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Buying spatially-coordinated ecosystem services and biodiversity conservation on forest land: an experiment on the role of auction format and communication.

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Abstract

Procurement auctions are one of several policy tools available to incentivise the provision of ecosystem services and biodiversity conservation. Successful biodiversity conservation often requires a landscape-scale approach and the spatial coordination of participation, for example in the creation of wildlife corridors. In this paper, we use a laboratory experiment to explore two features of procurement auctions in a forest landscape—the pricing mechanism (uniform vs. discriminatory) and availability of communication (chat) between potential sellers. We modify the experimental design developed by Reeson et al. (2011) by introducing uncertainty (and hence heterogeneity) in the production value of forest sites as well as an automated, endogenous stopping rule. We find that discriminatory pricing yields to greater environmental benefits per government dollar spent, chiefly due to better coordination between owners of adjacent plots. Chat also facilitates such coordination but also seems to encourage collusion in sustaining high prices for the most environmentally attractive plots. These two effects offset each other, making chat neutral from the viewpoint of maximizing environmental effect per dollar spent.

Keywords:

conservation auctions, spatial coordination, chat in experiments, discriminatory and uniform auctions, biodiversity conservation, provision of ecosystem services

JEL:

C92, D44, Q23, Q57, Q58

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1. Introduction

Procurement or reverse auctions are one of several policy tools available to incentivise the provision of ecosystem services (ES) on privately-owned land (Hanley et al., 2012). They have been attracting increased attention as a way to manage and supply ecosystem services because they offer the potential to deliver cost efficient allocation of limited government funds for conservation (Latacz-Lohmann and van der Hamsvoort, 1997; Schillizi and Latacz-Lohmann, 2007) and enable to overcome information asymmetries concerning private owners' costs (Ferraro, 2008, Reeson et al., 2011; Reeson and Whitten, 2014). The social benefits from the conservation auctions depend often on the spatial configuration of sites. In the case of provision of ES, spatial targeting requires a landscape-scale-approach rather than each bid being individually considered irrespective of its location in space relative to other offers (Goldman et. al, 2007; Windle et al., 2009). Either dispersed or agglomerated, the type of spatial configuration depends on the nature of the ES which are being "bought" (Parkhurst and Shogren, 2007). The nature of environmental benefits delivered by an auction must be understood by all the sellers and by the buyer, using a suitable metric. Reeson et al. (2011) describe an "effective metric " as one that "provide a measure of combined value rather than individual value, taking care to which combination "provides the best ecological outcome".

Due to the nature of the provision of some spatially-dependent ES, it would appear natural to use multi-unit procurement auctions to select bids that are optimal from the social point of view (Latacz-Lohmann and Schillizi 2005, Ferraro 2008). A multi-unit procurement auction is described as a way for the buyer to purchase multiple units of a good. Such auctions have attracted limited attention in the theoretical literature (Huh et al., 2004). Given this incomplete theory, auctions have been studied in an experimental way.

One of the first studies to use auction theory to analyse the provision of ecosystem services was Latacz-Lohmann and Van der Hamsvoort (1997). They analysed the potential benefits of auctions in allocating contracts for the provision of nonmarket goods in the countryside. The auction was applied to a hypothetical conservation program. The authors concluded that auctions are a valuable tool in allocating conservation contracts among farmers. Later, some experimental comparisons or field-trials allowed a better understanding of conservation auctions. In Schilizzi and Latacz-Lohmann (2007), a comparison between budget-constrained auction and target-constrained auction against the benchmark of a budget-equivalent and an outcome-equivalent fixed-price program is undertaken. The main results show that both target- and budget-constrained auctions perform better than any possible fixed-price program in a one-shot setting and that the latter format is clearly more robust to repetition than the former.

Recently, experiments have proved to be a very useful tool for the test-bedding of increasingly complex conservation auction designs. Jack et al. (2009) conducted a field experiment within the context of reducing soil erosion in a coffee-producing region in Indonesia. Their study illustrated an auction-based approach to revealing private information about the costs of supplying ecosystem services. The data were collected on a sample of landowners from two villages. The auction mechanism was uniform-price and the design did not allow for interdependence of the landowners' offers. The study of Rolfe et al. (2009) focused on improved vegetation management by the beef grazing industry in Australia. They applied a field experiment to test the cost efficiencies of a multiple bidding round auction where landowners are unfamiliar with conservation tender processes and the supply of environmental services. Their results suggest that multiple bidding rounds have the potential to deliver efficiency gains in conservation auctions. Windle et al. (2009) investigated the use of auctions to encourage the creation of landscape corridors in Queensland. They hold multiple bidding (three rounds) instead of the standard application of a single bidding round. Their results indicate that multiple bidding rounds improved auction efficiency but there was little improvement in connectivity.

Reeson et al. (2011) focused on the spatial aspect of conservation auction, adapting them to promote connectivity between sites in a decontextualized design. In their lab experiment, they considered a homogeneous landscape of 400 plots, divided among 10 owners/bidders. Each plot would bring the owner a fixed production value, unless used to provide ES. They investigated multi-round auctions. The number of rounds was exogenously fixed and made known to subjects in one experimental condition while concealed in another. The authors also investigated the effect of the lock-in rule, i.e., subjects could only make up to two new bids in one condition and in another they could additionally modify bids made in past rounds. They found that unknown number of rounds and the lock-in rule tended to deliver the highest environmental benefit within the budget constraint.

The most recent studies by Bamière et al., (2013) concerning habitat conservation on agricultural lands show that auctions were superior to an uniform subsidy and an agglomeration malus for cost-efficiency. The latest, however, did better for achieving a spatial pattern of reserves is a random mosaic than auctions. Banerjee et al. (2014) based on the results of their lab experiment conclude that knowledge about a specific spatial target which the government had in mind intensified subjects' rent-seeking but had no impact on auction efficiency.

In this paper, using a lab experiment we focus on testing an auction mechanism for the provision of ecosystem services in the forest context. We build upon the experimental design developed by Reeson et al. (2011) by introducing four principal modifications which seem important in improving the insights one can obtain from the lab in terms of achieving cost-effective spatial coordination in actual conservation auction schemes.

First, we account for heterogeneity in the production value of plots. In our experiment, the production values differ not only between forest owners but also within their properties. The rationale behind that is the fact that forests are usually not homogenous and differ in terms of tree species, age and density, and thus deliver different production values. Each landowner knows the production value (PV) of their own plots, but they do not know the PVs of plots owned by others.

Second, we use an automated, endogenous stopping rule—the auction stops when there is little change in behavior over a few rounds, rather than after some predetermined number of rounds. If subjects know which round is going to be the last one, they have limited incentive to bid carefully, let alone truthfully, in all the previous rounds. Furthermore, with a fixed number of rounds it may well be that the auction stops prematurely (before equilibrium is reached) or too late (so that bidders' time is wasted and they are tempted to start sending collusive signals, etc.).

Third, unlike Reeson et al. (2011), we analyse two different auction formats: discriminatory and uniform pricing. Both of them have their merits in practical applications. In discriminatory auctions, transaction prices are determined in a straightforward manner—they are identical to (accepted) offers—and this simplicity is a major virtue in these otherwise complicated markets. However, they create incentives for landowners to bid higher than their true willingness to accept. On the other hand, uniform auctions place less burden on the participants as far as the determination of their bidding strategy is concerned—bidding their own reservation prices is a reasonable option under uniform pricing only (although it is generally speaking not an equilibrium strategy as will be discussed later). For the same reason, their results are very likely to be more informative for the auctioneer, i.e. she learns more about the actual sellers' reservation prices. Finally, given that the resulting transaction prices are identical, the sellers may consider this auction format as more fair.

The last of principal modifications involves examining the effect of communication between subjects in the course of the auction. From practical viewpoint, this is an important consideration in conservation auctions because, firstly the owners of specific plots will typically know each other and might indeed want to coordinate their strategies and secondly, complex, multi-round auctions will often give the participants enough time to communicate.

The experiment is framed in the context of forest biodiversity protection. Specifically, we consider a national park (NP) surrounded by hitherto unprotected private forests. Such a situation is quite typical in the European context. Our assumption is that if private forest plots are not enrolled in a conservation scheme, then environmental benefit flows will fall over time. Spatial issues are implemented in the auction design by offering explicit bonuses for the proximity of the forest plots to the NP (creating a buffer zone) and habitat connectivity. Connectivity thus increases the score given to a bid, by increasing the value of the environmental metric. A forest-related (rather than a neutral) framing is used to make the situation more realistic for the subjects and to help them understand this relatively complex design.

The main objective of the paper is to explore the impact of auction format (discriminatory vs. uniform) and the availability of communication between participants on cost minimization and efficiency. In familiar single-object auctions, where just one unit of good may change hands, the analogue of the discriminatory auction is the first-price sealed-bid auction, while second-price (Vickrey, 1961) auction is the relative of the uniform auction formats. The properties of these two variants are well understood. Assuming private values (each bidder knows his valuation and does not care how much others would be willing to pay), second-price auctions induce truth-telling (bids identical to reservation prices) and first-price involves just the right degree of bid shading to make the expected revenue identical for the seller. In either case the auction is efficient, i.e. the player with higher valuation will always win the auction. The case of multiple potential sellers and single bidder interested in one unit (procurement auctions) which is obviously the relevant one for conservation auctions is just the mirror image – they should request more than the reservation price under first-price rules only.

The reason why (single-object) second-price auctions induce truthful bidding is simple: each buyer only submits one bid, so if his bids affects the price – he is not the winner, because his bid is only second-highest. There is thus no reason to shade the bids. In this sense, the *strategic uncertainty* that the bidders face is reduced, which is believed to encourage participation (particularly so for less-experienced bidders) and reduce costs. It is tempting to extend this reasoning to multiple-object auctions (in which buyers submit a number of bids for the first, second, $\dots$ n-th unit—a demand schedule). As a matter of fact, an economist not less eminent than Milton Friedman has advocated the use of the uniform format (as applied to treasury auctions) by claiming "*You do not have to be a specialist. You need only know the maximum amount you are willing to pay for different quantities*." (Wall Street Journal of 28 August, 1991). Alas, this is an oversimplification. In the case of multiple bids, any buyer's lower bid can affect the price paid to a (successful) higher bid so some shading pays off. In our case of uniform price auction with a spatial aspect finding a solution seems very difficult. Nevertheless, by analogy with the simpler situations sketched above, we generally expect offers in the discriminatory price treatment to be higher than reservation prices, and to be higher than comparable offers in the uniform price treatment.

It is also an interesting open question of how communication may affect auction results. In standard auctions we would expect that communication will facilitate collusion, thereby decreasing the auctioneer's revenue (or, in procurement auction as in our case, increasing the amount she will have to pay). *Inter alia* Balliet (2010) and Vogt et al. (2013) show that communication tends to increase cooperation among subjects and it is a good way for them to learn and to express some higher effort levels. However, in the case of auctions for the provision of ecosystem services, where efficiency may depend on participants' ability to coordinate strategies with their neighbors, such that larger contagious areas of wildlife protection are created, communication may turn out to support the auctioneer's effort to maximize environmental benefits.

2. Methods

2.1. Design

Participants of the experiment were divided into groups of 6 (typically, there were 18 subjects in one session). Each of them was assigned a property consisting of 16 *plots* (see Figure 1 showing the initial information displayed to subject owning plots A3-D6, the white lines delineating each player's property). Each property was a 4x4 square, except for the subject holding A1-D4 and A11-D12 squares, although this makes no strategic difference. Each plot had specific *production value* (PV) in experimental dollars (ED), drawn independently from a $U(50{,}150)$, that could be realized if that particular plot was retained by the owner at the end of the experiment. Each owner could also offer any subset of his plots at any plot-specific prices expressed in ED he wished at a multi-round auction run by an automated *government*.

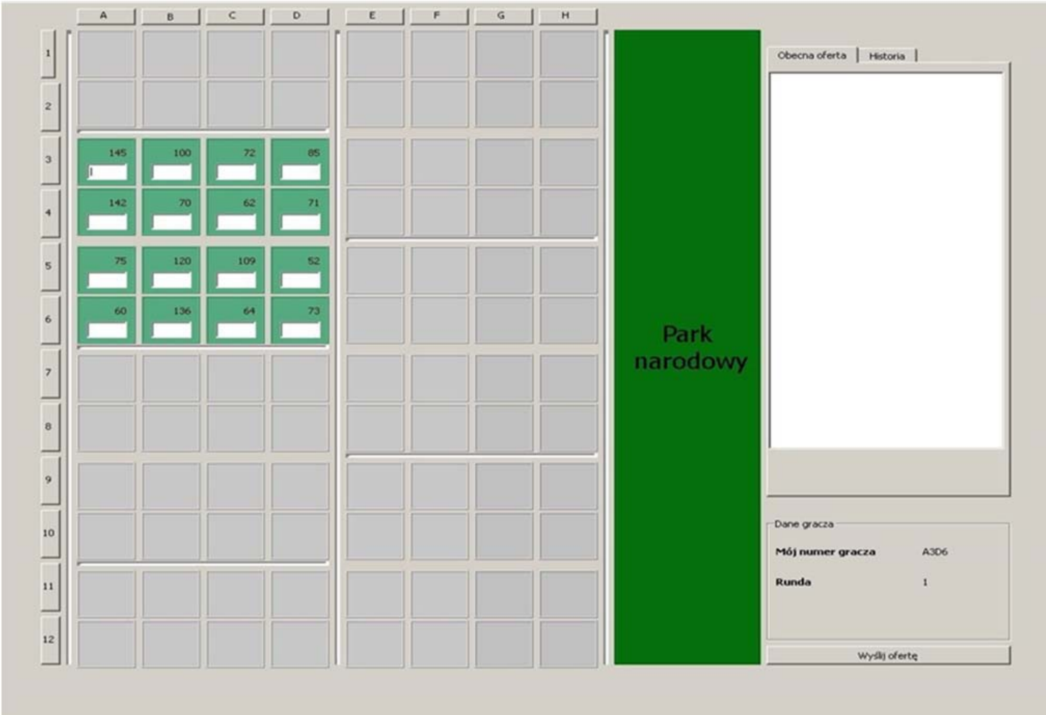

Figure 1. Screenshot showing the initial information displayed to subject owning plots A3-D6.

Note: "Park narodowy" means national park in English. Production values are shown in the upper-right corner of each plot.

In each round, the government would "provisionally purchase" such a combination of plots offered by some or all the sellers that would maximize *environmental value* (EV) per experimental dollar spent on purchases, subject to the constraint that an amount between 4000 and 5000 ED is spent.[1] Environmental value of any combination of plots that could be purchased would be calculated as follows:

- ne point per each plot purchased in columns A-F,
- two points per each plot purchased in columns G-H,
- additionally one point for each two purchased plots sharing a vertical border (i.e. constituting a horizontal corridor)[2].

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1 Forcing the government to spend some specific amount precisely would easily lead to poor results (in terms of EV per ED spent). On the other hand, real public agencies obviously operate within budget restrictions. Furthermore, avoiding any constraints could result in strong between-round volatility of plots provisionally purchased. Of course, the specific range used in the experiment is quite arbitrary.

2 For example, if the government buys plots 6-D, 6-E, 7-E, 7-F and 7-G the total environmental value (EV) equals:

1 [for 6-D] +1 [6-E] +1 [7-E] +1 [7-F] + 2 [7-G is in the buffer zone] + 1 [bonus for adjacent 6-D and 6-E] +1 [bonus for adjacent 7-E and 7-F] + 1 [bonus for adjacent 7-F and 7-G] = 9

In setting these rules we were trying to mimic some characteristic features of real landscapes, and the ecological factors determining the delivery of ES and biodiversity conservation. First, the plots close to the existing wilderness (the National Park) were considered more valuable. Second, creation of corridors stretching out of the wilderness, facilitating movements and migration of wild animals, was appreciated. At the same time, the rules were kept as simple as possible. By assigning one of the owners a discontinuous A1-D4, A11-D12 property we have made sure that each participant had exactly two neighbors with whom to build horizontal corridors – the situation was strategically identical for each of the three A-D owners and similarly among the three E-H owners.

The experiment would end for the group if the environmental value per ED spent failed to improve by more than 5% in each of 5 consecutive rounds (and otherwise it would end after round 30). The provisional purchases would then become actual purchases and the subjects would earn the amount in ED resulting from adding up the production values of non-sold plots and transaction prices of sold plots. It would be exchanged into Polish Zloty (zł) at the rate of 1ED=0.015 zł (ca. 4 eurocent). If a round was not the final one, the offers made in it had no direct impact but would by default be proposed for the subsequent round (yet they could be altered, altogether removed or supplemented with offers for previously un-offered plots at subjects' discretion).

2.2. Subjects' information

Subjects were presented with a map showing the private forest properties and the boundary of the state-owned National Park. Every participant knew all production values of their own but not others' plots (see Figure 1). They knew that the automated government aimed at high environmental value and how this environmental value was calculated[3]. After each round subjects were shown all subjects' bids and their locations.[4] The bids were marked in a way to distinguish provisional winners from losers (see Figure 2). Subjects were not informed about the exact stopping rule – they were told that each round could prove to be the last one (and thus its results would matter for real).

The EV bonus connected with creating a horizontal connection does not take into account whether the plots belonged to one or two participants. The example of the entire experimental instruction (the treatment combination: uniform and chat) can be found at: http://coin.wne.uw.edu.pl/bartczak/pliki/Appendix.pdf

[3] However, they were not told about a specific spatial target which the government had in mind: Banerjee et al., 2014.

[4] This could be considered a highly stylized feature. One reason for implementing it is that it facilitated learning – in a field application subjects would have more time and stronger incentives to understand the scheme and develop strategy. They could also make use of professional advisors.

Figure 2. Screenshot showing bids which were provisionally successful at which price (the discriminatory version with chat).

Note: This is an example of the screen shot shown to the participant owning plots A3-D6. The provisionally winning bids from the previous round are marked red for the subject A3D6 and orange for others and shown prior to the start of the next round. Bid levels are displayed in bottom-left corner of each plot.

2.3. Experimental treatments

Each group operated under one of two auction formats. Under the Discriminatory pricing condition, each accepted plot would be purchased at the price offered. Under the Uniform pricing condition, all purchases in columns A-F had to be at the same price. Similarly, all plots purchased in columns G-H would be bought at the same price.

This distinction would be crossed with the availability of chat: in around half the groups the subjects were allowed to send any chat message to any combination of other participants at any time. In the no-chat condition, no communication was allowed whatsoever. Table 1 shows the number of groups in each of four resulting treatments.

Table 1. Experimental treatments: number of groups.

Treatment	Discriminatory (D)	Uniform (U)
Chat (C)	6	6
No chat (NC)	7	7

2.4. Procedures

The experiment was conducted in the spring of 2013 at the Laboratory of Experimental Economics at the University of Warsaw, using the local (student) subject pool. It was computerized using a Python-based program.[5] Printed instructions were used. Both software and instructions were developed in pilot sessions to ensure that subjects had no problem understanding their decision environment. 11 sessions with 1 to 3 groups each were run. A short post-experiment questionnaire was deployed to collect demographic data. Table 2 shows the descriptive statistics of the sample.

Table 2. Descriptive statistics of the sample.

Subjects' characteristics	
Mean age (in years)	23
Share of females	52%
Share of students	84%
Share of subjects with experience in lab experiments	62%
Mean net household income (in zł)	5260

Nominal exchange rate 1€ = 4.20zł in 2013.

Average number of rounds equaled 7.62 in the Discriminatory condition, whereas it was much higher (14.31) under Uniform. In the Chat condition the average number of rounds was 12.08 and in the No Chat case it was 10. Not surprisingly, UC sessions lasted longest (106 minutes on average), corresponding figures for other treatments were 63 min., 48 min. and 38 min. for DC, UNC and DNC respectively. In one case, a UC group ended after round 30 without converging.

3. Experimental results

3.1. Rationality of individual behavior

Because the decision making environment was relatively complex, it may be worthwhile first to establish that subjects' behavior followed rules that we would find reasonable. First, we have argued that there were very limited incentives to bid below an individual plot's production value, especially in the discriminatory treatment. It is thus somewhat reassuring to see that such choices were rare. An average bidder in the Discriminatory condition would make 13.86 offers above the relevant production value (PV) and just 0.21 and 0.41 offers at or below it, respectively (remaining 1.52 plots on average would not be offered at all). Corresponding figures for the Uniform treatment were 10.69, 1.98, 1.03 and 2.30 (note that, in line with our expectations, offers at or below PV were much more common here).

[5] The program was developed by Jean-Marc Rousselle of INRA-LAMETA.

Another check of subjects' ability to respond to strategic incentives important for conservation efforts efficiency would be to compare the bids for "inner" and "outer" columns of each owner's property. Because of the horizontal connectivity bonus, it would on average be more important to have an offer in column B or C accepted than in column A or D because the former would increase attractiveness of two of the same owner's plots, while the latter would only help one offer. Similarly, we expect that offers in column F should be more competitive than in E and in G more than in H.[6] It turns out this is indeed the case: when we define a variable *relative offer* equal to the offer divided by relevant production value, we find it is indeed modestly but significantly higher for "outer" than "inner" columns: 1.499 vs. 1.484 in Discriminatory and 1.303 vs. 1.280 in Uniform.[7]

Finally, given that the plots in columns G and H had higher environmental value, we would expect our subjects to seize the opportunity and require higher profit margin. Indeed, when compared to plots in columns E and F (i.e. owned by the same subjects), the relative offers where much higher for them (1.728 vs. 1.390 in Discriminatory and 1.423 vs. 1.279 in Uniform, both differences are obviously highly significant).

3.2. Treatment effects

There are two major goals in a typical auction: revenue maximization and efficiency seeking. The first involves securing possibly high prices for the objects at sale. In our setting of a multi-unit procurement auction its counterpart was that the government sought to *minimize* unit price, or equivalently to maximize EV per dollar spent. This goal was thus incorporated in the procedure determining the government's purchase decisions, as explained before. Table 3 shows mean values of the Environmental Value per 1000 Experimental Dollars spent by the government, by treatment (in the last, and hence relevant, round of given auction).

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[6] Comparison for these columns is complicated by the fact that G and H provided higher environmental value but this is orthogonal to our definition of "inner" or "outer" columns.

[7] Each plot was treated as an independent variable and t-test was used to investigate means differences.

Table 3. Mean values of auction characteristics (final round).

Measure		Treatment DC	DNC	UC	UNC
Environmental value	per 1000 ED spent	19.678 (0.423)	18.828 (1.190)	18.636 (1.972)	18.130 (0.687)
	per ED (relative)	0.788 (0.037)	0.750 (0.064)	0.737 (0.057)	0.719 (0.018)
	per 1000 ED of PV lost	24.785 (0.971)	23.942 (0.954)	24.540 (1.929)	22.592 (2.011)
Bonuses	Connectivity	27.167 (1.472)	24.571 (1.718)	15.000 (6.229)	20.143 (3.805)
	NP proximity	5.833 (0.543)	4.714 (0.774)	6.778 (0.504)	5.143 (1.719)
Profit margins from sold plots	all plots	0.260 (0.059)	0.278 (0.117)	0.324 (0.100)	0.251 (0.144)
	plots in the NP buffer zone	0.347 (0.109)	0.430 (0.159)	0.396 (0.100)	0.357 (0.120)
	for plots outside the NP buffer zone	0.179 (0.036)	0.179 (0.098)	0.149 (0.088)	0.204 (0.155)
Earnings (zł)		26.391 (1.901)	26.437 (2.264)	26.344 (2.300)	26.328 (2.538)

Note: Standard deviations reported in parentheses.

As verified by conservative, group-level tests, Discriminatory auctions were marginally superior to Uniform auctions, while chat made no difference, see Tables 4 and 5. These tests do not account, however, for differences in production values between groups. If, by chance, plots with low production values tended to be relatively numerous, clustered in horizontal corridors and situated next to the National Park in, say, UNC groups, it would be easier to obtain high EV per ED values there, compared to other treatments. This corresponds to a situation in a real landscape where land with higher ecological potential also has the lowest costs of enrollment; or where there is a particular pattern of spatial correlation between opportunity costs across sites (Armsworth et al., 2012). For this reason we have also calculated relative EV per ED, whereby we divided the EV per 1000 ED by the highest possible EV per 1000 ED obtainable under the counterfactual assumption that every plot could be purchased at its true production value. The logic behind this procedure is that no owner should be forced to sell at a negative profit. The resulting values are also reported in Table 3 and tests in Table 4 and Table 5 verify that, again, chat did not make a difference but Discriminatory auctions fared slightly better than Uniform ones.

Table 4. Treatment effects on revenue maximization: Mann-Whitney test results at the group level.

Comparison	Variable	Z	P
Discriminatory vs. Uniform	EV per spent 1000 ED	1.923	0.0545
	Relative EV per ED	**2.077**	**0.0378**
	Connectivity bonuses	**3.840**	**0.0001**
	NP proximity bonuses	**- 2.014**	**0.0440**
Chat Vs. No Chat	EV per spent 1000 ED	1.286	0.1985
	Relative EV per ED	1.440	0.1498
	Connectivity bonuses	0.388	0.6982
	NP proximity bonuses	**2.694**	**0.0071**

Note: Effects significant at 5% shown in bold.

Table 5. Partial treatment effects on revenue maximization: Mann-Whitney test results at the group level.

Comparisons							
Discriminatory vs. Uniform				Chat vs. No chat			
Treatment	Variable	Z	P	Treatment	Variable	Z	P
Chat	EV per spent 1000 ED	1.121	0.2623	Discriminatory	EV per spent 1000 ED	1.000	0.3173
	Relative EV per ED	1.725	0.0845		Relative EV per ED	0.857	0.3914
	Connectivity bonuses	**2.812**	**0.0049**		Connectivity bonuses	**2.308**	**0.0210**
	NP proximity bonuses	**-2.290**	**0.0220**		NP proximity bonuses	**2.334**	**0.0196**
No chat	EV per spent 1000 ED	1.597	0.1102	Uniform	EV per spent 1000 ED	0.571	0.5677
	Relative EV per ED	0.961	0.3367		Relative EV per ED	0.429	0.6682
	Connectivity bonuses	**2.517**	**0.0118**		Connectivity bonuses	-1.724	0.0847
	NP Proximity bonuses	-0.965	0.3347		NP Proximity bonuses	1.803	0.0714

Note: Effects significant at 5% shown in bold.

It may also be instructive to look at the evolution of relative EV over time. As shown in Figure 3, there was a general increasing trend in all four treatments. It was particularly strong in early rounds, with relatively little dynamics after round 6 or so. We also note that Uniform auctions typically showed substantially higher volatility, which explains why they lasted longer.

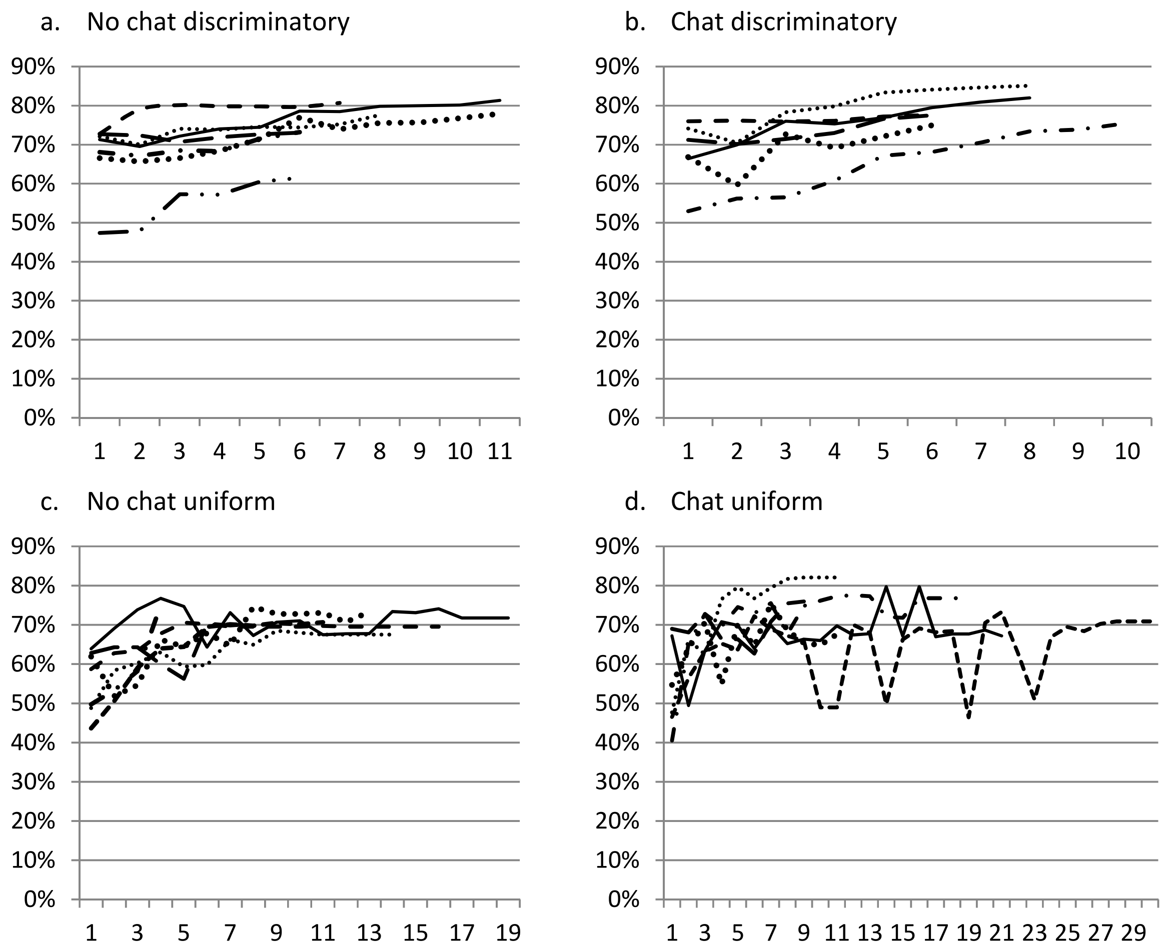

Figure 3. Evolution of relative Environmental Value in time per game.

Note: Horizontal axis indicates the number of rounds. Each line represents one game. Vertical axis indicates the relative EV (%) per experimental dollar spent.

Searching for specific reasons why EV could be purchased more cheaply under scenario D, we have looked at each mechanism's ability to encourage coordination of conservation efforts, resulting in horizontal corridors of adjacent plots purchased. The total value of connectivity bonuses paid appears to be the most appropriate simple aggregate measure in this respect. Table 3 shows mean values for each of our four treatments. It turns out that the figures were substantially higher for the Discriminatory condition than under uniform pricing, see test statistics in Table 4. This was largely due to longer corridors being built, with the average corridor length being 3.59 plots under Discriminatory pricing and only 2.75 under Uniform pricing. For example, there were eight maximal corridors (i.e. those of length 8) in Discriminatory groups and only one in the Uniform ones.

The other important goal for an auction is that of efficiency—ensuring that objects end up in the hands of agents who value them most. The equivalent in procurement auctions is that services are provided by agents whose costs (supply prices) are lowest. In our case the natural measure is EV obtained per 1000 ED lost in terms of foregone production value. We do not have a natural "ideal" benchmark here, because it is not clear how much each unit of EV is "really" worth and the government did not seek to maximize efficiency. We can however compare efficiency across treatments. As shown in tables 3, 6 and 7 we do not observe a difference across auction formats, while chat seems to cause a marginally significant, positive effect.

Table 6. Treatment effects on efficiency: Mann-Whitney test results at the group level.

Comparison	Variable	Z	P
Discriminatory vs. Uniform	EV per 1000 ED of PV lost	1.564	0.1178
Chat vs. No Chat		1.955	0.0506

Note: Effects significant at 5% shown in bold.

Table 7. Partial treatment effects: Mann-Whitney test results at the group level.

Comparisons							
Discriminatory vs. Uniform				Chat vs. No chat			
Treatment	Variable	Z	P	Treatment	Variable	Z	P
Chat	EV per 1000 ED of PV	0.961	0.3367	Discriminatory	EV per 1000 ED of PV	1.571	0.1161
No chat		1.469	0.1417	Uniform		1.429	0.1531

Note: Effects significant at 5% shown in bold.

Looking at the revenue maximization from a forest owners (subjects) perspective we did not observe any significant difference in profit margins and earnings between treatments (see table 3, 8, and 9).

Table 8. Treatment effects: Mann-Whitney test results at the group level.

Comparison	Variable	Z	P
Discriminatory vs. Uniform	Profit Margin (PM)	-1.051	0.2931
	PM in buffer zone	-0.077	0.9387
	PM outside buffer zone	-0.707	0.4795
	Earnings (zł)	-0.385	0.7005
Chat Vs. No Chat	PM	0.514	0.6070
	PM in buffer zone	-0.103	0.9181
	PM outside buffer zone	-1.150	0.2503
	Earnings (zł)	-0.309	0.7576

Note: Effects significant at 5% shown in bold.

Table 9. Partial treatment effects: Mann-Whitney test results at the group level.

Comparisons							
Discriminatory vs. Uniform				Chat vs. No chat			
Treatment	Variable	Z	P	Treatment	Variable	Z	P
Chat	PM	-1.601	0.1093	Discriminatory	PM	0.000	1.000
	PM in buffer zone	-0.641	0.5218		PM in buffer zone	-0.857	0.3914
	PM outside buffer zone	0.365	0.7150		PM outside buffer zone	0.429	0.6682
	Earnings (zł)	0.320	0.7488		Earnings (zł)	0.143	0.8864
No chat	PM	-0.192	0.8480	Uniform	PM	1.286	0.1985
	PM in buffer zone	0.703	0.4822		PM in buffer zone	0.429	0.6682
	PM outside buffer zone	-0.703	0.4822		PM outside buffer zone	-1.543	0.1229
	Earnings (zł)	-0.831	0.4062		Earnings (zł)	0.000	1.0000

Note: Effects significant at 5% shown in bold.

3.4. Discussion of the results

To understand why uniform pricing makes the formation of long conservation corridors very rare, consider the example shown in Figure 1. It is nearly impossible to purchase B6 under uniform prices – because of its high production value, even a modest price markup would require all plots (not adjacent to the NP) to be purchased at a very high price. This is similar to the “hold out” problem considered by Lennox et al. (2012). Thus, just one high-PV plot essentially excludes complete corridor in given row. On the contrary, if A6 and C6 are to be purchased under the discriminatory pricing treatment, it can be optimal for the government to additionally purchase B6, provided its owner is satisfied with a small profit margin on this plot. On the other hand, such operations may not be optimal from the viewpoint of efficiency, because a substantial production value is foregone. This may be one reason why we do not find Discriminatory auctions to be superior in terms of Environmental Value per ED of production lost.

Chat made limited impact overall, although it might have facilitated creation of long corridors under Discriminatory pricing, as can be seen in Table 5. As a result, it seemed to contribute to efficiency measured as EV per 1000 EC of production value lost (p=.0506). These findings are largely in line with our speculations concerning the equivocal impact of communication: facilitating coordination (and hence raising efficiency) but also increasing collusion, which offsets the potential benefits in terms of improvements in EV per dollar spent.

4. Conclusions

In this paper, we use a laboratory experiment to explore two features of auctions for the provision of ecosystem services. We do this in the context of a landscape where the environmental benefits of land being offered into a conservation scheme depends on location: that is, in a setting where spatial coordination results in an increase in environmental benefit (Parkhurst and Shogren, 2007). Spatial coordination has been argued to be important ecologically in terms of the creation of wildlife corridors and in creating “big enough” contiguous areas of enrolled in conservation schemes (Bartelt et al., 2010; Carvell et al., 2007). Firstly, we compare uniform and discriminatory pricing mechanisms, and secondly we investigate the influence of communication between subjects. As far as we are aware this is the first study examining these aspects in the context of conservation auctions. Additionally, the present study has extended previous analysis to account for heterogeneity in the production value of plots and uncertainty concerning the value of the other subjects properties. The novelty of this study arise also from the application in the auction mechanism an automated, endogenous stopping rule which incentives subjects to bid carefully. Finally, this study adds to the growing number of literature investigating spatial coordination in conservation auction schemes (Polasky et al., 2014; Banerjee et al.,2014; Windle et al., 2009; Rolfe et al., 2009; Reeson et al., 2011).

The obtained results suggest that auction format might make a difference in procurement auctions for the provision of ecosystem services. In particular, in our experiment the government obtained higher environmental value per dollar spent in discriminatory price auctions compared to a uniform pricing rule. This was chiefly because connectivity bonuses were higher.

It should be noted, however, that when we deal with uncertainty concerning the production value of the other subjects plots, from the individual landowners perspective the uniform price strategy is less sophisticated (i.e. requires lower effort) than participation in the discriminatory price type of auction. In real life situations, this may translate into lower costs associated with hiring consultants to help determine bids, and thus lower transactions costs.

Communication between subjects may facilitate coordination and thus can improve efficiency. This might explain the results obtained under the discriminatory pricing treatment. However, potentially chat can also have the opposite effect i.e. it can promote a formation on conspiracy aimed at increasing bids. In this case the minimization of costs is not achieved. We also note evidence for the US Conservation Reserve Programme of a decline in auction performance over time, which might be due to bidders learning more about each other's' offers over time, and so shading their individual bids upwards on average (Kirwan, 2005; Cowan, 2010).

Clearly, our setup has its limitations. It would be desirable to replicate our findings with experienced bidders, with more time for reflection and with higher stakes. It would also be useful to investigate the extent to which these findings carry over to other types of spatial coordination problems (other environmental metrics); and where the benefits of conservation actions depend not just on spatial coordination, but also on the characteristics of individual plots (eg their land use history). We also note that environmental benefits from a given set of actions contracted for in an auction on a given plot might also depend on land use patterns at the local landscape level, additionally to any coordination effects (Dallimer et al., 2010).

If results prove robust, discriminatory auction formats should be preferred in settings resembling that discussed here. In view of our results, this is particularly important in environments in which spatial connectivity plays a major role in the delivery of environmental benefits. However, what has not been addressed here is the relative performance of a discriminatory price auction compared to an agglomeration bonus scheme.

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