Applying Competitive Tenders for the Provision of Ecosystem Services at the Landscape Scale

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Abstract

Auctions, or competitive tenders, overcome information asymmetries to efficiently allocate limited funding for the provision of ecosystem services. Most tenders 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 is often much more effective if conserved sites are connected to other conserved areas to form a corridor or to increase suitable habitat area. Adapting competitive tenders 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, provides 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.

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1. Introduction

Payments for ecosystem services 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 scarce ES funding (Latacz-Lohmann & van der Hamsvoort 1998; Stoneham *et al*. 2003). In an ES auction, landholders submit bids to provide ES in return for a payment. Landholders are free to choose 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. Landholders whose bids are accepted are contracted to provide the ES. 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. The competitive nature of the auction mechanism encourages landholders to reveal their private information by submitting bids at or around their true opportunity cost of providing the ES.

Auctions have been applied for a range of ES. 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. For example, a number of metrics have been developed for conservation auctions, such as habitat hectares and the biodiversity benefits index (Parkes *et al*. 2003; Oliver *et al*. 2005; Chomitz *et al*. 2006; Wunscher *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 at the level of the individual property, this approach will select conservation projects which are scattered across a landscape.

This paper considers the design of payments for ES at the landscape scale, using conservation corridors as an example. Section two describes some of the landscape scale issues around biodiversity conservation. Section three addresses the issue of the coordinating individual landholders to deliver ES in desired spatial configurations. Sections four and five describe the application and results of an experimental economic study of iterated auction mechanisms designed to overcome the coordination issue while also addressing information asymmetry. The final section discusses the application of iterated auctions to conservation policy.

2. Ecosystem services at the landscape scale

The necessity of landscape-scale approaches to the conservation of biodiversity and ecosystem services is well known among land conservation professionals and biodiversity scientists. 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 landowners and managers within a given conservation region cooperate or collaborate in some concrete fashion to achieve those objectives (Levitt 2004). Since fragmented lands are often controlled by public and private landowners with varying objectives, landscape scale conservation initiatives are challenged by the complexity of managing linked socio-ecological systems over long periods of time (e.g. Swift *et al*. 2004).

Connectivity between conservation sites facilitates the dispersal of fauna and plant propagules, potentially increasing the contribution of individual projects to viable populations. Although different species respond to connectivity in different ways (e.g. Hostetler 1999; Lindborg & Eriksson 2004), the spatial configuration of sites is often critical to the biological success of conservation efforts (e.g. 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 tender 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.

There are two key issues to be addressed in scaling up from the individual property level. The first is scientific – it is necessary to identify the combinatorial values of ES provision at various points across the landscape. The second issue is coordinating 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.

3. Coordination issues

Coordinating the actions of autonomous agents is difficult as it requires agents 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 & 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 & Shogren 2007). Where there is no clear equilibrium, agents will require a 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 & Sefton 2001). However, in the case of public goods experiments, with repetition people commonly contribute less to the public good (see Hichri & Kirman 2007). This could influence auction design since repetition could lead to reduced efficiency (see Schilizzi & Latacz-Lohmann 2007).

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. However experience of a different coordination task hampered coordination (Parkhurst & Shogren 2007). Iteration combined with incentives for coordination therefore have the potential to facilitate coordination among autonomous agents. In a conservation auction it could allow landholders to converge on a coordinated solution without having advance knowledge of each other's costs and likely strategies. As discussed above, setting incentive payments at the optimal level requires full information, an impediment which can be overcome by an auction mechanism.

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*. 2005).

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. There is a danger that a mechanism intended to promote coordination among landholders may at the same time reduce competition. For example, neighbours may collude on price, or an individual near the centre of a potential corridor may be tempted to submit an offer well in excess of costs. Such behaviour will erode the efficiency gains achievable in an auction, and could result in the environmental objective not being met.

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 many 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 discriminate 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. Auction design and testing

To test different mechanisms where landholders might coordinate corridor formation, experiments have been conducted to replicate auction procedures. 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 offers 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 area of their bid 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.

Minor details in the design of auctions and other market institutions can have a major impact on market performance (e.g. Klemperer 2002). Economic theory provides limited guidance as to the design of iterated auctions for conservation, necessitating 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 how successfully the environmental objective is achieved. Experimental economics was applied to test and compare a number of variations of iterated competitive tenders under controlled laboratory conditions.

Software was develop 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, each with a defined land type, with an associated commodity production value and conservation value. The landscape was divided into ten properties, with each cell assigned to one property. Participants were presented with a map showing the whole landscape, with the various property boundaries marked out (figure 1). They could distinguish land types across the landscape, and commodity values for each cell on their own land.

Experiments featured ten participants, with approximately equal-sized properties. The landscape was homogenous, with the same commodity and production values for every cell. This provided a simple, context-free landscape in which to test and compare alternative action mechanisms. If a landholder chose to do nothing in the experiment, they would receive the commodity value of 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.

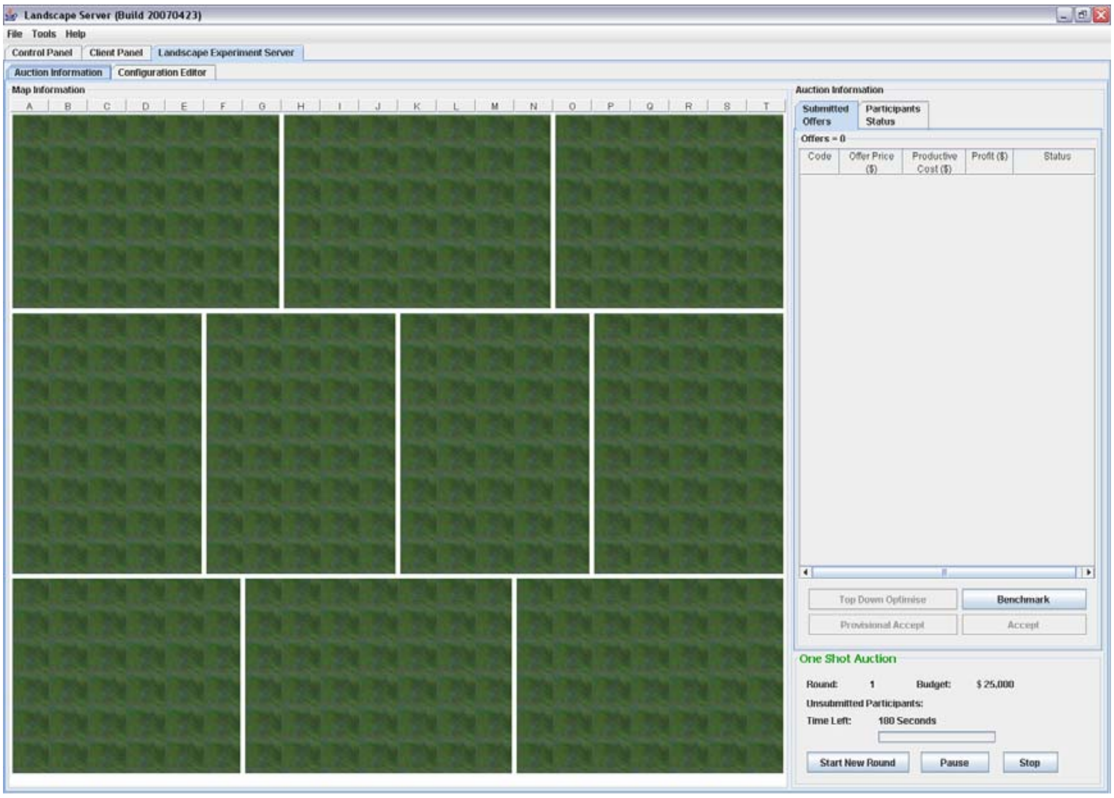

Figure 1: Screen shot from the experimental scenario. The ‘landscape’ consists of 400 cells across 10 properties.

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 commodity 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 wish 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 commodity 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’. Each cell had a conservation value, which would be triggered if it was successfully rented out in the auction. The assessment metric also included 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. 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.

A series of independent auctions were run in which a number of parameters were varied. Experiments were run with two, three and 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 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 – neither the price nor the area offered could be adjusted. Another treatment involved varying the way in which the funding was allocated. In the standard version, the whole budget was allocated in the first round to identify provisional winners. In the alternate version, only a proportion of the funding was provisionally allocated in the first round, which progressively increased through the rounds.

Table 1: Experimental variables and treatments

Variable	**Treatments**	
Number of rounds	2, 3 or 4	
Known	Number of rounds known to participants	Number of rounds unknown to participants
Lock-in	Provisional winners locked	Provisional winners can modify their bids
Fixed budget	Full funding allocated in each round	40% of total allocated in round one, 80% in round two and 100% in rounds three and four

5. Experimental results

Individual bidding behaviour, and overall simulated biodiversity outcomes, were analysed with general linear models (GLM) using Genstat (9th edition). Rent seeking and overall biodiversity value were used as measures of the efficiency and cost-effectiveness properties of 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 an overall 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. 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 large and small areas. Variables were included in the models for the known/unknown number of rounds and the bid improvement rule (on/off). The total number of rounds was included as a continuous variable.

Considering only bids from the first round of each experiment, rent seeking was significantly greater when the number of rounds was known in advance (table 2). The lock-in rule for provisional winners had no effect on rent seeking in the initial round. 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.

Table 2: GLM for profit in the first round

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	3	115.1	38.36	27.24	<.001
Residual	540	760.5	1.41		
Total	543	875.6	1.61		

Parameter	estimate	s.e.	t(540)	t pr.
Constant	4.100	0.185	22.20	<.001
Price	0.0006116	0.0000788	7.76	<.001
Known	0.442	0.109	4.05	<.001
Lock-in	-0.145	0.102	-1.42	0.156

Considering only the first round of each experiment in which the number of rounds was known, rent seeking was showed a significant positive relationship with the total number of rounds (table 3). By the final round (table 5) this effect had disappeared. This suggests that participants in longer auctions initially ask for higher prices in the knowledge 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.

Table 3: GLM for profit in the first round, considering only experiments in which the total number of rounds was known

Source	d.f.	s.s.	m.s.	v.r.	Fpr.
Regression	3	40.3	13.42	12.92	<.001
Residual	366	380.1	1.04		
Total	369	420.4	1.14		

Parameter	estimate	s.e.	t(366)	tpr.
Constant	4.332	0.289	14.98	<.001
Price	0.0004799	0.0000834	5.76	<.001
Total rounds	0.1657	0.0798	2.08	0.039
Lock-in	-0.160	0.107	-1.50	0.134

Considering bids in the final round of each experiment (table 4), rent seeking remained significantly higher when the total number of rounds was known to participants. This is a surprising observation, as in the known treatment participants were fully aware that this was the final round, yet rent seeking remained higher than in the unknown treatment, where there remained the possibility of additional rounds. The total number of rounds had no effect, nor did having a fixed vs ascending budget. By the final round, rent seeking was significantly lower where provisional winners were locked. 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.

Table 4: GLM for profit in the final round of each experiment

Source	d.f.	s.s.	m.s.	v.r.	Fpr.
Regression	5	89.0	17.810	11.62	<.001
Residual	544	833.8	1.533		
Total	549	922.9	1.681		

Parameter	estimate	s.e.	t(544)	tpr.
Constant	4.319	0.328	13.19	<.001
Price	0.0005010	0.0000784	6.39	<.001
Total rounds	0.0096	0.0784	0.12	0.903
Known	0.267	0.116	2.30	0.022
Lock-in	-0.275	0.109	-2.52	0.012
Fixed budget	-0.073	0.109	-0.67	0.505

Table 5: GLM for profit in the final round, considering only experiments in which the total number of rounds was known

Source	d.f.	s.s.	m.s.	v.r.	Fpr.
Regression	4	52.4	13.09	9.78	<.001
Residual	368	492.5	1.34		
Total	372	544.8	1.47		

Parameter	estimate	s.e.	t(368)	tpr.
Constant	4.474	0.332	13.47	<.001
Price	0.0005246	0.0000904	5.80	<.001
Total rounds	0.0258	0.0909	0.28	0.777
Lock-in	-0.183	0.123	-1.49	0.138
Fixed budget	-0.141	0.124	-1.13	0.259

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 does not accept fractions of bids).

Considering only the last round of each experiment, overall biodiversity value was significantly higher when provisional winners were locked in (table 6). Biodiversity in the final round was significantly higher when the total number of rounds was unknown to participants in advance. Overall value was higher with the lock-in rule, although this was not significant at the 5% level (p=0.06). Having a fixed or ascending budget had no impact.

Table 6: GLM for overall landscape in the final rounds

Source	d.f.	s.s.	m.s.	v.r.	Fpr.
Regression	5	1143023115	228604623	17.09	<.001
Residual	23	307726983	13379434		
Total	28	1450750098	51812504		

Parameter	estimate	s.e.	t(23)	tpr.
Constant	-69390	13823	-5.02	<.001
Funds spent	5.023	0.562	8.93	<.001
Total rounds	-56.	1032	-0.05	0.957
Lock-in	2921	1478	1.98	0.060
Known	-3990	1515	-2.63	0.015
Fixed budget	-159	1421	-0.11	0.912

With the data from the known and unknown treatments pooled (table 6), the total number of rounds had no significant effect. Considering only the known round number treatment, biodiversity value was significantly positively correlated with the total number of rounds.

6. Discussion

Iterated auctions have the potential to address the key issues around the design of incentives for efficient connectivity conservation. 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 projects. Laboratory experiments indicate that a danger of multi-round auctions is that participants will focus on price competition and will strategically raise their bid prices to try and extract some additional rent. The results show that these problems can be minimised if the number of rounds is unknown in advance, and a bid-improvement rule is included.

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 round, which is likely to reflect uncertainty about the end point. Lower bid prices increases the amount of land that can be purchased in the auction, hence its overall cost effectiveness. A more surprising result was that rent seeking in the unknown round number treatment was lower even than in the final round where the end point was known. This suggests that the uncertainty has prevented strategic behaviour and prompted intense price competition. The lock-in rule was also effective at increasing overall landscape biodiversity outcomes. It prevented provisional winners from increasing their prices, without causing them to be higher in the first place. The lock-in rule works particularly well with the unknown number of rounds – initial bids are lower, and the lock-in rule ensures they cannot creep upwards.

Progressively allocating the budget over a number of rounds did not have any significant effect on bidding behaviour or overall outcomes. A fruitful area for future research will be considering how the auction process may be spread over a number of years. 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 & Pressey 2001; Pressey & Taffs 2001; Sarkar *et al*. 2006; Pressey *et al*. 2007). Conservation action scheduling can be represented as a multistage constrained optimization problem which aims to maximize the number of biodiversity surrogates that have met their targets at the end.

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 to a 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. 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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