Adapting Auctions for the Provision of Ecosystem Services at the Landscape Scale

Andrew Reeson,[1,2]✉ Luis C. Rodriguez,[1] Stuart Whitten,[1] Kristen Williams,[1] Karel Nolles,[2,3] Jill Windle[4] and John Rolfe[4]

[1] CSIRO Sustainable Ecosystems, Canberra, Australia

[2] Faculty of Agriculture Food and Natural Resources, University of Sydney, Australia

[3] Aton Experimental Economics, Sydney, Australia

[4] Centre for Environmental Management, CQUniversity, Rockhampton, Australia

✉ Correspondence: andrew.reeson@csiro.au; GPO Box 284, Canberra 2601, Australia. Tel: +61 2 6242 1640 Fax: +61 2 6242 1705

Abstract

Auctions, or competitive tenders, are capable of overcoming information asymmetries to efficiently allocate limited funding for the provision of ecosystem services. Most auctions focus on ecosystem services on individual properties to maximise the total amount provided across the landscape. However, for many services it is not just the total quantity but their location in the landscape relative to other sites that matters. For example, biodiversity conservation may be much more effective if conserved sites are connected to other conserved areas. Adapting auctions to address ecosystem services at the landscape scale requires a good scientific understanding of the biophysical system. It also requires an auction mechanism which can promote coordination while maintaining the competition required to overcome information asymmetries. Iterated auctions, in which bidding is spread out over a number of rounds, with information provided between rounds on the location of other bids in the landscape, offers an approach to cost effectively deliver landscape-scale ecosystem services outcomes. Experimental economic testing shows that these auctions work best when the number of rounds is unknown in advance, which minimises rent seeking behaviour. It also shows that a bid improvement rule facilitates coordination and reduces rent seeking. Where the biophysical science is well developed, such auctions should be relatively straightforward to implement and participate in, and have the potential to provide significantly better outcomes than standard 'one-shot' tenders.

Keywords: Conservation; competitive tender; experimental economics; ecosystem services; market-based instrument

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1. Introduction

Payments for ecosystem services (ES) are increasingly being applied to promote conservation and other environmental policy goals. Auctions, or competitive tenders, are a proven method of overcoming information asymmetries concerning landholders’ private costs and ensuring the efficient allocation of limited ES payments (Latacz-Lohmann and Van der Hamsvoort, 1997; Stoneham et al., 2003). In an ES auction, landholders submit bids to provide ES in return for a payment. Landholders are free to choose the level of their payment. However the auction mechanism is competitive, with only those that offer the best value for money (quantity of ES provided per dollar requested) likely to be successful. Most ES auctions adopt a sealed bid, discriminatory price mechanism, in which successful landholders are paid their bid price (e.g. Stoneham et al., 2003; Windle et al., 2009). A rational landholder will request at least the opportunity cost of providing the ES; they can ask for more, but the higher their price the less likely they are to have their bid accepted.

In order to rank the offers made by landholders in an auction, a metric is required to measure and compare the level of ES provided by alternative bids. A number of metrics have been developed for conservation auctions, such as habitat hectares and the biodiversity benefits index (e.g. Chomitz et al., 2006; Oliver et al., 2005; Parkes et al., 2003; Wünscher et al., 2008). These calculate the value of each bid in terms of ecological outcomes, and express it as a single unit. This means the auction mechanism can select the individual projects which provide the best value for money. However, by focussing on individual bids this approach will not necessarily select the optimal spatial configuration of conservation projects across a landscape. This paper considers how ES auctions may be modified to address the landscape-scale. The following section considers the ecological basis for the type of metric required for landscape-scale auctions, and section three considers how incentive payment mechanisms could be structured. Section four describes the experimental testing of alternative auction mechanisms, with the results presented in section five, followed by discussion of the policy implications in section six.

2. Landscape-scale conservation

In many cases the effective conservation of biodiversity requires a landscape-scale approach, rather than a focus on individual properties. Landscape-scale conservation is broadly based on the idea that: (1) initiatives should encompass some regional system of interconnected areas; (2) efforts are in some way organized to achieve one or several specific conservation objectives; and (3) various landholders within a given conservation region cooperate or collaborate in some concrete fashion to achieve those objectives (Levitt, 2004). Connectivity between conservation sites facilitates dispersal of biota, potentially increasing the contribution that individual management actions make toward the goal of viable populations. Although different species respond to connectivity in different ways (e.g. Hostetler, 1999; Lindborg and Eriksson, 2004), the spatial configuration of sites is often critical to the biological success of conservation efforts (e.g. Drielsma and Ferrier, 2009; Jiang et al., 2007; McAlpine et al., 2006) and the selection of projects should be considered at a landscape scale in order to achieve lasting biodiversity outcomes.

The desired spatial configuration of conservation actions will depend on the characteristics of the target species or community, such as dispersal ability and range requirements. Species which are poor dispersers may require connected habitat, while others may be able to make use of stepping stones across a fragmented landscape. In some cases a mosaic of different habitat types may be required, for instance for species which use different resources at different times of the year. Other considerations, such as the length of habitat edge and the characteristics of adjoining land, can also be important. Some degree of habitat connectivity is required for most conservation outcomes in the short term. In the medium and long term it is likely to be of even greater importance, allowing species and communities to progressively adjust their ranges in response to climate change. The highly modified and fragmented nature of agricultural landscapes means that adapting to climate change may be particularly problematic for many species and communities.

Where there are landscape-scale objectives such as riparian networks and biodiversity corridors, the ecological metric becomes more complex. In this case the values are combinatorial – the biodiversity benefits from one project depend in part on which other projects are selected. This interdependency between sites is not new to conservation biologists who have long worked within the principle of biodiversity complementarity, a calculus for the marginal contribution each site makes toward the global option values of biodiversity (e.g. Faith, 1994). An auction to deliver a desired spatial configuration of conservation actions must therefore be underpinned by a metric which can account for these combinatorial values. As well as requiring very detailed ecological knowledge to quantify the conservation benefits of alternative landscape configurations, this also changes the mechanics of the auction mechanism. As the value of any one bid depends on which other bids end up in the final package, it is not possible to come up with a meaningful biodiversity value for an individual bid. Rather it is necessary to consider each possible combination of bids, and work out which combination provides the best biodiversity outcomes within the budget constraint. That is, the metric provides a measure of combined value rather than individual value.

3. Auction mechanisms

To address landscape-scale conservation objectives it is also necessary to have a mechanism for coordinating the actions of individual landholders to offer the desired configuration (or at least something approaching it), for example by offering adjoining parcels of land to form a wildlife corridor. Coordinating the actions of autonomous agents is difficult as it requires them to have both information about the actions of others and an incentive to coordinate with them. A series of studies by Parkhurst, Shogren and others investigate the use of a ‘smart subsidy’, which is a fixed payment with an agglomeration bonus, to provide an incentive for neighbouring landholders to coordinate their offers (Parkhurst et al., 2002; Parkhurst and Shogren, 2005, 2007). In laboratory experiments, the bonus mechanism was successful in prompting experimental participants to coordinate their actions for a number of simple spatial configurations. These approaches build on game theory in which the complete payoff matrix is known and/or private information of other agents’ costs and benefits is available. With complete information coordination may occur if it is a clear Nash equilibrium.

In more complex and realistic coordination experiments the bonus mechanism proved less effective (Parkhurst and Shogren, 2007). Where there is no clear equilibrium, agents will require an additional mechanism in order to coordinate their actions. In experimental games, iteration can promote coordination as agents acquire information on the strategies of others. For example, in diverse experimental designs subjects generally fail to attain the desired outcome in a one-shot game, but are successful in achieving the goal as the game is repeated (e.g. Clark and Sefton, 2001). Iteration has been shown to promote coordination by neighbouring landholders in economic experiments; coordination was more likely when the experiment was repeated, and participants were able to use their experience from previous rounds (Parkhurst and Shogren, 2007). Iteration combined with incentives for coordination therefore has the potential to facilitate coordination among autonomous agents.

A conservation auction with multiple bidding rounds offers a mechanism through which landholders can identify potential synergies with other bids and adjust their own bids accordingly (Rolfe et al., 2009). It could allow landholders to converge on a coordinated solution without having advance knowledge of each others’ costs and likely strategies. In an auction setting, as opposed to a fixed payment scheme, landholders have an incentive to coordinate their offers even in the absence of a bonus. Provided the bid assessment process places a positive value on connectivity, bids which coordinate with others will have a greater chance of success. All things being equal, landholders should therefore attempt to submit offers which align with those of their neighbours. Therefore multi-round auctions, in which landholders are provided with information on the location of offers from the previous round, have the potential to promote the coordination required to achieve landscape connectivity (Rolfe et al., 2009; Windle et al., 2009).

However, auctions work by compelling landholders to compete, thereby revealing their costs and enabling the purchaser to select those projects with the lowest cost per unit of biodiversity. In a discriminative price auction, bidders are likely to inflate their bid prices above their true costs, depending on their expectations of their costs relative to other bidders, in order to seek a surplus (Latacz-Lohmann and Van der Hamsvoort, 1997). If an auction is repeated, bidders' expectations will become more accurate and those with low costs will increase their price to the average value, eroding the efficiency benefits (Schilizzi and Latacz-Lohmann, 2007). There is evidence of this occurring in the US Conservation Reserve Program (Kirwan et al., 2005; Reichelderfer and Boggess, 1988). There is also a danger that a mechanism intended to promote coordination among landholders may at the same time promote strategic behaviour. For example, neighbours may collude on price, or an individual near the centre of a potential corridor may be tempted to submit a bid price well in excess of costs.

A critical problem in corridor formation is individuals not participating, or holding out for excessively high prices. In this form of iterated auction there will be greater opportunity for participants to identify and work around such hold-outs. Where there are different ways of forming a corridor across a landscape, corridors can evolve over multiple rounds according to the bidding behaviour of individual landholders. Potentially an iterated auction may deliver a coordinated outcome across a number of landholders without the need for complex negotiation. A confidential discriminatory price mechanism also means that different landholders can be paid different amounts based on their opportunity costs, whereas in collective negotiations it is likely that all would seek the same payment, which would have to be at least as much as the highest individual opportunity cost.

4. Experimental testing of auction mechanisms

Competitive tenders for ES are effectively multi-unit procurement auctions, a type of auction for which theory is relatively under-developed (Schilizzi and Latacz-Lohmann, 2007). However, it is well established that relatively minor details in the design of auctions and other market institutions can have a major impact on market performance (e.g. Klemperer, 2002). The limited theoretical guidance on the design of iterated auctions for conservation necessitates an experimental approach. Experimental economics provides a methodology for integrating human decision-making behaviour with economic theory. Real people display a raft of psychological and behavioural complexities which are lacking in abstract economic agents. Experiments can reveal these features, and show how people respond to alternative economic mechanisms. This experimental methodology can therefore be used to test and compare alternative auction mechanisms to determine how people respond, in terms of coordinating their offers while still competing on price, and so measure how successfully the environmental objective is achieved.

There are a variety of ways in which an iterated auction might be structured. The number of rounds is clearly a crucial issue, and may or may not be known to participants in advance. An unknown end point may result in some participants missing opportunities to make or modify their offers; on the other hand it may reduce strategic behaviour, as there is always the chance that the auction will close and a participant who is holding out will end up missing out. Providing information is critical to enabling landholders to coordinate their bids. Identifying the locations of the most competitive bids can provide a basis for other participants to coordinate with. However, the iterated auction process may cause participants to focus more on price competition than on modifying the configuration of their bids to coordinate with their neighbours. There is potential for those who find a corridor forming around them to try raising their price in order to extract some extra rent, behaviour which could hamper coordination and erode any efficiency benefits of the auction process.

Experimental economics was applied to test and compare a number of variations of iterated competitive tenders under controlled laboratory conditions. Thirty independent auctions were run in which a number of parameters were varied. Auctions were run with two, three or four rounds in total, where the number of rounds was known to participants from the beginning. In another treatment, the number of rounds was unknown to participants, so they could not be sure whether the current bidding round would be their last opportunity. In the standard version of the auction, all bids could be modified between rounds. This was compared to an alternative, in which provisional winners were locked in between rounds – neither the price nor the area offered could be adjusted, nor could the bid be withdrawn.

Table 1: Experimental variables and treatments

Variable	**Treatments**
Number of rounds	Two, three or four
Known endpoint	Number of rounds known or unknown to participants
Bid improvement rule	Provisionally winning bids locked-in, or can be modified

Software was developed to create a simulated landscape linked to an auction for land-use change, with a simple combinatorial metric for selecting the optimal package of bids within a budget constraint. Human subjects took on the role of landholders. The landscape consisted of 400 cells, with each cell assigned to one of ten properties. Participants were presented with a map showing the whole landscape, with the various property boundaries marked out (figure 1). The landscape was homogenous, with the same production and conservation values for every cell. This provided a simple, context-free landscape in which to test and compare alternative auction mechanisms. If a landholder chose to do nothing in the experiment, they would receive the production values of the cells in their property at the end of each experimental 'year' – this represents a baseline income from agriculture. According to standard experimental economics protocols, participants were paid based on the income they 'earn' in the experiment, which means decisions have real financial consequences.

To test the auction mechanisms, participants were told that they had the opportunity to rent out some, or all, of their land. Terms such as 'conservation' were avoided to keep the context as neutral as possible. If land was successfully rented out, the landholder would not receive its production value, but they were free to determine the payment they required for renting it. To offer their land for rent, participants could click on the cells they wished to offer, and then enter a price. They were told in the initial instructions that if the price they asked for was less than the production value of the land they could lose money from entering the auction. They were also told that it was a competitive auction, so the higher their price, the less chance they would have of successfully renting their land. In each auction round, participants had three minutes in which to enter their bids.

A global optimisation was used to select the package of bids which provided the best ‘biodiversity value’. The assessment metric consisted of a fixed value for each cell conserved plus a connectivity bonus, which added a weighting for connections between conserved cells. There was also a ‘north-south’ bonus, an extra weighting for connectivity in a north-south (i.e. top to bottom on the map) direction, to reflect situations in which connectivity in a particular direction is preferred. The overall biodiversity value for a landscape with a particular package of bids is the sum of the conservation value of each conserved cell plus its connectivity weighting bonuses. The instructions told participants that the purchaser preferred to rent cells that were connected to other rented cells, and that it preferred top-bottom connections. It was explained that their offer was more likely to be successful if it was connected to other rented cells. This provides the incentive to coordinate with neighbours. Participants were restricted to two bids each per round in order to make the optimisation tractable in an experimental setting.

Once participants had submitted their bids, the combinatorial bid assessment metric was applied to select the package of bids that provided the best value, considering conservation value and connectivity. Once the calculation was complete, participants’ screens were updated to show the results. If the auction was not yet complete, bids that formed part of the best package were identified as ‘provisional winners’. Participants could see the location of all provisional winners in the landscape, and their screen also labelled their own bids as either provisional winners or unsuccessful. The auction was then re-opened, and participants had the opportunity to modify their bids (by changing the price or the cells offered) or enter additional bids (still with a maximum of two). If participants chose to do nothing, their bids remained live. The bid assessment metric was then re-run to select the optimal package of bids.

5. Experimental results

Individual bidding behaviour, and overall simulated biodiversity outcomes, were analysed with general linear models (GLM) using Genstat (9th edition). The level of rent seeking and simulated biodiversity values were used as measures of the efficiency and cost-effectiveness of bids submitted in the various auction mechanisms. The lower the rent seeking the better the auction performs in terms of revealing costs and hence efficiently allocating funding. The overall biodiversity value achieved in each simulated auction provides a measure of the effectiveness of each auction mechanism. Mechanisms which promote increased connectivity will have higher biodiversity outcomes, as will mechanisms which result in lower rent seeking (as more land can be acquired within the budget constraint).

Rent seeking

Rent seeking was assessed by considering the profit (price requested – opportunity cost) in each bid as the dependent variable. Profit was normalised with a log transformation in order to meet the assumptions of GLM. The small number of bids with a negative or zero profit were assigned a value of one to allow the transformation. The price of each bid was included in the model to account for differences in profit between bids covering larger and smaller areas. Variables were included in the models for the known/unknown endpoint and the bid improvement rule (on/off). The total number of rounds was included as a continuous variable. To avoid problems of repeated measures, analyses used a single bidding round of each auction replicate.

Considering bids from the first round of each auction, rent seeking was significantly greater when the number of rounds was known in advance (F=4.05; p<0.001). The lock-in rule for provisional winners had no effect on rent seeking in the initial round (F=1.42; p=0.156). This suggests that the rule does not cause people to raise their prices initially, even though they are prevented from subsequently raising their price if their offer is a provisional winner. Considering only the first round of each experiment in which the number of rounds was known, rent seeking showed a significant positive relationship with the total number of rounds (F=2.08; p=0.039). By the final round this effect had disappeared (F=0.28; p=0.777). This suggests that participants in longer auctions initially ask for higher prices in the knowledge that they will have more opportunity to subsequently reduce their price if they are not competitive. Therefore increasing the number of rounds will not necessarily improve overall efficiency.

In the final round of each auction, rent seeking remained significantly higher when the total number of rounds was known to participants (F=2.30; p=0.022). This is a surprising observation, as in the known endpoint treatment participants were fully aware that this was the final round, yet rent seeking remained higher than in the unknown endpoint treatment, where there remained the possibility of additional rounds. The total number of rounds had no effect (F=0.12; p=0.903). By the final round, rent seeking was significantly lower where provisional winners were locked-in (F=2.52; p=0.12). These results suggest that the lock-in rule does not cause people to raise their bid prices initially, but does succeed in preventing provisional winners from seeking greater profits in subsequent rounds.

Overall landscape values

The combinatorial metric used in the experiments provides a measure for the overall simulated landscape biodiversity value achieved under the various experimental treatments. Data were analysed by GLM using the same treatment variables described above. ‘Funds spent’ was included as a covariate to account for small differences in the amount of available funding that was allocated to each optimal package (as the optimisation did not accept fractions of bids). In the last round of each auction, biodiversity value was significantly higher when the total number of rounds was unknown to participants in advance (F=2.63; p=0.015). Considering only the known endpoint treatment, biodiversity value was significantly positively correlated with the total number of rounds. Overall value was higher with the lock-in rule, although this was not significant at the 5% level (F=1.98; p=0.060).

6. Discussion

Iterated auctions have the potential to address the key issues around the design of incentives for efficient provision of ecosystem services requiring complementary site actions to achieve landscape scale outcomes. By spreading the auction over a number of rounds, with information about the location of other bids in the landscape provided between rounds, coordination can occur across the landscape without the need for advance knowledge of others' likely actions or additional incentives. Coordination by individual landholders is rewarded by an increased probability of success in the auction. At the same time the competitive nature of the auction mechanism encourages landholders to accurately reveal their opportunity costs of carrying out conservation or other environmental management projects.

However, there are also risks in using multi-round auction mechanisms. Landholders are likely to learn more about their costs relative to other bidders over the course of the auction, resulting in those with lower than average costs inflating their prices. Conversely those who initially submit higher prices may learn to reduce their prices in order to be more competitive. The auction process is likely to be unfamiliar to most participants, so multiple rounds may provide an opportunity for them to learn about the auction mechanism itself and submit more considered bids in later rounds (even independent of strategic considerations) (see List and Shogren, 1999). In real-world applications (though not in our laboratory scenario), bidders are also likely to be uncertain about their true costs. In order to avoid risking the winner's curse they may submit higher prices initially, which they may revise down in the light of others' estimates of their own costs (Rolfe et al., 2009).

In our experiments, some participants appeared to focus more on price competition than coordination, strategically inflating their bid prices in order to seek additional rent. This was countered by the use of the bid-improvement rule, and not revealing the total number of rounds in advance. Having an unknown end point means that engaging in strategic behaviour becomes a risky business. As the auction can end at any time, someone who enters an inflated bid may not get the chance to reduce it if they are unsuccessful, and so may miss out entirely. Rent seeking was substantially lower in the initial rounds under this treatment, which is likely to reflect uncertainty about the end point. Lower bid prices increase the amount of ES (in this case, land conserved) that can be purchased in the auction, and hence its overall cost effectiveness. A more surprising result was that rent seeking was lower when the number of rounds was unknown than in even the final round where the end point was known. This suggests that the initial uncertainty has reduced strategic behaviour and prompted intense price competition.

The bid-improvement rule also resulted in more cost effective outcomes. It effectively ensures that the impacts of learning are unidirectional – participants may learn to lower their prices if their bids are relatively expensive, but are restricted in their ability to increase their price if their initial bid is relatively cheap. In our experimental scenario this treatment increased overall simulated landscape biodiversity outcomes. It prevented provisional winners from increasing their prices without causing them to be higher in the first place. The bid-improvement rule worked particularly well when the number of rounds was unknown – initial bid prices were lower, and the lock-in rule ensured they could not creep upwards.

A fruitful area for future research will be considering how the auction process may be spread over a number of years, similar in concept to the scheduling of priority conservation actions. In reality a funding agency will often have insufficient resources to achieve any significant degree of landscape connectivity in a single auction. Conservation plans and strategies are often implemented partially, in stages over a planning period with the number of sites and management actions constrained by a budget (Cowling and Pressey, 2001; Pressey and Taffs, 2001; Pressey et al., 2007; Sarkar et al., 2006). Conservation action scheduling can be represented as a multistage constrained optimization problem which aims to maximize the number of biodiversity types that have met their management targets by the end of a funding program. In these planning models, reserve design constraints such as connectivity and minimum area often interact with other conservation goals such as representation via complex objective functions (e.g. Kingsland, 2002; Oetting et al., 2006; Rothley, 2006).

A competitive tender for ecosystem services is only as good as the metric used to assess bids. Further work will be required on metric assessment and package optimisation in order to fully assess the benefits of alternative landscape configurations. Detailed ecological or biophysical knowledge is required as the basis for developing an effective metric. This combinatorial nature of the problem also creates a challenge for assessing offers. For even relatively small numbers of bids, the number of possible combinations rises rapidly. For example with just three bids (A, B, C) there are seven possible packages (A; B; C; AB; AC; BC; ABC). For five bids there are 31 possible packages, rising to over one thousand for 10 bids, one million for 20 and one billion for 30. Considerable computational power will therefore be required to assess even relatively small numbers of bids. With larger numbers the problem becomes NP-hard and cannot be solved. Search heuristics such as genetic algorithms or simulated annealing can be applied to find approximate solutions in such cases (Hajkowicz et al., 2007).

The policy recommendations from these initial experiments are clear. Iterated auctions can deliver coordinated outcomes most efficiently where the number of rounds is unknown to participants in advance, and provisional winners cannot raise their prices. These simple rules should be applicable in the field, although it will clearly be more complex than a traditional ecosystem services auction (e.g. Parkes et al., 2003). An agency may run the tender over a number of rounds, stopping once a desired ES target is reached. Clearly the transaction costs will increase with the number of rounds. Allowing bids to automatically carry over from one round to the next would minimise the extra transaction costs for participants imposed by the iterated process. Uncertainty about whether any particular round will be the last has been shown to reduce strategic bidding, which reduces the number of rounds required. These simple rules can enable complex landscape scale objectives to be achieved in a relatively straightforward and cost effective manner.

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Figure 1: Screen shot from the experimental scenario. The ‘landscape’ consists of 400 cells across 10 properties.