategic adjustment of the bids under discriminatory payments, the expenditures of the discriminatory price procurement auction could be higher or smaller. Figure 5 shows a situation where the costs of the discriminatory price auction (the yellow shaded area OABq) is slightly larger than the costs of the uniform price auction (the square Op_UCq). This corresponds to comparing the sizes of the darker shaded areas Ap_UX and XBC.

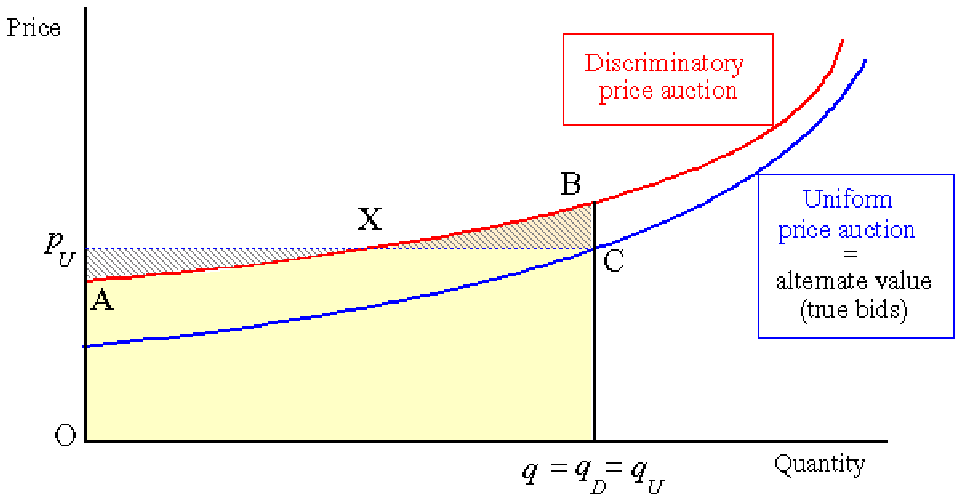

Figure 5: Auction revenues under quantity targets

Latacz-Lohmann and Schilizzi (2005:41) *argue* that the discriminatory price auctions are preferable over uniform price auctions for the following reasons:

(1) Uniform price auctions expose bidders to more risk as the value of the bid is unknown.

(2) Owners of the least productive land would capture large rents compared to owners of more productive land and introduce a bias in who wins in the auction.

(3) For the same reasons as in (2) above, owners of the more productive land may be discouraged to participate. This would augment the bias of the uniform price auction even more.

(4) Uniform pricing is more complex and more difficult to comprehend than the discriminatory pricing rule. This may act as a barrier particularly to those who are not familiar with bidding situations. On the other hand, it may increase the risk of collusion from the few who do understand the rules and are able to spot loopholes.

I see things differently. Admittedly, the size of the compensation is under uniform pricing is unknown at the time the bids are placed, but this is offset by the rents that winners are secured in uniform pricing auctions. This relates directly to (1) as bids under uniform price auctions by design equal bidders' opportunity costs.

Case points (2) and (3) can partly be offset if the auction is made regional and/or habitat type specific. For example, it is quite clear that auctioning of biodiversity management contracts for a temperate deciduous forest requires a different per hectare compensation payment than for a low productive taiga forest.

The fourth point on the additional complexity of uniform price auctions carries more merits, but we contend that the auction rules are one of the least complicated issues anyone who seriously considers bidding for a contract needs to understand. Specifically, getting an accurate estimate of own costs related to a contract is more difficult. Here, the information rents under uniform price procurement auctions serve to reduce barriers of participation.

This section has focused on meeting the participation constraint as a central aspect of solving adverse selection problems. In cases involving the division of surpluses (from trades or contracts) the participation constraint may involve more than being better off than in the initial situation. This is frequently seen in economic experiments (for an overview of observed violations to economic (expected utility) theory see Henrich *et al.*, 2004).

Fairness considerations and fears of being conned may also influence biodiversity management contracts in the sense that policy makers will be reluctant to engage in deals that grossly overcompensate forest owners. Uniform price multi contract auctions leave some information rents to the forest owner, but the size of these rents are revealed to the policy makers once the auction is completed. This knowledge and the acknowledgement that other procurement approaches hide the information rents to policy makers, make it easier to politically accept outcomes – at least for those trained in economics who are well aware of the fact that society-at-large also gains as long as perceived benefits exceed costs (an extended *consumer surplus* argument).

3.3 Asymmetric information – moral hazard

Moral hazard occurs when the party with more information about its actions or intentions has a tendency or incentive to behave inappropriately from the perspective of the party with less information. It may also take place in principal-agent settings, where the agent usually has more information about his or her actions or intentions than the principal does, because the principal usually cannot completely monitor the agent. The agent may then have an incentive to act inappropriately (from the viewpoint of the principal) if the interests of the agent and the principal are not aligned.

Compliance to (environmental management) contract terms is one source of moral hazard in our setting because it is costly for policy makers to completely monitor landowners' actions in terms of meeting contract obligations. This gives rise to two types of problems:

(1) Society may not get what it pays for in terms of environmental management.

(2) If potential providers of environmental goods and services know that monitoring will be incomplete[5], they may be tempted to bid strategically to gain a contract where they do not intend to meet contract terms.

3.3.1 Compliance and contract performance: post contractual manipulation

The basic approach to securing compliance under incomplete and costly monitoring is to secure that the expected penalty exceeds the expected gains of noncompliance. Let U_i^c and U_i^n denote the respective payoffs of compliance and noncompliance for agent *i*, let *S* denote the penalty for being caught in noncompliance, and let *p* denote the composite probability of being monitored and caught in if in noncompliance. Compliance will then take place if the expected payoff of compliance is greater than or equal to the expected payoff of noncompliance:

$$pU_i^c+(1-p)U_i^c \geq p(U_i^n-S)+(1-p)U_i^n \qquad [1]$$

which after some transformation leads to the *basic equation for compliance*:

$$p \geq \frac{U_i^n-U_i^c}{S} \qquad [2]$$

From [2] it is easy to see that if the penalty is increased, the probability of being caught in non-compliance can be decreased. Equation [2] has therefore been referred to as the “hang the prisoner with probability zero” proposition (after Becker 1968).

Increased effort on behalf of the police authorities increases on average the probability of being found guilty. As effort is costly, it is tempting to set penalties high to reduce resources that need to be devoted to law enforcement.

Under uncertainty about the accused being guilty, the applicability of strict sentences may be limited (Shavell 1987; Mitchell and Shavell 2000) for two connected reasons: First, the consequences of any errors made by the police increases with high penalties (and are uncorrectable under capital punishment). Second, in any democratic society, high penalties therefore increase the burden of proof on behalf of the prosecutor, which in turn has two undesirable effects: (i) it increases the litigation costs, and (ii) it becomes less likely that the accused will be found guilty. The probability of being found guilty and the size of the penalty are therefore both endogenous variables. Romstad (2006) summarizes further extensions on monitoring and compliance like reputation based models and how to deal with uncertainty about compliance performance.

These insights also carry over to contracts. Under uncertainty about compliance with contract terms, high penalties for failure to comply with these terms may increase the payment needed for the provider of goods and services under the contract (in our case forest owners) to accept contract terms. Most contracts therefore limits punishable damages (*S*).

5 Incomplete monitoring is optimal if it is costly for the regulator to monitor agent behavior.

3.3.2 Expected compliance and bidding behavior

Truthful revelation of costs in the bidding process also depends on agents' expectations about having to deliver the contracted management from the auctions. This is equivalent to the information value of prices generated in tradable permit markets (Malik 1990), where the prices generated under expected noncompliance are grossly deflated. Auctions will of course be subject to the same kind of issues.

An agent with a low bid from a uniform price multi contract auction signals low costs of meeting contract terms. This implies that the costs of complying to contract terms is low, which in turn means that the gains from not complying to contract terms, $\Delta U_i = U_i^n - U_i^c$, are low. Using [2] this enables making the condition for compliance agent specific:

$$\gamma_i \geq \frac{\Delta U_i}{S} \qquad [3]$$

There is one problem about utilizing [3] to tailor agent specific monitoring probabilities: it removes the linkage between the bid and expected payoff that induces truthful revelation in uniform price multi contract auctions. It would be tempting not to inform agents about this linkage to preserve truthful revelation in the bidding process, but most likely news would leak about this connection. This could reduce the public's trust of the environmental regulatory agency, and damages related to conflict resolutions could be quite harmful. Moreover, such behavior is not conducive with what the public has the right to expect from public agencies.

One insight that can be used from [3] is to signal to bidders that while there is a maximum fine for noncompliance, the size of the expected penalty will be set so that among all agents receiving a contract, the expected payoffs of compliance will exceed the expected payoffs of noncompliance (Romstad and Alfnes 2012). Figure 6 provides a numerical illustration of the perceived behavior when the expected penalty, γS, is ex ante fixed to 30.

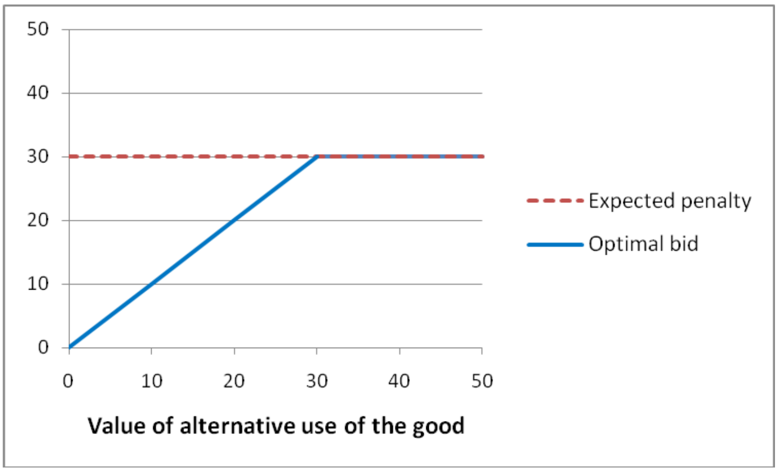

Figure 6: The expected penalty and bidding behavior (Romstad and Alfnes 2012)

The numerical illustration captures the theoretical result that agents with alternative values above the expected penalty of 30, will bid exactly 30. This corresponds to experimental valuation results for marketed goods – if a chocolate bar is sold that people know have a market price of 30 in the experiment, nobody will bid above 30 for it. The known penalty provides the forest owners with information about society's implicit valuation of the contract. Hence, if awarded a contract, agents with higher costs of complying than the expected penalty will not comply to contract terms.

As long as the regulator does not know what the cutoff price will be, it cannot set the size of the expected penalty without running into the risks of the outside option. On the other hand, an unknown penalty may make environmental management contracts less desirable from the viewpoint of forest owners. Before the bidding starts, the regulator must therefore inform potential bidders that the size of the expected penalty, γS, will exceed the (yet unknown) auction price, but that it will not be unreasonably higher. One way of securing this is to fix the ratio of the expected penalty, for example by setting $\gamma S = 1.25\, p$, where p is the auction price.

Another way to partially correct for this failure is to apply reputation based monitoring schemes along the lines of Greenberg (1984), where the monitoring probability is adjusted based on past compliance history, but damages to the reliability of parts of the bid curve has then already been made.

However, reputation based models for monitoring and enforcement can be used once the system is implemented to gradually make monitoring probabilities agent specific as illustrated in [3]. As a matter of fact, [3] provides an important yardstick to how far down the monitoring probabilities can be adjusted for habitual compliers.

3.4 Physical and spatial issues pertaining to environmental goods and services

This section exemplifies some of the spatial issues to biodiversity, and area where the spatial issues are clear and easy to see. It is already well established that different species have different requirements in terms of habitat size or distance between habitats. By making policies forest type and region specific, some of these differences in requirements will be captured as the species composition varies across forest types and climate regions. Moreover, our focus on the need for forest type and region specific policies is an implicit acknowledgment that least cost is a relative term that needs to be seen in relation to perceived benefits. On the other side, to preserve the price taking behavior needed for uniform price multi contract auctions to work as intended, one cannot make regions too small or forest type too specific. This implies that it may be necessary to add extra elements into any policy to capture spatial issues.

Decentralized policies, like auctions, have been criticised for not being able to capture the need for spatial coordination (Vatn *et al.* 2005). 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 full information solution, both because the "wrong landowners" are enrolled and because of the inability to price discriminate. The Nelson *et al.* (ibid.) finding also holds for spatially coordinated policies as long as these involve separate properties. Under coordinated policies among individual property owners, the idea is that deliberations will result in better coordination (Vatn *et al.* 2006). Such negotiations can be viewed as a game, which involves many of the same asymmetric information issues. To sum up, deliberative processes do not guarantee that information asymmetries between landowners will be fully resolved. Moreover, if a collection of landowners reach an agreement, their negotiation power vis-a-vis the regulator may be stronger (for example if few other collections of coordinated land owners exist), which increases the risk that these landowners will seek to utilize their oligopoly powers.

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 property a function of the responses of neighboring properties (Drechsler *et al.* 2007, Lewis and Plantinga 2007, Lewis *et al.* 2008, Parkhurst *et al.* 2002, Parkhurst and Shogren 2007, 2008, Warziniack *et al.* 2007). This literature shows that it is possible to coordinate decentralized landowner decisions by making payoffs contingent on neighbors' decisions.

The basic conclusion, however, on spatial coordination is that trying to optimally coordinate across multiple landowners with private information to get an optimal pattern of conservation is a difficult, and yet not fully solved problem. This holds for decentralized as well as centralized policies due to the inherent information asymmetries involved.

4 Procurement auctions and the environment – some special issues

This section deals with the design of auctions for environmental conservation and management contracts. Three key issues are truthful revelation of costs, the implications of compliance on bidding behavior, and spatial coordination. The latter is of particular concern when using auctions as they by their original design are decentralized decisions.

4.1 Revelation of agents' private information

When conservation or environmental management contracts are to be allocated, the agency would like to assign all contracts of one kind in a region at once to reduce the opportunities for strategic behavior among landowners. This implies that the agency faces the issues of multi contract auctions. Unfortunately, few N+1 price auctions have been used to allocate conservation or environmental management contracts.

The standard multi unit auction setting involves identifying low cost providers. The implicit assumption behind such an approach is that all potential providers have equal quality of the environmental assets in question. In such cases any standard N+1 price procurement auction would succeed in maximizing net benefits.

4.1.1 Extended asymmetric information in the standard N+1price setting

Polasky and Romstad (2012) extends this analysis by assuming that in addition to having private cost information, agents (landowners) also have better information about (some) environmental attributes on their land than the agency. On the other hand, the environmental agency has better information than landowners about what is to be conserved or managed. Maximizing net benefits under these settings corresponds to solving the matching problem of attracting low cost providers with the desired (high) conservation values on their land.

Polasky and Romstad (2012) introduce a survey fee to create a separating equilibrium between high and low quality habitats that has to be paid if a site is surveyed. This fee creates a separating equilibrium (Rotchild and Stiglitz, 1976) between landowners who have more secure information about having high quality habitat and those with less secure priors.

Following Polasky and Romstad (ibid.), let c_i denote the costs (foregone profits) and b_i the bid for landowner i of having a contract, let α_i^h be the subjective probability agent i has for habitat i satisfying contract eligibility criteria , let y be the contract price, and let φ denote the survey fee any landowners pay per habitat that is surveyed. Because landowners are uncertain about the quality of the pre-survey signal of quality (a low α_i^h), indifference between bidding and not bidding creates a markup in the bid that implies that the bid is given by:

$$b_i = c_i + \frac{\varphi}{\alpha_i^h} \quad \text{where} \quad \frac{\varphi}{\alpha_i^i} \quad \text{is the markup fee} \qquad [4]$$

Consequently, agents with low priors, i.e., a low α_i^h, will be "underrepresented" among the low bidders. This creates a separating equilibrium that enables reducing surveying costs by surveying the lowest bids first.

Landowners are endowed with resources that also determine their costs of conservation or environmental management. The order of the moves are as follows: (1) the landowners receive an imperfect (high or low) signal about the conservation quality of their habitat, (2) landowners decide to bid or not, and if they bid they decide on the size of their bid(s), (3) bids are sorted in an ascending order and surveyed sequentially, starting with the lowest bid, (4) surveyed habitats are charged with the survey fee, φ, (5) landowners with habitats that pass the survey are informed they will get a contract, (6) surveying continues until the conservation target is met or the agency's budget for this conservation program is exerted, and (7) the price, *y*, is set by the N+1[th] bid. Figure 7 explains the order of the moves.

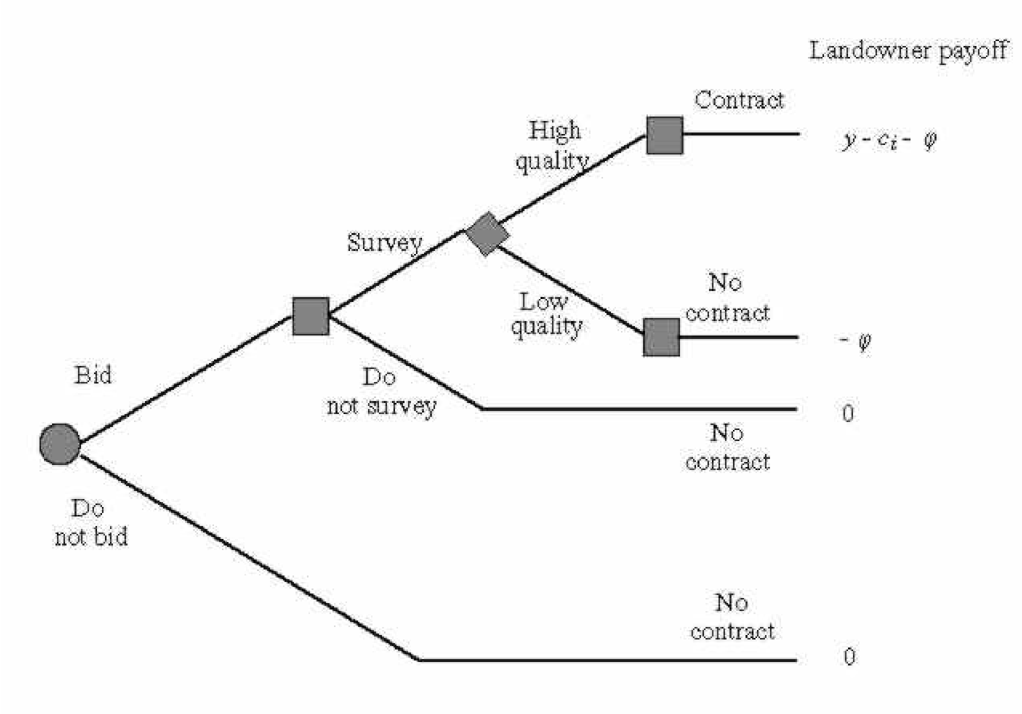

Figure 7: The decision tree summarizing the order of moves and landowner payoffs. A circle indicates landowner choice, a square indicates conservation agency choice, and a diamond indicates the outcome is due to chance. The initial move of nature that generates a high or low signal to the landowner is not shown.

An intriguing property of the Polasky and Romstad (ibid.) mechanism is that it is not manipulation free under some restrictive, but unlikely conditions. Suppose:

- an agent *j* has extra knowledge about the distribution of costs and hence the bid structure[6],
- the same agent *j* adjusts his bid so $b_{N+1} < b_j < b_{N+2}$, and

6 If bidders on a contract are form the same area one cannot rule out that elements of such information is available to some agents, cfr. Seabright's (1993) work on local commons.

- that the N+1 bid does not pass the survey eligibility criteria.

Then the equilibrium price, $y' = b_{N+2}$, differs from $y = b_{N+1}$, i.e., the compensation paid price has been manipulated and landowners get an extra rent equal to $b_{N+2} - b_{N+1}$.

How likely is this to happen? It depends on how accurate is the information landowners have about the bid distribution which involves two elements, the costs, c_i, and the markup, φ/α_i^i, which again contains the subjective beliefs of agent i. In brief, chances appear to be small.

4.1.2 Designing an experiment to test strategic bidding in the Polasky-Romstad mechanism

Section 2.3 describes the basic framework for testing multi unit uniform price auctions. The more challenging part is how to conduct the experiment. While this experiment has not been conducted, and most likely never will in relation to the work Polasky and Romstad (2012), it is a setting that is worth while to think about.

Polasky and Romstad (ibid.) claim that manipulation of this auction is possible but highly unlikely. It would therefore be of interest to test when agent behavior suggest that efforts to manipulate the proposed mechanism. I see the current experiments taking place:

(a) The *Polasky-Romstad information setting*, i.e., participants are given a distribution of costs, knowledge about the distribution of high and low quality assets, and some uncertainty about own asset quality.

(b) Knowledge about the distribution of costs, uncertainty about other participants' prior beliefs on asset quality, but full certainty on own asset quality. Let the uncertainty about other participants' priors be given by a binomial distribution, and let the distribution of bids be known.

(c) Full information about costs, uncertainty about other participants' prior beliefs on asset quality, but full certainty on own asset quality. Let the uncertainty about other participants' priors be given by a binomial distribution with for example half of assets being of high quality. One implication of this information set up is that no participant knows the sequence of winning bids with certainty, which makes it more difficult to bid strategically.

(d) The *full information setting*, i.e., supply participants in the experiment with full information about the cost structure of other agents, their prior beliefs about the quality (high or low) asset (in “real life” the habitat is of high or low quality), complete certainty about the quality of own asset, and how many contracts that are to be awarded. This basically means that any participant should be able to figure out the sequence of winning bids (sufficiently low bids and with a high quality asset). Under this setting, no participant with a low quality asset would enter the auction as it entails the risk of paying the survey fee, φ, without getting any returns.

(e) A *collusion setting*, where participants have the Polasky-Romstad information, but are allowed to talk and coordinate bids, but where bids handed in are still the private information of participants. This experiment would test the robustness of the independent bids conditions behind auctions.

The outcomes of the experiments may depend on the order in which the experiments are conducted. Therefore, in repeats of the experiments, I would also consider the order a-e-d-c-b.

4.2 Compliance and strategic bidding

Section 3.3 looked at impacts of compliance and bidding behavior. Here, I foresee two experiments of relevance: (1) Bidding behavior and the existence of an outside option, and (2) Impacts on bidding behavior when agents know bids will be used to monitor contract compliance. In both cases the compliance issue would be captured by allowing participants to resell their asset at the risk of being caught and being levied a fine, *S*.

4.2.1 Bidding behavior and the existence of an outside option[7]

Section 3.3.2 of this paper looked at the impacts of bidding behavior when there exists an outside option. This would be one aspect of the bidding-compliance relationship that it would be of interest to test experimentally. After the initial trials with the *N*+1 auction to make participants familiar with the auction mechanism, the basic test would consist of three experiments involving the size of the expected penalty, γS:

- The prior announcement of the expected penalty, where it is below the expected cutoff price. In this experiment one would expect to see the kinked bidding curve of Figure 6.
- As above, but with the expected penalty set above the expected cutoff price. Again, one would expect a kinked bid curve as in Figure 6, but it would not influence who gets the contract.
- A situation where participants are informed that the expected penalty is set after the cutoff price in the auction is determined, so that one would expect all bids to truthful, i.e., around the 45 degree line in Figure 6.

After each of the above auction rounds, we would test actual compliance performance.

4.2.2 Bidding behavior when monitoring probabilities depend on bids

From equation [3] (also on page 12) it follows that the necessary monitoring probability to secure compliance varies among agents depending on the difference between the state dependent payoffs of noncompliance and compliance, i.e.,

$$\gamma_i \geq \frac{\Delta U_i}{S} \qquad [3]$$

This implies that the regulator could reduce monitoring effort by differentiating the monitoring probability between agents. Romstad, Alfnes and Qvale (2008). They looked at bidding behavior with uniform monitoring probability (experiment I and II) and a bid dependent monitoring probability (III).

Each experiment consisted of the following steps:

(1) Each participant receives an induced value card that is their private information.

(2) A reverse *N*+1 price auction for contracts (multi unit contract auction with single unit contract sellers) for not selling the induced value cards to third party.

(3) Auction price and winners announced.

(4) Possibility of selling the induced value cards to a third party at a price equal to the induced value.

7 This experiment is to be conducted early this fall with Frode Alfnes.

(5) Monitoring of a percentage of the winners to see if they have complied to the contract of not selling to the third party, or if they have broken the contract and sold to the third party (in experiment one all agents were monitored).

(6) The participants get their monetary rewards.

The bid dependent monitoring probability was structured a bit differently from [3] in the sense that participants were informed that the monitoring probability would be half for the lowest half of those receiving a contract compared to the others receiving a contract. Figure 8 shows a graphical representation of the bids.

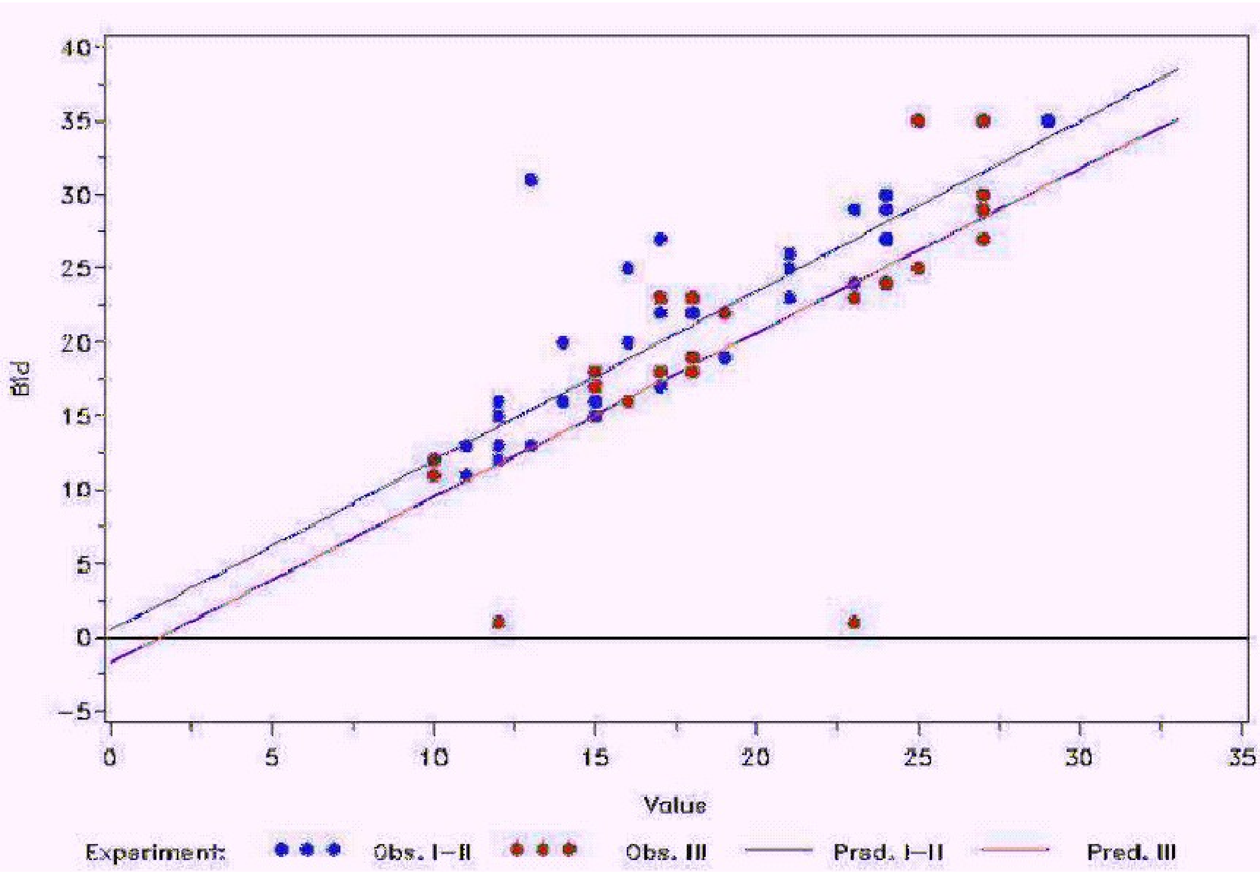

Figure 8: Bidding behavior under uniform and differentiated monitoring probability. (Romstad, Alfnes and Quale, 2008)

The two most noteworthy aspects of Figure 8 is the bidding behavior of two participants (the red dots of bids close to zero) and the downward adjustment in the predicted bids in experiment 3. However, not too much emphasis should be placed on these results because as we worked through the data we saw that the experiment was not that well designed. This was particularly the case for the penalty structure that was changed from [3] to the tiered monitoring probability.

When testing for compliance, we found that compliance increased with increased expected penalty, γS, as predicted. Again, this result came about because the condition [3] was not met for all agents implying that agents could benefit from cheating at some point.

This experiment was our first compliance experiment. Needless to say, we committed several errors due to not being very careful in our specification of the penalty structure.

4.3 Spatial coordination

As mentioned in section 2.2 auctions constitute a highly decentralized decision process, implying that the spatial coordination may be insufficient. This is clearly an issue for biodiversity, where species thrives under various shapes and sizes of habitats. In a series of experiments Parkhurst and Shogren (2005, 2007), Parkhurst *et al.* (2002), and Warziniack *et al.* (2007) tested what they term an *agglomeration bonus*, i.e., auction payoffs were increased by a pre-announced bonus (subsidy) if certain spatial patterns were entered into the bids. Their results are quite promising that one can increase the conservation benefits by careful selection of such bonuses.

5 Non-market valuation

There are many difficult issues related to stated preference elicitation. The contingent valuation (CV) method is one that probably has received the most attention in this regard (see for example Diamond and Hausmann, 1994; and the response by Hahnemann, 1994). The community of CV researchers have been quite responsive to these concerns, but many argue that the proposed fixes have not solved the fundamental issues of CV (see for example Harrison, 2006).

Mitchell and Carson (1989) argue that dichotomous choice formats solve the issue of truthful revelation. While it is possible to show that closed ended CV studies have weak incentives for truthful revelation, other problems – like the absence of a budget constraint – remain. This brief section on non-market valuation seeks to outline how the budget constraint could be "reintroduced" in CV studies using a variant of the Becker-de Groot-Marschak (1964) (BDM) mechanism described briefly in section 3.3.

Unlike in the classical BDM mechanism where the price is determined by a random draw from a know distribution, consider that the price is set by the bid of the voter whose bid is just below the median voter bid. In theory this would imply that the proposal would pass a referendum. Provided that the revenues one could collect from such a tax (the bid just below the median bid times the number of tax payers) covers the costs, one has introduced budget constraint onto respondents that:

(1) is binding in a probabilistic sense, and

(2) is endogenously determined by the bidding procedure.

Concerns about the BDM providing incentives for truthful revelation have been voiced because of the randomness in setting the price, and Horowitz (2006) showed that even when the price is not set randomly, the BDM may not lead to truthful responses on willingness-to-pay.

Rather than going into further details on this issue, I will focus on how an experiment could be set up to test for truthful revelation of the proposed mechanism. The experiment contains follows the standard BDM approach except that the price is determined by the next lowest bid to the median bid.

6 Concluding remarks

This paper has presented some of the relevant auction theory in terms of environmental goods and services. Multi unit uniform price auctions in various variations are at the center of attention, in particular for obtaining estimates of the costs of supplying environmental goods and services.

There are limited experience on the performance of multi unit uniform price auctions relative to the discriminatory price auctions. The problem with using discriminatory price auctions is that there ar incentives for strategic bidding. In turn, that may give rise to questions on the legitimacy of policies founded on results from auctions. Until there has been more experience on the cost differences between uniform and discriminatory price auctions, care should be taken advocating the latter because without securing truthful revelation in the elicitation process we have no way of knowing the size of the strategic biases.

I expect a growing number of applications of auctions onto environmental issues in the years to come. Good experimental research will greatly improve the quality of these applications, and will serve as a source for further development of auction theory onto what loosely is called "public goods". The dire fact that the term is loose, should not justify sloppy practices.

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