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**Incentives for spatially-coordinated conservation**

**under imperfect ecological information**

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# **ABSTRACT**

Increasing attention is being paid to the design of economic incentives for conservation on private land to encourage spatial coordination. We investigate the effects of using incorrect information on the ecological benefits of spatial coordination in the design of a conservation auction, using a framed field experiment with real farmers as participants. We find that auction performance can be substantially weakened if the parameters adopted are ‘wrong enough’ to change which farms are prioritised, although parameters that under-estimate the true coordination benefits are less damaging to policy performance than those which over-estimate these benefits.

**KEYWORDS**

agglomeration bonus, conservation auctions, framed field experiment, imperfect information, spatial coordination

**JEL CLASSIFICATION**

C93, D44, Q18, Q57

# **1. INTRODUCTION**

In the literature on the design of economic incentives for biodiversity conservation on private land there has been a recent and increasing emphasis on incentives which promote *spatially contiguous* rather than fragmented conservation. This is reflected in a common belief that the contiguity of habitats provides extra benefits for many species’ survival and diversity (Conte et al., 2023; Engel, 2016; Hanley et al., 2012; Nguyen et al., 2024a). Such spatial coordination benefits are also claimed in the wider literature on agri-environmental policy design and the agglomeration bonus, in contexts such as reducing soil erosion and non-point source pollution (e.g., Banerjee et al, 2014, Banerjee et al 2017). However, the ecological literature suggests that the impacts of spatial contiguity vary substantially across species or ecosystem attributes and may depend on the moderating role of contextual factors (Valente et al., 2023). This poses a challenge to the design of incentives for spatial coordination: what if the coordination mechanism assigns high weights to contiguity but the ensuring benefits for the target species are in fact very limited, or vice versa? That is, what are the implications of using the wrong ecological information in incentive design?

This study for the first time empirically explores this question in the context of the design of a *conservation auction* which allocates contracts in such a way that prioritises farmers who can provide higher environmental benefits and/or who ask for lower payments. This type of competitive allocation mechanism has been widely adopted in higher income countries such as the US (Ferraro et al., 2024; Hellerstein, 2017) and Australia (Rolfe et al., 2017), and has attracted considerable interest from lower income countries too (Engel, 2016; Jack, 2013; Liu et al., 2019). Drawing on network theory, additional conservation benefits due to spatial coordination of conserved areas are referred to in this literature as ‘edge’ benefits, while those associated with the site-specific benefits of conserving habitat patches are termed ‘node’ benefits. We adopt this network theory-based use of the terms ‘edge’ and ‘node’ in our paper, but note that meanings may differ from discussions of edge effects in ecological writing on habitat fragmentation.[[2]](#footnote-2)

Two mechanisms have been suggested to account for spatial coordination in conservation auctions. One mechanism is the spatially coordinated (SC) auction, as described in Banerjee et al. (2015), Krawczyk et al., (2016), Nguyen & Latacz-Lohmann (2024) and Reeson et al. (2011). Here, edge benefits explicitly constitute part of the total conservation benefits score (environmental value) generated, and the bid scoring and selection rules prioritise a spatial configuration of farmers that offers the highest total conservation benefits. An alternative mechanism is to offer agglomeration bonuses (AB) in auctions, as in Banerjee et al. (2021), Fooks et al. (2016), Liu et al. (2019, 2024) and Nguyen et al. (2024b). Here, farmers are offered bonus payments for the provision of edge benefits, in addition to the basic payments they ask for. In this instance, farmers better positioned to provide edge benefits would expect higher bonus payments and thus would be likely to ask for lower basic payments, which would augment these farmers’ likelihood of receiving a contract (under a budget constrained auction). Both auction mechanisms – SC and AB – facilitate contiguous conservation.

However, both mechanisms also require the quantification of edge benefits. This can be a difficult matter in real world applications because the benefits of contiguous conservation (edge benefits) vary widely from highly positive to essentially zero. Even for one taxon (e.g., forest birds), there exist species where the edge benefits are very high, and other species where these benefits are very low (Bradfer-Lawrence et al., 2024; Dolman et al., 2007; Hofmeister et al., 2017; Terraube et al., 2016). Indeed, variability in ecological responses to habitat contiguity and fragmentation gave rise to the ‘single large or several small’ (SLOSS) debate in ecology (Chase et al., 2020; Fahrig, 2017; Fletcher et al., 2018; Wintle et al., 2019). This long-standing debate examines whether large, spatially contiguous conservation measures like protected areas offer greater benefits for biodiversity than many, small, dispersed, conservation measures of equivalent total area.

Despite this considerable ecological variability, policy designers in the real world might only consider edge benefits in a simplified and generic way (for example, in designing a scheme which operates nationwide across a wide range of species), likely due to equity concerns and resource constraints in quantifying and adopting species- and location-specific parameters. As a consequence, ecological assumptions about edge benefits may not be well customised for a particular target species, ecosystem function, or context. Mis-understanding the true ecological benefits of contiguous conservation could cause considerable efficiency losses, but how big a problem this is remains un-quantified at present. For instance, if the policy designer’s estimate of edge benefits is low but the target species or ecosystem attribute actually benefits a lot from contiguous habitats, the SC auction and AB mechanisms may not induce a sufficient level of contiguity to deliver desired ecological outcomes. By contrast, if the policy designer’s estimate of coordination benefits is high but the target species or ecosystem attribute actually benefits very little from contiguous habitats, it is possible that a substantial proportion of the budget will be spent on achieving an unnecessarily high level of contiguity. Such efficiency losses have yet to be formally investigated, a gap in evidence which our paper takes a first step towards filling.

To do this, we undertake a framed field experiment using real farmers as participants in China’s Qinling Mountain region. Our experiment consisted of a total of 240 farmers from 20 villages who bid in groups of six in experimental auctions which, despite being hypothetical, had implications for the farmers’ real payoffs from attending the experiment (to incentivise their decisions in the experiment). Participants were assigned randomly into one of two auction mechanisms, an SC auction not offering an AB, and a non-SC auction offering an AB, to investigate how the implications of mis-understanding of edge benefits differ between the two approaches to incentivising spatially-coordinated conservation. Each auction group participated in three separate auctions which adopted different sets of parameters concerning the ecological benefits and farmers’ private costs of conservation. In these auctions, which farms are contracted into conservation and the resultant spatial configuration of conservation were always determined using the edge benefit parameters adopted by the auctions, which could align with or deviate from ‘true’ edge benefits. However, the true ecological benefits of the farms conserved were always computed using the true edge benefits. For example, using a given set of true edge benefits, we computed the ecological benefits firstly for the farms conserved in one set of auctions that adopted correct parameters, and then for the farms conserved in another set of auctions that adopted incorrect parameters. This allowed us to assess statistically the implications of adopting incorrect edge benefit parameters in conservation auctions under the two auction mechanisms.

Our experiment employs farmer subjects who represent the target population potentially participating in real-world conservation auctions. This contrasts with much recent literature on conservation auctions involving spatial coordination where the empirical evidence base is disproportionately dominated by laboratory experiments using university student subjects (e.g., Banerjee et al., 2015, 2021; Krawczyk et al., 2016; Nguyen et al., 2024b; Nguyen & Latacz-Lohmann, 2024).[[3]](#footnote-3) However, policymakers are interested in findings drawn from the policy’s target population, such as farmers in the case of conservation auctions, since it is the behaviour of these agents that policymakers seek to influence (Cason & Wu, 2019; List, 2011; Liu et al., 2024). Therefore, this study contributes to this literature more broadly through diversifying the subject pools of the evidence base in an attempt to enhance its policy relevance, which is a crucial next step to promote novel mechanisms featuring spatial considerations.

We chose China’s Qinling Mountain region to conduct our fieldwork because this is a globally recognised biodiversity hotspot which accommodates many endangered and rare species including crested ibis and giant pandas (Hilty et al., 2020; Zhang et al., 2017). China has been spending heavily on agri-environment (AES) programmes, such as the Sloping Land Conversion Programme (SLCP),[[4]](#footnote-4) which is the Chinese counterpart of the American Conservation Reserve Program (CRP) and covers extensive areas of agricultural land in the Qinling Mountain region (Ding & Yao, 2021; Li et al., 2011). These AES programmes in China often prioritise the enrolment of contiguous land as a means to achieve both enhanced ecological benefits and savings in administrative costs (Liu et al., 2019). In the Qinling Mountain region, this is done in order to provide connected habitats for giant pandas, a species cited by the IUCN as an exemplar of the benefits of conserving connected rather than spatially-isolated habitats (Hilty et al., 2020). Understanding the implications of over- and under-estimating the ecological benefits of contiguous conservation provides highly pertinent and important insights for AES programmes in our study area.

In what follows, Section 2 further explains the design of the experiment, and Section 3 discusses the expected outcomes to be tested. Section 4 provides more details about fieldwork, including the procedures of the experiment. Section 5 reports the results of the data analyses and addresses the main research questions. The paper concludes in Section 6 with a discussion of the implications of our findings for policy designers.

# **2. EXPERIMENTAL DESIGN**

We conducted experimental auctions in the context of a hypothetical AES programme, where the results of the auctions had implications for participating farmers’ payoffs from attending the experiment. The design of the auction was adapted from that of Liu et al. (2024) and Banerjee et al. (2021). For brevity, this section focuses on the main features of the auction and the treatments, whilst Section 4 outlines the main procedures of the experiment, to provide a basis for the subsequent analyses. Please refer to Liu et al. (2024) for further details about the design features of the auction and the justifications.

Each auction group consisted of six farmers and was randomly assigned to one of two auction mechanisms (‘between’ group treatments): 1) a spatially coordinated (SC) mechanism, where the objective of the contract allocation algorithm was to maximise the total conservation benefits, including both edge and node benefits, under a fixed budget constraint for each auction group, in the absence of agglomeration bonuses, and 2) an Agglomeration Bonus (AB) mechanism, where bonus payments were offered to incentivise the provision of edge benefits, and the contract allocation algorithm sought to maximise only the total node benefits, under the same budget constraint as the SC mechanism.

In both mechanisms, each farmer was allocated to one of the six equally-sized farms on a circular network (as shown in Figure A1 in Appendix A), where each farm had one neighbouring farm on the left and one on the right. Each farmer was assumed to use their land to grow corn using chemical herbicides which would harm wildlife.[[5]](#footnote-5) The six farmers on each network were invited to participate in a hypothetical AES auction intended to contract a subgroup of the six farmers to switch from chemical to biological herbicides, which would be safer for wildlife while ensuring the same corn yields. However, switching from chemical to biological herbicides incurs an additional private cost for each farmer . If farmer was contracted, they would be required to switch herbicides on their farm for one year, and receive a farm-specific payment in compensation for this additional private cost . Farmers without an AES contract would continue to use chemical herbicides and would not receive any payment from the AES programme. Each farmer’s core task in the experiment was to bid for the amount of the AES payment which would make them willing to switch herbicides from chemical to biological. Switching herbicides on farm on its own generates an environmental node benefit . Switching herbicides on both farms and its left (right) neighbouring farm generates an edge benefit () in addition to the node benefit.

The SC mechanism aimed to contract farms in such a way to maximise the total conservation benefits under the budget constraint:

|  |  |
| --- | --- |
| (2.1) | ,  *s.t.* . |

The binary variable indicates whether farm enters an AES contract or not, and () indicates whether the left (right) neighbouring farm enters or not. Thus, total conservation benefits are the sum of node and edge benefits aggregated over all farms who win a contract in the auction. is the bid tendered by farmer , and is the budget constraint for the auction group. Each farmer’s net payoff would be:

|  |  |
| --- | --- |
| (2.2) | . |

In contrast, for the AB mechanism the objective of the contract allocation algorithm was to:

|  |  |
| --- | --- |
| (2.3) | *,*  *s.t.* |

Each farmer’s net payoff would be:

|  |  |
| --- | --- |
| (2.4) | *.* |

Note that the contract allocation rule in Equation 2.3 did not include edge benefits, because the ecological benefits of contiguous conservation were incentivised by the agglomeration bonus payments if farmer *i* and the left (right) neighbour were contracted simultaneously, where the bonus payment would equal to the edge benefit achieved: for contiguous conservation with the left

neighbour, for the right, and for both.[[6]](#footnote-6)

Each auction group undertook one trial session and then three formal auction periods. Each auction period was an independent auction with a new set of parameters for each farmer (, , and ). The farmers earned real payoffs from the three formal auction periods which were determined by auction results, as described in Equation 2.2 and 2.4. This allowed us to adopt ‘within’ group treatments, where we randomly assigned one of the four sets of parameters in Table 1 to each auction period. In particular, the edge benefits in parameter sets and were randomly drawn from a higher uniform distribution [5, 15]; the edge benefits in and were randomly drawn from a lower uniform distribution [0, 10]. The node benefits were randomly drawn from the same uniform distribution [40, 60]. The cost parameters were randomly drawn from a uniform distribution [60, 100], and their correlation coefficients with the environmental benefit parameters were restricted to be below 0.2. and had the same set of node benefits and costs, and had another set, and the two sets were different. This introduced within-group and within-bidder variation into all types of parameters (costs and node and edge benefits).

**Table 1. Parameters**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
|  | 55 | | 48 | |
|  | 42 | | 43 | |
|  | 43 | | 47 | |
|  | 40 | | 49 | |
|  | 48 | | 53 | |
|  | 42 | | 55 | |
| *,* | 7,12 | 9,2 | 5,11 | 3,2 |
| *,* | 15,10 | 4,9 | 14,7 | 6,8 |
| *,* | 15,11 | 10,3 | 13,13 | 3,4 |
| *,* | 5,13 | 1,8 | 13,10 | 7,9 |
| *,* | 14,7 | 10,6 | 8,6 | 1,9 |
| *,* | 8,15 | 10,5 | 14,13 | 4,1 |
|  | 78 | | 75 | |
|  | 63 | | 86 | |
|  | 82 | | 80 | |
|  | 76 | | 83 | |
|  | 72 | | 61 | |
|  | 71 | | 67 | |
| Benchmark farms, SC: | 1,2,3 | 1,5,6 | 4,5,6 | 4,5,6 |
| Benchmark farms, AB: | 1,3,5 | 1,3,5 | 4,5,6 | 4,5,6 |

Under the SC mechanism, , and had different sets of ‘benchmark farms (BF)’, which refers to the subset of the six farms that would be contracted if each farmer bids for a base payment that just equals to their private net cost of switching herbicides (), ensuring zero rents are earned. and had the same BF. This allowed us to test whether the consequences of wrong parameterisation depend on whether it changes the set of BF or not. Under the AB mechanism, and (or and ) always had the same BF, because the two parameter sets had the same node benefits, and the contract allocation objective in the AB mechanism considered only node benefits (as described in Equation 2.3). Despite that, the BF in and were different from those in and . Across the SC and AB mechanisms, and had different BF, and and had the same, which allowed us to test whether the between-group treatment effects depend on whether the BF are changed or not. All the auction periods had the same budget constraint (*M* = 280 for each period), although the exact amount of the budget was not announced to the farmers. The BF listed in Table 1 were derived using this budget constraint and the cost and environmental benefit parameters (accounting for bonus payments if any).

The bidders (here, farmers) and the auctioneer were faced with the same set of edge benefit parameters, because conservation auctions in practice typically hire ecological experts to quantify environmental benefits, such as the American CRP (Hellerstein, 2017) and the Australian conservation tenders (Rolfe et al., 2017), and farmers tend to have relatively less knowledge about the landscape-scale ecological processes and the associated edge benefits (Conte & Griffin, 2017). Moreover, we assume that the auctioneer would use the edge benefit parameters that are believed to be correct: they would not *intentionally* use incorrect parameters. Therefore, bidding behaviour and contract allocation in all the auction periods depended entirely on the edge benefit parameters being used, regardless of whether these were right or wrong for a hypothetical target species. The correct ecological benefits were computed separately, using the contract allocation results from the experimental auctions, and the correct edge benefit parameters, which could be equal to or different from the parameters used in the auctions.

# **3. EXPECTED OUTCOMES**

This section discusses the expected consequences of adopting incorrect edge benefit parameters under the auction settings described in Section 2.

We start with the SC auction mechanism. As mentioned above, benchmark farms (BF) will be contracted if each farmer bids for a base payment that equals to their private net cost of switching herbicides (). In our experimental auctions, farmers are likely to bid higher than their private costs in pursuit of higher net payoffs, balancing higher asking prices against a lower chance of winning a contract. Despite that, if is close to , it remains highly likely that an auction can afford to and will contract the BF determined at the edge benefit parameters adopted, yet this would be a sub-optimal outcome if the true edge benefits imply a different set of BF. This suggests the possibility that:

**Hypothesis 1.** *Auctions under the SC mechanism have weaker performance when adopting incorrect edge benefit parameters that change the BF, compared to the same auction run with correct edge benefit parameters.*

Moreover, a wrong set of edge benefit parameters could be either higher or lower on average than the true parameters, and the two types of deviations could have different implications for auction performance. Intuitively, bidding behaviour and auction outcome depend on the cost and ecological parameters (, , and ) jointly. Edge benefit parameters ( and ) might become more influential relative to other parameters if an SC auction adopts a higher set of edge benefit parameters, compared to a lower set, which implies that over-estimating edge benefits might be more costly than under-estimating. For example, over-estimating edge benefits is perhaps more likely to alter the BF because and become more sizeable relative to , and a sub-optimal BF could weaken auction performance, as discussed above. Even if the BF are not changed, farmers with higher ecological benefit parameters might bid for higher payments in an SC auction as a rent-seeking strategy, which has been found in real-world and experimental conservation auctions alike (e.g., by Hellerstein, 2017, Liu et al., 2024). If so, over-estimating edge benefits in an SC auction might induce higher bids in general, implying that it is more expensive to contract farms into conservation, which could lead to fewer farms being contracted under the budget constraint and thereby reduce the total ecological benefits achieved. To sum up:

**Hypothesis 2.** *In SC auctions, over-estimating edge benefits leads to worse ecological outcome than under-estimating.*

In the AB mechanism, the consequences of using the wrong edge benefit parameters are more complex. The objective of the contract allocation rule (as in Equation 2.3) depends on node benefits only, and so the BF would not be changed by incorrect edge benefit parameters. However, using the wrong edge benefit parameters would change the bonus payments being offered, and so could have implications for farmers’ bidding behaviour and thus for the number of contracts affordable to the budget constraint. The AB mechanism in this study incentivises contiguous conservation by offering bonus payments according to the magnitudes of the edge benefits provided by successful bids. Under this mechanism, when edge benefits are over-estimated, a farmer anticipates a higher bonus payment as part of the total payment if they are contracted, and thus may bid for a lower base payment to increase their probability of being contracted and the expected total payment, compared to when the true edge benefit parameters are adopted. However, the aggregate impact on the total payment per contract (base payment plus bonus) is theoretically ambiguous, which precludes a theoretical expectation on whether/how it might change the number of contracts affordable to the budget constraint. Likewise, for AB auctions that under-estimate edge benefits, we cannot theoretically predict how auction performance might be impacted. We thus have the following hypothesis where the direction of the impact (being positive, negative or zero) is open to empirical investigation:

**Hypothesis 3.** *Using an incorrect set of edge benefit parameters in the AB mechanism impacts auction performance, compared to adopting the true parameters.*

As discussed above, using the wrong edge benefit parameters may have different implications under the SC and AB mechanisms. This warrants a further investigation into which mechanism has better auction performance when adopting the correct parameters: even if one mechanism is found to be less affected by incorrect edge benefit parameters, this may not be the preferred mechanism if it underperforms the other when adopting the correct parameters.

Similar to the preceding discussion, if is modestly above , the two mechanisms’ relative performance may depend largely on whether they have different sets of BF. Both situations are captured by our purposefully designed parameter sets. As shown in Table 1, SC and AB auctions have different sets of BF under the same parameter set or , where AB auctions’ BF have lower total ecological benefits, because these are the farms that provide the highest total node benefits only, due to the contract allocation rule specified in Equation 2.3, whereas SC auctions’ BF are the optimum that accounts for both node and edge benefits, according to Equation 2.1. Thus, in this situation, SC auctions are likely to deliver higher total ecological benefits than AB auctions. On the other hand, parameter sets and allow us to explore the other situation where SC and AB auctions have the same set of BF and therefore may have more comparable ecological performance, if is reasonably close to and so the BF are affordable to the budget constraint in both SC and AB mechanisms.

When net bids () are higher, auction performance may rely more on the number of farms affordable to the budget constraint, and so farmers’ bidding behaviour becomes more relevant in comparing the performance of SC and AB auctions. Farmers in AB auctions are likely to bid for lower base payments in anticipation of bonus payments, compared to those in SC auctions. However, AB auctions offer bonuses in addition to base payments, making it unclear whether the total payment per contract is still lower than that in SC auctions, and whether AB auctions can afford to contract more farms and achieve higher ecological benefits. In other words, the AB mechanism could outperform the SC mechanism ecologically, when both of them adopt the correct edge benefit parameters, yet this is not guaranteed theoretically and needs to be tested empirically. We therefore propose:

**Hypothesis 4.** *When adopting the correct edge benefit parameters, AB auctions have different ecological performance than SC auctions.*

# **4. FIELDWORK**

Our experimental auctions were conducted in 20 villages in two counties of China’s Qinling Mountain region,[[7]](#footnote-7) as shown in Figure 1, with a total of 240 farmers divided into 40 auction groups. Each auction group was randomly assigned to the SC or AB mechanism in a balanced manner, amounting to a total of 20 auction groups in each mechanism. To test Hypothesis 4, we compared the two mechanisms’ auction performance at the auction group level, and so the sample size was 20 per treatment and 40 in total. We primarily assessed two indicators of auction performance:

1. **total benefit**, which was measured as the total ecological benefit achieved in each auction group on average (over the three formal auction periods which will be further described below), and:
2. **cost effectiveness**, which was defined as the average ecological benefit procured per unit of payment for each auction group.

For both indicators, we calculated the statistical powers of a range of sample sizes using the data from Liu et al. (2024). We adopted two calculation methods separately, including a formula recommended by Moffatt (2021), assuming the treatment effects would be estimated using standard *t*-tests, and a simulation-based approach of Bellemare et al. (2016), assuming the treatment effects would be estimated using nonparametric rank-sum tests to relax distributional assumptions. We calculated the statistical powers in testing whether two treatments are at least 10% different in an auction performance indicator using a 10% critical *p*-value. The results are reported in Figure 2, which suggest that our sample size at the auction group level (20 per treatment) achieves over 90% statistical power, which exceeds the conventionally expected level 80% according to Ioannidis et al. (2017).

Hypotheses 1–3 were tested using auctions with a particular mechanism (SC or AB) and parameter set (, , or in Table 1). Each auction group conducted four independent auction periods, where the first period was a trial auction with no implications for the participants’ payoffs, and the subsequent three periods were formal auctions with real financial incentives. We focused on the formal auction periods in our data analyses, consisting of a total of 60 formal periods for each auction mechanism. For each auction group, the four sets of parameters in Table 1 were randomly assigned to the four auction periods in a balanced manner, and so each parameter set was assigned to a total of 15 formal auction periods in each auction mechanism. Therefore, our sample size is 15 per treatment in a hypothesis test by auction mechanism and parameter set. As shown in Figure 2, the statistical power of this sample size remains above 80% under both calculation methods for both auction performance indicators.

A map of the world with a map of the country

Description automatically generated

**Figure 1. Fieldwork locations**

A graph of a number of groups

Description automatically generated

**Figure 2. Power calculations**

The procedures of the experiment are detailed in the protocol in Appendix B. Each session started with a preparation stage, where the six participating farmers were seated randomly in a circle at least one metre apart and facing outwards, representing the spatial layout in Figure A1. This seating remained the same throughout the entire session. Each farmer then received an information sheet containing the spatial layout of the six farms, the context about the farming and conservation practices, the core task in the experiment and the parameters for their own farm. In addition, each farmer received a bid sheet to write their bids in private. After that, the experimenter explained to the entire group the details on the information sheet, the contract allocation rule (highlighting the objective and the budget constraint without revealing the exact amount of the budget) and how net payoffs would be calculated with and without a contract.

The experiment then proceeded to a trial auction period. The farmers were told that the trial period was for practice and would not affect their payoffs from participating in the experiment. The trial period consisted of two independent rounds of bidding. Each round started with a communication stage which allowed the farmers to discuss freely with the left or the right neighbour, one at a time, for a maximum of three minutes in total. They were told not to show the information sheets to their neighbours but were allowed to verbally discuss their parameters if they would like to. After that, each farmer wrote a bid in private on their bid sheet. The experimenter then came to each farmer individually to enter all the bids into an Excel algorithm to work out which farmer(s) would be contracted under the allocation rule, and then announced to the entire group the seat number(s) of the farmer(s) contracted (if any). The experimenter then returned to each farmer to write on their bid sheet in private their own net payoff and reminded them that this would not be paid. These steps were then repeated for a second trial round.

After the trial period, the experimenter announced the first formal auction period and replaced the information sheets with a new set of parameters. Each formal period was designed as a multiple-round sealed-bid auction, consisting of a minimum of three and a maximum of six bidding rounds with the same set of parameters, and the results of the period were determined by the final bidding round. In the third, fourth or fifth round, the auction period would conclude if the current round had the same farmers contracted as in the previous round. Otherwise, the next round would be conducted till the sixth round, which would be the final round regardless of the outcome. The farmers were told that the final round would determine the results of the auction period and their payoffs, and they were allowed to freely update their bids in each round, but they were not made aware of the stopping rule or the minimum/maximum number of rounds. The procedures of each round were the same as in the trial period, except that the communication stage was shortened to one minute. After the first formal auction period, the farmers undertook another two periods following the same procedures, using a new set of parameters for each period.

Lastly, each farmer completed a one-to-one questionnaire survey with the experimenter or an assistant. Each farmer was asked questions about their demographic and socioeconomic characteristics, risk attitudes, and social relations with other farmers in the same auction group. The entire session (including the preparation stage, the trial and formal auction periods, and the survey) lasted 84 minutes on average. All the payments were made in cash after the completion of the survey, including the net payoffs from the three formal auction periods and a show-up fee of CNY 30 (USD 4.26) for each farmer regardless of the results of the auctions. Out of the 240 participants of our experiments, 192 were contracted at least once in the experimental auctions (i.e., were successful in at least one formal auction period), earning an additional net payoff of CNY 26.67 (USD 3.78) per person on average. The show-up fee alone exceeded the minimum wage in our study area (CNY 20 per hour, or USD 2.84 per hour).

We performed two sets of balance tests at the farmer level for a total of 12 covariates as listed in Table 2. These covariates were selected following Liu et al. (2024) to characterise each farmer’s demographic and socioeconomic features, risk attitudes and social relations with their neighbours in the experiment which may correlate with their bidding behaviour. Hypothesis 4 was tested by comparing the auction performance of the two auction mechanisms (SC vs. AB). Therefore, we firstly conducted *t*-tests for the 12 covariates individually between the two auction mechanisms and estimated the standardised mean differences as per Austin (2009). As shown in Table 2, the *p*-values from these *t*-tests are above 15% for all 12 covariates, and above 40% for 9 of them. The standardised mean differences are below 20% for all 12 covariates, and below 10% for 8 of them. Hypotheses 1–3 concern auction performance by auction mechanism and parameter set across 8 subsets of our full sample. We therefore conducted *F*-tests across the 8 subsamples to check the balance of the 12 covariates, and estimated the standardised mean differences for each pair of the 8 subsamples and then took the averages. It can be seen in Table 2 that the *p*-values from these *F*-tests are above 10% for all 12 covariates, and above 40% for 10 of them. The averages of the standardised mean differences are below 20% for all 12 covariates, and below 10% for 7 of them. Table A1 in Appendix A presents the full descriptive statistics of the 12 covariates by auction mechanism and parameter set.

**Table 2. Covariate balance tests**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Full sample**  **mean**  **(SD)** | | **SC vs. AB** | | | **By mechanism and parameter set** | | |
| ***p*-value, *t*-test** | **Standardised  mean diff. (abs.)** | | ***p*-value, *F*-test** | **Standardised  mean diff. (abs., avg.)** | |
| Age (years) | 49.33  (13.71) |  | 0.66 | 5.64% |  | 0.92 | 7.82% |  |
| Cattle (count, past year) | 1.13  (2.23) |  | 0.86 | 2.24% |  | 0.95 | 6.94% |  |
| Collaborate (1 = bidder had real-life agricultural collaboration in the past  5 years with one or both neighbours in the experiment, 0 = otherwise) | 0.21  (0.41) |  | 0.43 | 10.20% |  | 0.85 | 8.42% |  |
| Cropland area (mu, past year) | 3.73  (3.13) |  | 0.70 | 5.03% |  | 0.56 | 11.58% |  |
| Education (years) | 8.28  (3.92) |  | 0.19 | 17.01% |  | 0.14 | 15.84% |  |
| Gender (1 = male, 0 = female) | 0.55  (0.50) |  | 0.15 | 18.52% |  | 0.27 | 14.05% |  |
| Household size (count of household members, past year) | 4.03  (1.63) |  | 0.50 | 8.68% |  | 0.83 | 7.95% |  |
| Household income (CNY 1,000, past year) | 39.17  (23.63) |  | 0.50 | 8.81% |  | 0.97 | 6.40% |  |
| House value (CNY 1,000, current valuation) | 22.58  (16.69) |  | 0.17 | 17.66% |  | 0.43 | 12.59% |  |
| Leader/CCP (1 = bidder is currently a village leader or a member of  the Chinese Communist Party, 0 = otherwise) | 0.28  (0.45) |  | 0.57 | 7.47% |  | 0.46 | 12.18% |  |
| Market experience (1 = bidder had businesses or urban employments  in the past 5 years, 0 = otherwise) | 0.55  (0.50) |  | 0.90 | 1.68% |  | 0.92 | 7.60% |  |
| Risk averse (1 = bidder is risk averse, based on a 5-level self-rating  question, 0 = otherwise) | 0.31  (0.46) |  | 0.68 | 5.40% |  | 0.98 | 5.78% |  |
| Obs. (number of bidders) | 240 |  | 120 per treatment | | | 90 per treatment | | |

*Note:* 1 hectare = 15 mu; USD 1 = CNY 7.05 in 2023.

# **5. DATA ANALYSIS AND RESULTS**

This section reports the results from our experimental auctions regarding the implications of using the wrong edge benefit parameters in SC and AB auctions. Throughout the analysis, we focus on data from the last bidding round of each auction period, because the results of each auction period (on which payments to participants were based) are those of the last round.

## **5.1. Implications of using the wrong parameters in Spatially Coordinated auctions**

We start with testing Hypotheses 1 and 2 regarding SC auctions. This is based on data at the auction period level from the four within-group treatments with different sets of parameters (SC\_, SC\_, SC\_ and SC\_).

As mentioned in Section 2, our experimental auctions allocated contracts according to the ecological benefit parameters adopted, assuming that the auctioneer believed that these were the correct parameters. However, the ecological benefits actually achieved need to be computed using the true parameters, which could equal to or differ from the parameters adopted in the experimental auctions. For instance, consider the auctions in SC\_ and SC\_, and suppose the true parameters are . In that case, the auctions in SC\_ have used the correct parameters, and the true ecological benefits achieved should be computed using for the farms contracted in SC\_. However, if the true parameters are , this suggests that the auctions in SC\_ have used the wrong parameters, and the true ecological benefits achieved should be computed using for the farms contracted in SC\_. The results of these two situations are shown in the left half of Figure 3A, which suggests that, when the true parameters are , mistakenly using in SC auctions leads to a lower total ecological benefit than using the correct parameters, although the magnitude of the mean difference is rather small (1%), despite being statistically different from zero (*p*-value < 0.01). This *p*-value was derived from a non-parametric rank-sum test which does not rely on strong distributional assumptions, because we have only 15 observations at the auction period level in SC\_ and another 15 in SC\_, making it difficult to justify the distributional assumptions of parametric tests such as the *t*-test. Similarly, the right half of Figure 3A suggests that, when the true parameters are , mistakenly using in SC auctions leads to a lower total ecological benefit than using the correct parameters (*p*-value < 0.01), and the magnitude of the mean difference is more sizeable (7%).

Cost-effectiveness was measured as the true ecological benefits produced relative to payments made for contracts awarded in an auction, where the true ecological benefit was computed as described above, and the payment was the total amount paid to the farmers contracted in an experimental auction (the sum of all the base payments and agglomeration bonuses if any). As shown in the left half of Figure 3C, when the true parameters are , SC auctions using the incorrect parameters are less cost-effective than those using the correct parameters , although the mean difference (3%) is marginal and has a *p*-value (0.12) that narrowly misses the conventional cut-off level for statistical significance (0.10). The right half of Figure 3C suggests that, when the true parameters are , SC auctions using the incorrect parameters are less cost-effective than those using the correct parameters , by 6% on average, which is statistically different from zero (*p*-value = 0.03).

|  |  |  |  |
| --- | --- | --- | --- |
| ***A*** | *A graph of a number of boxes  Description automatically generated with medium confidence* | ***B*** | *A graph of a number of different sizes and numbers  Description automatically generated with medium confidence* |
|  |  |  |  |
| ***C*** | *A graph of a graph with a number of boxes  Description automatically generated with medium confidence* | ***D*** | *A graph of a number of boxes  Description automatically generated with medium confidence* |

**Figure 3. Consequences of adopting the wrong parameters under the SC mechanism**

*Note:* White bars in grey boxes: means; grey boxes: 90% confidence intervals; capped spikes: 95% confidence intervals; darker grey: *p* < 0.10, lighter grey: *p* ≥ 0.10; the *p*-values of the differences were derived from Wilcoxon rank-sum tests; number of observations: 15 auction periods each box. See Table A2 in Appendix A for further details.

Panels A and C in Figure 3 represent the situation where the BF are changed when SC auctions adopt incorrect edge benefit parameters. (Recall that parameter sets and have different BF under the contract allocation rule of the SC mechanism, as shown in Table 1.) Our findings provide supporting evidence for Hypothesis 1 that SC auctions have weaker performance when adopting incorrect edge benefit parameters that target different BF than the true parameters.

By comparison, Panels B and D in Figure 3 present another situation where adopting incorrect parameters does not change the BF, based on data from SC\_ and SC\_, because parameter sets and have the same BF. It can be seen that mis-using and for each other has very limited consequences: the mean differences in the total ecological benefit and cost-effectiveness are all below 2% in relative terms, and the lowest *p*-value is 0.69. Overall, mis-using and for each other is much less consequential to auction performance compared to mis-using and . This implies that, despite considerable challenges in quantifying the exact values of the true edge benefits, the performance of SC auctions would not be substantially undermined as long as the parameters adopted are ‘qualitatively correct’ in suggesting which farms are more worth conserving.[[8]](#footnote-8) In other words, we find:

**Result 1.** *SC auctions have weaker performance if the parameters adopted are ‘sufficiently wrong’ that a sub-optimal set of BF is targeted than those that should be prioritised according to the true edge benefits.*

We next explore Hypothesis 2 by comparing the implications of over- and under-estimating the true edge benefits in our experimental auctions. Returning to Figure 3, the cases of over-estimating include adopting the parameters () when the true parameters are (), and the cases of under-estimating include adopting the parameters () when the true parameters are (), as explained in Table 1. Panels A and C of Figure 3 suggest that auction performance is more sensitive to over-estimating the true edge benefits (mistakenly using instead of ) than to under-estimating (mistakenly using instead of ), in terms of both the magnitude and statistical significance of the consequences.[[9]](#footnote-9) A similar pattern can be found in Panels B and D of Figure 3, even conditional on the same BF. This is likely because, as discussed in Section 3, when an SC auction adopts a higher set of edge benefit parameters ( or ), farmers tend to bid higher in general as a rent-seeking strategy, leading to fewer farms being contracted and thus weaker auction performance, compared to when adopting a lower set of parameters ( or ), as shown in Figure A4A in Appendix A. These findings are in line with Hypothesis 2, suggesting:

**Result 2.** *SC auctions using incorrect edge benefit parameters are likely to have better performance when under-estimating the true edge benefits than over-estimating.*

## **5.2. Implications of using the wrong parameters in Agglomeration Bonus auctions**

We now turn to AB auctions, starting with investigating whether auction performance is impacted by incorrect edge benefit parameters, using data at the auction period level from the four within-group treatments with different sets of parameters (AB\_, AB\_, AB\_ and AB\_).

Figure 4 presents the true ecological benefits and cost-effectiveness achieved in AB auctions with the correct and incorrect edge benefit parameters, respectively, where both performance indicators were computed as described in Section 5.1. Overall, these results find no evidence of statistically significant consequences caused by incorrect edge benefit parameters. For both ecological performance and cost-effectiveness, the *p*-values of the mean differences caused by incorrect parameters are all higher than the conventional threshold level of statistical significance (0.10). This is likely because, under the AB mechanism designed in this study, using the wrong set of edge benefit parameters would not change the BF in any case, because the contract allocation rule prioritises farms that give the highest total node benefit, and so does not rely on edge benefit parameters in any case.[[10]](#footnote-10)

That said, comparing the estimated impacts of over- and under-estimating the true edge benefits, we can see that under-estimating is less consequential to auction performance, such as adopting () while the correct parameters are (), compared to over-estimating, such as adopting () while the correct parameters are (). As discussed in Section 3, adopting higher edge benefit parameters in the AB mechanism has two opposite effects on the typical payment per contract, and so the direction of the aggregate effect is theoretically ambiguous. As shown in Figure A4B, our results find that auctions with higher edge benefit parameters (AB\_ and AB\_) have higher net payment per contract on average than those with lower parameters (AB\_ and AB\_). Consequently, AB\_ and AB\_ cannot afford to contract as many farms as in AB\_ and AB\_, as shown in Figure A4B. This perhaps explains the observation in Figure 4 about the difference in over- and under-estimating the true edge benefits, although none of these findings is statistically significant.

Overall, linking back to Hypothesis 3, we have:

**Result 3.** *We find no evidence that using the wrong edge benefit parameters would impact auction performance under the AB mechanism in this study.*

Although the AB mechanism appears to be less sensitive to incorrect edge benefit parameters than the SC mechanism, the remaining important question is which auction mechanism has better performance when the correct ecological parameters are used to incentivise spatial coordination (Hypothesis 4). We compare the two mechanisms’ auction performance using data at the auction group level, focusing on the averages of the total ecological benefit and cost-effectiveness over the three formal auction periods of each auction group. The two auction performance indicators were computed using the parameters adopted in the experimental auctions, assuming that these are the correct parameters. The results in the left half of Figure 5A suggest that, in our experimental auctions, the SC mechanism achieves higher ecological benefits than the AB mechanism, by 14% on average, with a *p*-value below 0.01. Moreover, SC auctions are found to be more cost-effective than AB auctions, by nearly 16% on average, with a *p*-value below 0.01, as shown in the right half of Figure 5A. These results lend support to Hypothesis 4 that the two auction mechanisms have different performance when adopting the correct parameters, and, more specifically, the SC mechanism outperforms the AB mechanism in terms of both ecological benefits and cost-effectiveness.

We might wonder whether the weaker performance of AB auctions is because fewer farms are contracted for conservation activities due to a higher total payment per contract compared to SC auctions. Starting with the left half of Figure 5B, we firstly find that farmers in AB auctions indeed tend to ask for lower base payments in anticipation of receiving bonus payments: the average net bid in AB auctions is 19% lower than that in SC auctions, with a *p*-value around 0.01. This is in line with our expectation (e.g., Liu et al, 2019) and confirms the potential of the AB mechanism to achieve better auction performance than the SC mechanism. However, as can be seen in the right half of Figure 5B, after accounting for bonus payments, the total net payment per contract in AB auctions exceeds that in SC auctions, although the mean difference (8%) is much smaller than that for net bids and has a large *p*-value close to one. Despite that, the two auction mechanisms have contracted the same number of farms on average, as shown in the left half of Figure 5C. Taken together, AB auctions tend to pay more per contract on average, which has likely contributed to the under-performance in cost-effectiveness, but not necessarily to the lower ecological benefits achieved.

Instead, AB auctions’ lower ecological performance is more likely to stem from the contract allocation objective which may prioritise a sub-optimal set of BF, especially under the parameter sets and , where the optimal BF should be those targeted in the SC mechanism, not those in the AB mechanism, as shown in Table 1, because the contract allocation objective of the AB mechanism is to maximise the total node benefit only, whereas the objective of the SC mechanism targets the highest total ecological benefit including both node and edge benefits. As shown in the right half of Figure 5C, SC auctions have conserved a higher number of farms in the optimal selections, by 22% on average than AB auctions, which has likely caused the difference in the two mechanisms’ ecological performance. In fact, if we focus on auction performance under the parameter sets and , the two mechanisms’ ecological performance would be much more comparable, where the mean difference reduces to 5%, with a *p*-value higher than 0.10, as shown in the left half of Figure 5D, likely because the two mechanisms’ contract allocation objectives target the same BF under the parameter sets and . However, the SC mechanism remains more cost-effective, by 9% on average than the AB mechanism (*p*-value = 0.02), which is likely due to SC auctions’ lower payment per contract.

These findings can be summarised as:

**Result 4.** *When the correct edge parameters are used in auction design, the AB mechanism is less preferable than the SC mechanism due to the former’s under-performance in both ecological benefits and cost-effectiveness.*

|  |  |  |  |
| --- | --- | --- | --- |
| ***A*** | *A graph of a number of boxes  Description automatically generated with medium confidence* | ***B*** | *A graph of a number of boxes  Description automatically generated with medium confidence* |
|  |  |  |  |
| ***C*** | *A graph of a graph with a number of boxes  Description automatically generated with medium confidence* | ***D*** | *A graph of a graph with a number of text  Description automatically generated with medium confidence* |

**Figure 4. Consequences of adopting the wrong parameters under the AB mechanism**

*Note:* White bars in grey boxes: means; grey boxes: 90% confidence intervals; capped spikes: 95% confidence intervals; darker grey: *p* < 0.10, lighter grey: *p* ≥ 0.10; the *p*-values of the differences were derived from Wilcoxon rank-sum tests; number of observations: 15 auction periods each box. See Table A3 in Appendix A for further details.

|  |  |  |  |
| --- | --- | --- | --- |
| ***A*** | *A diagram of a cost effectiveness  Description automatically generated* | ***B*** | *A graph of a number of different numbers  Description automatically generated with medium confidence* |
|  |  |  |  |
| ***C*** | *A graph of a diagram  Description automatically generated with medium confidence* | ***D*** | *A graph of a graph with a number of columns  Description automatically generated with medium confidence* |

**Figure 5. Outcomes of SC and AB auctions**

*Note:* White bars in grey boxes: means; grey boxes: 90% confidence intervals; capped spikes: 95% confidence intervals; darker grey: *p* < 0.10, lighter grey: *p* ≥ 0.10; the *p*-values of the differences were derived from Wilcoxon rank-sum tests; number of observations: 20 auction groups each box. See Table A4 in Appendix A for further details.

# **6. DISCUSSION AND CONCLUSIONS**

Novel economic incentives aiming to optimise the spatial layout of pro-environmental actions delivered by land managers typically rely on quantitative metrics to assess and rank the ecological benefits of different spatial configurations of conservation activities (Nguyen et al., 2024a). For example, one quarter of the direct payments given to Swiss farmers for providing biodiversity benefits are given as agglomeration bonuses that farmers earn by taking conservation actions near those being taken by their neighbours (Huber et al., 2023).However, there exists considerable heterogeneity in the ecological benefits of spatial coordination in wildlife conservation. Different spatial configurations of habitat conservation can deliver widely-varying overall conservation benefits, because the additional benefits of spatially-contiguous conservation (edge benefits) vary substantially across species and contexts (Chase et al., 2020; Fahrig, 2017; Fletcher et al., 2018; Valente et al., 2023; Wintle et al., 2019).

This paper presents the first framed field experiment on the implications of adopting wrong edge benefit metrics for one specific type of incentive mechanism, namely conservation auctions. We focus on two auction mechanisms intended to facilitate the spatial optimisation of conservation activities: the spatially coordinated (SC) mechanism which directly accounts for edge benefits in the contract allocation objective and scoring algorithm; and the agglomeration bonus (AB) mechanism which incentivises contiguous conservation using bonus payments based on edge benefit metrics. We conducted experimental auctions with a total of 240 Chinese farmers who participated in 40 auction groups which were randomly assigned into one of the two auction mechanisms. Each auction group undertook multiple auction periods with different sets of ecological benefit parameters as within-group treatments. The experimental design enabled us to explore the implications of implementing an auction design with the ‘wrong’ edge benefit parameters in the two auction mechanisms.

Our findings suggest that the implications for SC auctions of using incorrect edge benefit parameters which deviate from the true values depend on whether the parameters adopted are ‘qualitatively correct’ about which farms should be prioritised for awarding conservation contracts (the set of benchmark farms). When this is so, these auctions’ ecological performance and cost-effectiveness would not be substantially undermined, compared to a situation where the ‘true’ parameters are used in the auction design. In general, we expect the subset of benchmark farms that should be prioritised to be robust to some degree of parameter error describing edge benefits. We expect this, in part, because the choice of benchmark farms is determined by the benefit over cost ratio on offer from different farms. As a ratio distribution this will often be right-skewed, meaning the gap between the benefit-cost ratios on offer from the very best farms and those on offer from less desirable farms will be relatively large. Moreover, the underlying node benefits themselves may be right-skewed, as might be expected, for example, if considering abundances of priority species across farms (Gaston & Blackburn, 2000, Simpson et al., 2023). The resulting gap in benefit-cost ratios should create some robustness in the choice of benchmark farms to moderate errors in parameter estimates.

That said, SC auctions are likely to have weaker performance if the parameters adopted are ‘sufficiently wrong’ and thus target a sub-optimal set of farms. In that case, SC auctions tend to have better performance when adopting parameters that under-estimate the true edge benefits, compared to those that over-estimate these spatial coordination benefits. These findings suggest that policy designers of conservation auctions should be cautioned against adopting stylised or typical edge benefit parameters measured for different species or locations, which are highly likely to differ from the true edge benefits and to compromise auction performance. We would encourage informing scheme design with the most locally relevant ecological data possible, which echoes the value of information theory in the conservation literature (e.g., Canessa et al., 2015). This will likely be easiest to do when the conservation target for a particular scheme is clearly defined (e.g., increasing the local abundance of a particular species rather than improving the plight of biodiversity defined broadly) and its responses to past management actions well-monitored. In addition to collecting quantitative data onedge benefits for a particular application, it might be equally helpful to qualitatively assess which spatial configurations are ecologically more important in the context of the auctions’ target species and sites. In case of high uncertainty, it might be advisable to be conservative about edge benefits and adopt parameters in a lower range, which might help mitigate the negative consequences of using incorrect parameters.

The AB mechanism implemented in this study appears to be less sensitive to the use of incorrect ecological parameters by the policy designer. However, if the correct parameters are used, this AB mechanism is likely to underperform the SC mechanism, in terms of both ecological outcome and cost-effectiveness. The AB mechanism we used offers bonus payments to reward contiguous conservation outcomes, but does not account for edge benefits in the contract allocation objective. The AB mechanism we explored was purposefully designed as such, because alternative versions (e.g., Banerjee et al., 2021, Liu et al., 2024) offer bonus payments in addition to a scoring rule that accounts for edge benefits in the contract allocation objective. Our study confirms again that the contract allocation rule outweighs bonus payments in agri-environmental auctions. A next step might be to assess whether the SC auction on its own outperforms an AB offered on top of a fixed-rate payment in non-auction settings, accounting for non-participation, because conservation auctions are likely to deter participation due to the complex procedures and high transaction costs(Palm-Forster et al., 2016; Rolfe et al., 2018)*.*

Applied ecologists have written extensively about the effect of parameter uncertainty of the type we consider here on conservation decision-making, usually seeking to understand when collecting more information would be worthwhile (Moore & Runge, 2012; Canessa et al., 2015; Bolam et al., 2019). However, many such studies focus on optimal decision-making where policy-makers are assumed free to target interventions where they are most needed, regardless of the willingness of land managers to actually participate. Our approach instead evaluates the role of ecological uncertainty within the context of an incentivised auction. Moreover, we rely on a framed field experiment to reflect the types of decisions actual landowners might take, since our subject pool consists of those farmers likely to be targeted with the mechanism. We find the economic and ecological implications of using incorrect ecological information when designing economic incentives for conservation depend on the specific way in which the policy designer tries to encourage spatial coordination.

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# **APPENDIX A. SUPPLEMENTARY FIGURES AND TABLES**

***4***

***2***

***3***

***c1***

***q1***

***e1l***

***e1r***

***5***

***6***

***1***

***c2***

***q2***

***e2l***

***e2r***

***c3***

***q3***

***e3l***

***e3r***

***c4***

***q4***

***e4l***

***e4r***

***c5***

***q5***

***e5l***

***e5r***

***c6***

***q6***

***e6l***

***e6r***

**Figure A1. Spatial layout of the farms and parameters**

|  |  |  |  |
| --- | --- | --- | --- |
| ***A*** | *A graph of a number of benefits  Description automatically generated* | ***B*** | *A graph of a number of benefits  Description automatically generated with medium confidence* |
|  |  |  |  |
| ***C*** | *A graph of a number of benefits  Description automatically generated with medium confidence* | ***D*** | *A graph of a number of benefits  Description automatically generated with medium confidence* |

**Figure A2. Total environmental benefits achieved in SC auctions for other true edge benefits**

|  |  |  |  |
| --- | --- | --- | --- |
| ***A*** | *A graph of a cost effectiveness  Description automatically generated* | ***B*** | *A graph of a normal distribution  Description automatically generated* |
|  |  |  |  |
| ***C*** | *A graph of a function  Description automatically generated* | ***D*** | *A graph of a function  Description automatically generated* |

**Figure A3. Cost effectiveness achieved in SC auctions for other true edge benefits**

|  |  |
| --- | --- |
| ***A*** | *A graph of a number of numbers  Description automatically generated with medium confidence* |
|  |  |
| ***B*** | *A graph of different numbers  Description automatically generated with medium confidence* |

**Figure A4. Net bids, net payments and farms conserved under different auction mechanisms and parameter sets**

*Note:* White bars in grey boxes: means; grey boxes: 90% confidence intervals; capped spikes: 95% confidence intervals; darker grey: *p* < 0.10, lighter grey: *p* ≥ 0.10; the *p*-values of the differences were derived from Wilcoxon rank-sum tests; number of observations: 30 auction periods each box.

**Table A1. Descriptive statistics by auction mechanism and parameter set**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Mean (SD)** | | | | | | | | | | |
|  | **SC** | | | | |  | **AB** | | | | |
|  | **All** | **W1** | **W2** | **W3** | **W4** |  | **All** | **W1** | **W2** | **W3** | **W4** |
| Age (years) | 48.94  (13.50) | 48.13  (12.97) | 49.17  (13.87) | 49.63  (13.54) | 48.83  (13.63) |  | 49.72  (13.97) | 50.68  (14.29) | 49.41  (13.76) | 50.36  (14.52) | 48.42  (13.24) |
| Cattle (count, past year) | 1.16  (2.30) | 1.19  (2.53) | 1.26  (2.51) | 1.23  (2.42) | 0.96  (1.59) |  | 1.11  (2.18) | 1.14  (2.41) | 1.22  (2.37) | 1.16  (2.31) | 0.91  (1.48) |
| Collaborate (1 = bidder had real-life agricultural  collaboration in the past 5 years with one or both  neighbours in the experiment, 0 = otherwise) | 0.23  (0.42) | 0.21  (0.41) | 0.21  (0.41) | 0.26  (0.44) | 0.26  (0.44) |  | 0.19  (0.40) | 0.18  (0.38) | 0.18  (0.38) | 0.20  (0.40) | 0.21  (0.41) |
| Cropland area (mu, past year) | 3.80  (3.10) | 3.54  (3.12) | 3.82  (3.29) | 4.24  (3.26) | 3.62  (2.63) |  | 3.65  (3.17) | 3.34  (3.09) | 3.86  (3.42) | 3.97  (3.21) | 3.43  (2.91) |
| Education (years) | 7.95  (4.07) | 8.20  (4.00) | 7.52  (4.10) | 7.97  (4.30) | 8.09  (3.85) |  | 8.61  (3.76) | 7.89  (3.39) | 8.76  (3.91) | 8.81  (3.82) | 8.98  (3.82) |
| Gender (1 = male, 0 = female) | 0.60  (0.49) | 0.60  (0.49) | 0.58  (0.50) | 0.62  (0.49) | 0.60  (0.49) |  | 0.51  (0.50) | 0.48  (0.50) | 0.47  (0.50) | 0.57  (0.50) | 0.52  (0.50) |
| Household size (count of household members,  past year) | 3.96  (1.71) | 4.01  (1.69) | 3.78  (1.66) | 4.02  (1.76) | 4.02  (1.74) |  | 4.10  (1.55) | 4.02  (1.63) | 4.17  (1.59) | 4.18  (1.54) | 4.03  (1.43) |
| Household income (CNY 1,000, past year) | 38.13  (24.68) | 38.03  (25.10) | 38.50  (25.10) | 37.33  (24.84) | 38.64  (23.76) |  | 40.21  (22.58) | 39.19  (22.83) | 40.36  (22.98) | 40.67  (21.19) | 40.61  (23.37) |
| House value (CNY 1,000, current valuation) | 21.11  (16.01) | 20.54  (16.43) | 20.84  (15.96) | 20.83  (14.46) | 22.23  (17.12) |  | 24.05  (17.28) | 22.94  (16.14) | 24.82  (17.87) | 24.77  (17.95) | 23.68  (17.13) |
| Leader/CCP (1 = bidder is currently a village leader or  a member of the Chinese Communist Party, 0 = otherwise) | 0.26  (0.44) | 0.23  (0.43) | 0.24  (0.43) | 0.31  (0.47) | 0.24  (0.43) |  | 0.29  (0.46) | 0.21  (0.41) | 0.31  (0.47) | 0.33  (0.47) | 0.31  (0.47) |
| Market experience (1 = bidder had businesses or urban  employments in the past 5 years, 0 = otherwise) | 0.56  (0.50) | 0.54  (0.50) | 0.53  (0.50) | 0.57  (0.50) | 0.59  (0.49) |  | 0.55  (0.50) | 0.53  (0.50) | 0.59  (0.49) | 0.50  (0.50) | 0.58  (0.50) |
| Risk averse (1 = bidder is risk averse, based on a 5-level  self-rating question, 0 = otherwise) | 0.33  (0.47) | 0.32  (0.47) | 0.32  (0.47) | 0.34  (0.48) | 0.31  (0.47) |  | 0.30  (0.46) | 0.32  (0.47) | 0.27  (0.44) | 0.32  (0.47) | 0.29  (0.46) |
| Obs. (number of bidders) | 120 | 90 | 90 | 90 | 90 |  | 120 | 90 | 90 | 90 | 90 |

*Note:* 1 hectare = 15 mu; USD 1 = CNY 7.05 in 2023.

**Table A2. Further results about the consequences of adopting the wrong parameters under the SC mechanism**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Correct par.** | | | **Wrong par.** | | | **Wrong – Correct** | | | |
| **Par.** | **Mean (SD)** | | **Par.** | **Mean (SD)** | | **Mean diff. (SE)** | | **Rank-sum** | ***t*-test** |
| *Panel 1: Total benefit* | | | | | | | | | |
|  | 186.27  (17.84) |  |  | 184.00  (4.14) |  | –2.27  (4.73) |  | *p* < 0.01 | *p* = 0.64 |
|  | 173.00  (4.14) |  |  | 160.07  (16.09) |  | –12.93  (4.29) |  | *p* < 0.01 | *p* < 0.01 |
|  | 186.00  (23.55) |  |  | 189.73  (17.27) |  | 3.73  (7.54) |  | *p* = 0.93 | *p* = 0.62 |
|  | 173.87  (15.53) |  |  | 171.67  (20.65) |  | –2.20  (6.67) |  | *p* = 0.93 | *p* = 0.74 |
| *Panel 2: Cost-effectiveness* | | | | | | | | | |
|  | 0.74  (0.07) |  |  | 0.72  (0.03) |  | –0.02  (0.02) |  | *p* = 0.12 | *p* = 0.31 |
|  | 0.67  (0.03) |  |  | 0.63  (0.06) |  | –0.04  (0.02) |  | *p* = 0.03 | *p* = 0.03 |
|  | 0.74  (0.09) |  |  | 0.76  (0.08) |  | 0.01  (0.03) |  | *p* = 0.69 | *p* = 0.64 |
|  | 0.70  (0.07) |  |  | 0.69  (0.08) |  | –0.01  (0.03) |  | *p* = 0.88 | *p* = 0.77 |
| Obs. (periods): 15 | | | Obs. (periods): 15 | | |  |  |  |  |

**Table A3. Further results about the consequences of adopting the wrong parameters under the AB mechanism**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Correct par.** | | | **Wrong par.** | | | **Wrong – Correct** | | | |
| **Par.** | **Mean (SD)** | | **Par.** | **Mean (SD)** | | **Mean diff. (SE)** | | **Rank-sum** | ***t*-test** |
| *Panel 1: Total benefit* | | | | | | | | | |
|  | 140.27  (15.13) |  |  | 147.73  (6.71) |  | 7.47  (4.27) |  | *p* = 0.26 | *p* = 0.09 |
|  | 146.33  (1.29) |  |  | 140.27  (15.13) |  | –6.07  (3.92) |  | *p* = 0.26 | *p* = 0.13 |
|  | 179.47  (28.40) |  |  | 184.73  (18.39) |  | 5.27  (8.74) |  | *p* = 0.77 | *p* = 0.55 |
|  | 171.07  (15.62) |  |  | 168.07  (21.98) |  | –3.00  (6.96) |  | *p* = 0.77 | *p* = 0.67 |
| *Panel 2: Cost-effectiveness* | | | | | | | | | |
|  | 0.55  (0.06) |  |  | 0.58  (0.03) |  | 0.03  (0.02) |  | *p* = 0.19 | *p* = 0.11 |
|  | 0.57  (0.03) |  |  | 0.55  (0.06) |  | –0.02  (0.02) |  | *p* = 0.33 | *p* = 0.19 |
|  | 0.67  (0.11) |  |  | 0.73  (0.14) |  | 0.05  (0.05) |  | *p* = 0.41 | *p* = 0.25 |
|  | 0.68  (0.14) |  |  | 0.63  (0.09) |  | –0.04  (0.04) |  | *p* = 0.43 | *p* = 0.30 |
| Obs. (periods): 15 | | | Obs. (periods): 15 | | |  |  |  |  |

**Table A4. Further results about the outcomes of SC and AB auctions**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **SC** | **AB** | **AB – SC** | | | |
|  | **Mean (SD)** | **Mean (SD)** | **Mean diff. (SE)** | | **Rank-sum** | ***t*-test** |
| *Panel 1: All parameter sets* | | | | | | |
| Total benefit | 179.78 | 158.37 | –21.42 |  | *p* < 0.01 | *p* < 0.01 |
|  | (15.39) | (15.92) | (4.95) |  |  |  |
| Cost-effectiveness | 0.71 | 0.61 | –0.10 |  | *p* < 0.01 | *p* < 0.01 |
|  | (0.06) | (0.07) | (0.02) |  |  |  |
| Net bid | 14.66 | 11.92 | –2.75 |  | *p* = 0.01 | *p* = 0.41 |
|  | (8.29) | (12.33) | (3.32) |  |  |  |
| Net payment | 14.66 | 15.82 | 1.15 |  | *p* = 0.99 | *p* = 0.72 |
|  | (8.29) | (11.64) | (3.20) |  |  |  |
| Farms conserved | 2.93 | 2.93 | 0.00 |  | *p* = 1.00 | *p* = 1.00 |
|  | (0.23) | (0.23) | (0.07) |  |  |  |
| Optimal farms conserved | 2.72 | 2.23 | –0.48 |  | *p* < 0.01 | *p* < 0.01 |
|  | (0.46) | (0.38) | (0.13) |  |  |  |
| Obs. (groups) | 20 | 20 |  |  |  |  |
| *Panel 2: Parameter sets and* | | | | | | |
| Total benefit | 181.83 | 173.50 | –8.33 |  | *p* = 0.16 | *p* = 0.18 |
|  | (17.42) | (21.07) | (6.11) |  |  |  |
| Cost-effectiveness | 0.72 | 0.66 | –0.06 |  | *p* = 0.02 | *p* = 0.02 |
|  | (0.07) | (0.09) | (0.03) |  |  |  |
| Net bid | 16.76 | 13.07 | –3.69 |  | *p* = 0.03 | *p* = 0.32 |
|  | (9.35) | (13.47) | (3.67) |  |  |  |
| Net payment | 16.76 | 20.48 | 3.72 |  | *p* = 0.09 | *p* = 0.28 |
|  | (9.35) | (11.96) | (3.39) |  |  |  |
| Farms conserved | 2.93 | 2.95 | 0.03 |  | *p* = 1.00 | *p* = 0.74 |
|  | (0.24) | (0.22) | (0.07) |  |  |  |
| Optimal farms conserved | 2.80 | 2.45 | –0.35 |  | *p* = 0.05 | *p* = 0.06 |
|  | (0.10) | (0.15) | (0.18) |  |  |  |
| Obs. (groups) | 20 | 20 |  |  |  |  |

# **APPENDIX B. EXPERIMENTAL PROTOCOL**

(This is the protocol for AB auctions, which is identical to that for SC auctions aside from the selection criteria and the bonus payments, as explained in the main text. This protocol was translated back and forward into Chinese. The information in parentheses was added for peer review.)

*[Please be noted that the information in brackets was meant to help the surveyors to implement the experiment and should NOT be read out to the subjects. This is the experimental protocol. Please precisely read out this protocol to each group of subjects in the most similar way possible. In order to ensure that the subjects thoroughly understand the rules, please remain patient and respond properly to the subjects’ questions.]*

***[1 Greeting and general information]***

Hello! We are university students from ... (The institution’s name has been removed for peer review.) We would like to invite the six of you to play a game together. This game is about growing corn. The results of the game will be used for scientific research only. Your personal information will be kept strictly confidential. The game is hypothetical and has no connection with your actual situation. The whole game will take about two hours. If you complete the entire game, we will pay each of you at least RMB 30 in cash immediately. But if you fail to complete the whole game, we would not be able to pay you. Would you like to play this game?

*[If ‘yes’, please continue with the following instructions; otherwise please record the reasons why the subject refuses to participate and contact your supervisor.]*

Thanks for agreeing to participate! After we finish the game, we will definitely pay you RMB 30 for your time, which has nothing to do with the result of the game. In addition to this RMB 30, you may also get some extra money from the game, but whether you get this extra money and how much you get depend on the result of the game. Therefore, after finishing the game, each of you will get at least RMB 30, but whether you can get more than RMB 30 depends on the result of the game. Any questions?

Thank you. Please do not talk to each other during the game unless allowed to. If you have any questions, please raise your hand, and we will come to you to answer your questions. If you do not follow these rules, we would have to ask you to leave the game and would not be able to pay you any money. Any questions?

***[2 Rules of the game]***

Thank you! We will now start explaining how to play the game. Please listen carefully. If you have any questions, please feel free to raise your hand.

*[2.1 Handouts]*

We will now distribute two handouts. Please look at only your own handouts and do not look at others’. Otherwise, we would have to ask you to leave the game and would not be able to pay you any money. *[Distribute the information and answer sheets.]*

*[2.2 Seat number and land]*

Now please look at the handout with circles. *[Show farmers the information sheet.]* This is your seat number. *[Show farmers the seat number.]* This was randomly decided just now by drawing lots. Suppose you have a plot of land. This land plot is in this graph. Each circle represents a land plot. Your land plot has the same number as your seat. For example, if your seat number is 1, your land plot is number 1; if your seat number is 2, your land plot is number 2, and so on. Each land plot has one neighbouring plot on the left and another one on the right. The numbers of your neighbours also match your seat numbers. For example, if you are number 1, the neighbour on your left is number 6 and the neighbour on your right is number 2. *[Show farmer No.1 their neighbours.]* If you are number 3, the neighbour on your left is number 2 and the neighbour on your right is number 4. *[Show farmer No.3 their neighbours.]* If you are number 6, the neighbour on your left is number 5 and the neighbour on your right is number 1. *[Show farmer No.6 their neighbours.]*. Throughout the whole game, everyone’s seat number and land plot are fixed and will not change. Any questions? *[Pause briefly to make sure all the farmers have fully understood this part before continuing. If some of them do not fully understand this part, explain it again.]*

Suppose you grow corn on your land plot. Originally you would use chemical herbicides. However chemical herbicides would poison wildlife, such as birds and bees. Now there is an environmental programme which wants to protect wildlife. This programme wants to choose some of you to participate. We will tell you shortly how this programme selects participants. If you are selected into the programme, you can only use bio-herbicides. Bio-herbicides are less toxic to birds, bees and other wildlife, but are equally effective against weeds, and corn can grow equally well. However bio-herbicides are more expensive, which means you would spend more money buying herbicides. The amount of this extra money is here. *[Point at the additional cost on the first page of the information sheet.]* The environmental programme will give you some subsidies to compensate for the extra money you spend on bio-herbicides.

In this game, you need to do only one thing. **Please tell us how much subsidy you would like to have, by writing down a number on this answer sheet.** *[Show farmers the answer sheet.]* In addition, you could have a bonus in some situations. These situations are shown on these pages, which we will explain shortly. *[Show farmers all possible results on the information sheet.]* Shortly we will ask the six of you to write down on this answer sheet how much subsidy you want. After that, we will work out the result and announce which of you are selected.

If you are selected, your net earning from the game would be calculated like this: the subsidy you ask for, plus the bonus if any, minus the extra money spent on bio-herbicides. Therefore, from your perspective, the subsidy you ask for plus the bonus should be greater than the extra money spent on bio-herbicides. Otherwise you may lose money. The six of you have different land plots which may be affected by different kinds of weeds. Therefore each of you may need different kinds of bio-herbicides and the extra money you spend on bio-herbicides is also different. This means you may want different amounts of subsidy.

If you are not selected into this programme, you can use the usual chemical herbicides, in which case you would not spend additional money on herbicides and would not receive any subsidy or bonus either. This means your net earning would be zero. In other words, you will not be able to earn any money from the game unless you are selected into the environmental programme. Any questions? *[Pause briefly to make sure all the farmers have fully understood this part before continuing. If some of them do not fully understand this part, explain it again.]*

*[2.4 Selection criteria]*

Now we talk about how this environmental programme selects participants. The selection rules are as follows. First, we have a limited budget for this programme. The budget needs to cover the total amount of the subsidies and bonuses for all participants that are selected. *[DO NOT tell farmers the total budget].* Therefore, if you ask for too much subsidy which exceeds our budget, you would not be selected. This means that the less subsidy you ask for, the more likely that you will be selected and get the subsidy. However, as we said earlier, if you are selected, your net earning from the game would be, the subsidy you ask for, plus the bonus if any, minus the extra money spent on bio-herbicides. Therefore, if the subsidy you ask for is too low, you may earn less money or even lose money. In short, on the one hand, if you ask for less subsidy, you are more likely to be selected and get the subsidy; on the other hand, if the subsidy you ask for is too low, you may earn less money or even lose money. You need to consider both aspects.

In addition, the objective of this environmental programme is to protect wildlife such as birds and bees. If you join this programme and switch to bio-herbicides, this will benefit birds and bees nearby. We have provided a score for your land, which shows how much you can benefit wildlife if you switch to using bio-herbicides on your land. *[Show farmers the environmental benefit in the first possible result.]* We will call this score the environmental score. A higher environmental score means a greater benefit for wildlife if you switch to bio-herbicides. Therefore, the higher the environmental score your land has, the more likely that you will be selected into this environmental programme. This score is provided by us and cannot be changed by yourself. In addition, if you and your neighbours are simultaneously selected into the programme and switch to bio-herbicides, the benefit for wildlife on your land will become greater. *[Point at the environmental benefit in the second possible result.]* This is because wildlife is less likely to be poisoned if you and your neighbours’ land plots simultaneously switch to bio-herbicides, compared to the situation where only your own land switches to bio-herbicides.

To sum up, if you ask for less subsidy, and if switching to bio-herbicides on your land has a higher benefit to wildlife, you are more likely to be selected into the programme and get the subsidy. The characteristics of your land plots are different: the extra money spent on bio-herbicides is different, and the benefits to wildlife are also different. Please DO NOT look at these details on others’ information sheets. Any questions? *[Pause briefly to make sure all the farmers have fully understood this part before continuing. If some of them do not fully understand this part, explain it again.]*

*[2.5 Bonus]*

Now we will explain the last part of the rules. Please remain patient and listen carefully. Now we talk about the situations where you can get a bonus. If you and at least one of your neighbours are simultaneously selected into the programme, you will get a bonus. This is because wildlife is less likely to be poisoned if you and your neighbours’ land plots simultaneously switch to bio-herbicides, compared to the situation where only your own land switches to bio-herbicides.

For example, please look at the second possible result. *[Point at the second possible result under the first way to apply.]* If you are selected into the programme, and one of your neighbours is also selected, then you can get a bonus in addition to the subsidy you have asked for, and the amount of the bonus is this much. *[Point at the bonus.]*

To sum up, as long as you and at least one of your neighbours are simultaneously selected into the program, you will get a bonus. Any questions? *[Pause briefly to make sure all the farmers have fully understood this part before continuing. If some of them do not fully understand this part, explain it again.]*

***[3 Trials]***

Before we formally start, let us run a few trials. These trials do not count, and do not affect your earning from the game. Now you may discuss with your left side neighbour or your right side neighbour. You could discuss anything, but you can talk to only the two people sitting next to you, one at a time. You have a maximum of 3 minutes. You can now start talking. *[Timer starts. Wait for 3 minutes, prepare the Excel algorithm, and remind farmers of the last minute.]*

OK. The time is up. Please stop talking. Now please turn to the answer sheet. Please write down in the first row of the left half of the answer table how much subsidy you would like to ask for. *[Show farmers this row.]* When you have finished, please raise your hand. *[Go to each farmer, enter their bid in private into the Excel algorithm and work out the result.]*

OK. In this round, the people who are selected into the environmental programme are ... *[Announce the seat numbers of the selected bidders.]* This round is a trial. It does not count, and does not affect your earning from the game. Now we will come to you to fill in the results and explain the meaning of the results. *[Fill in the results in the right half of the answer table.]*

*[Explain to each farmer in private the meaning of the results. Please spend a maximum of 3 minutes with each farmer.]*

*[If the farmer was selected but did not get a bonus:]*

As you can see, you are selected, which means you would get the subsidy you have asked for. *[Point at the subsidy on the answer sheet.]* However neither of your neighbours is selected. *[Point at the results of the neighbours on the answer sheet.]* Therefore you would not get a bonus. This is your result. *[Point at the corresponding result on the information sheet.]* Your net earning would be, the subsidy of ... *[the amount of the subsidy the farmer has asked for]*, minus the ... *[the amount of the farmer’s extra cost on bio-herbicides]* spent on bio-herbicides, which is ... *[the amount of the net earning.]* Therefore, these are all the possible results of the game. *[Point at all possible results on the information sheet.]* However, when considering how much subsidy you would like to ask for, you do not know the result of your application. You only know that the result will be one of these. *[Point at all possible results on the information sheet.]* You need to consider all these possible results, since you do not know in advance which of these will be the final result.

*[If the farmer was selected and got a bonus:]*

As you can see, you are selected, which means you would get the subsidy you have asked for. *[Point at the subsidy on the answer sheet.]* In addition, your neighbour(s) is (are) also selected. *[Point at the results of the neighbours on the answer sheet.]* Therefore you would get a bonus. This is your result. *[Point at the corresponding result on the information sheet.]* Your net earning would be, the subsidy of ... *[the amount of the subsidy the farmer has asked for]*, plus the bonus of ... *[the amount of the bonus]*, minus the ... *[the amount of the farmer’s extra cost on bio-herbicides]* spent on bio-herbicides, which is ... *[the amount of the net earning.]* Therefore, these are all the possible results of the game. *[Point at all possible results on the information sheet.]* However, when considering how much subsidy you would like to ask for, you do not know the result of your application. You only know that the result will be one of these. *[Point at all possible results on the information sheet.]* You need to consider all these possible results, since you do not know in advance which of these will be the final result.

*[If the farmer was not selected:]*

Unfortunately you are not selected, which means your net earning is zero. *[Point at the farmer’s provisional net earning on the answer sheet.]* This is likely because the subsidy you asked for is too high, or others’ land plots have a greater impact on wildlife. This is your result. *[Point at the corresponding result on the information sheet.]* Therefore, these are all the possible results of the game. *[Point at all possible results on the information sheet.]* However, when considering how much subsidy you would like to ask for, you do not know the result of your application. You only know that the result will be one of these. *[Point at all possible results on the information sheet.]* You need to consider all these possible results, since you do not know in advance which of these will be the final result.

*[For the entire group:]*

OK. Now you have seen the situation of this round. This round is a trial. It does not count, and does not affect your earning from the game. Let us try again. Please reconsider how much subsidy you would like to ask for. *[Run another trial and explain the result following the instructions above.]*

***[4 Quiz]***

Before we begin the game, let us start with a quiz to see whether we have clearly explained the rules of the game. On the answer sheet, there are a few statements about the rules of the game. *[Show farmers the quiz.]* Please put a tick mark next to a statement if you think it is correct, or a cross mark if you think it is wrong. Your answers in this quiz do not affect how much money you get from the game. Once you have finished, please raise your hand. We will then come to you to go through your answers and further explain the rules of the game if needed.

***[5 Auction Period 1]***

Now we formally start. Now we will come to you, collect your information and answer sheets, and then give you a new set of handouts. *[Collect the old information and answer sheets, and then distribute the new ones.]*

*[5.1 New handouts]*

First, please look at this new information sheet with circles on it. It contains all the information you need for playing the game. Your seat number and your neighbours are the same as in the trial. *[Show farmers the information sheet.]* But three things may have become different: the extra money you would need to spend on bio-herbicides if you are selected into the environmental programme, the environmental benefits to wildlife if you switch to bio-herbicides on your land, and the amount of bonus you would receive if you and your neighbours are simultaneously selected into the programme. *[Point at these details on the information sheet.]* Please read through these carefully. The answer sheet is the same as in the trial. *[Show farmers the answer sheet.]*

*[5.2 Bidding rounds]*

The rules of the game remain the same. We will repeat the procedure for a few rounds. *[DO NOT tell farmers the following rule: the auction period has a minimum of 3 rounds and a maximum of 6 rounds; the auction period concludes if the same farmers are selected or if it has completed all 6 rounds.]* The result of the last round will be the final result. Only the result of the last round counts and affects your earning from the game. The results of all previous rounds do not count and do not affect your earning from the game. Any questions? *[Pause briefly to make sure all the farmers have fully understood this part before continuing. If some of them do not fully understand this part, explain it again.]*

*[5.3 First round]*

Now we are ready for the first round. You may discuss with your left side neighbour or your right side neighbour. You could discuss anything, but you can talk to only the two people sitting next to you, one at a time. You have a maximum of 1 minute. You can now start talking. *[Timer starts. Wait for 1 minute, prepare the Excel algorithm, and remind farmers of the last 30 seconds.]*

OK. The time is up. Please stop talking. Now please turn to the answer sheet. Please write down in the first row of the left half of the answer table how much subsidy you would like to ask for. *[Show farmers this row.]* When you have finished, please raise your hand. *[Go to each farmer, enter their bid in private into the Excel algorithm and work out the result.]*

OK. In this round, the people who are selected into the environmental programme are ... *[Announce the seat numbers of the selected bidders.]* Now we will come to you and fill in the results. *[Fill in the results in the right half of the answer table.]* OK. Now you have seen the situation of this round. This round does not count, and does not affect your earning from the game. Let us try again.

*[5.4 Subsequent rounds]*

*[Repeat this bidding procedure for a minimum of 3 rounds. DO NOT tell farmers the following rule: in the 3rd, 4th or 5th round, the auction period concludes if the current round selects the same farmers as in the previous round*; *otherwise proceed to the next round until the 6th round is completed, and the auction concludes regardless of the outcome.]*

Now let us move on to the next round. You may discuss with your left side neighbour or your right side neighbour. You could discuss anything, but you can talk to only the two people sitting next to you, one at a time. You have a maximum of 1 minute. You can now start talking. [Timer starts.] [Wait for 1 minute, prepare the Excel algorithm, and remind farmers of the last 30 seconds.]

OK. The time is up. Please stop talking. Now please turn to the answer sheet. Please write down in the … *[the ordinal number of this round]* row of the left half of the answer table how much subsidy you would like to ask for. *[Show farmers this row.]* When you have finished, please raise your hand. *[Go to each farmer, enter their bid in private into the Excel algorithm and work out the result.]*

OK. In this round, the people who are selected into the environmental programme are ... *[Announce the seat numbers of the selected bidders.]* Now we will come to you and fill in the results. *[Fill in the results in the right half of the answer table.]*

*[If this is not the last round:]*

OK. Now you have seen the situation of this round. This round does not count, and does not affect your earning from the game. Let us try again.

*[If this is the last round:]*

OK. Now you have seen the situation of this round. This is the final round, and the result of this round is the final result. The result of this round counts and affects your earning from the game. We will now prepare the money for you. *[Prepare the payments for this auction period.]*

***[6 Auction Period 2]***

Thanks for your participation! We have completed one game. Now let us play this game one more time. Now we will come to you, collect your information and answer sheets, and then give you a new set of handouts. *[Collect the old information and answer sheets, and then distribute the new ones.]*

*[6.1 New handouts]*

First, please look at this new information sheet with circles on it. It contains all the information you need for playing the game. Your seat number and your neighbours are the same as in the last game. *[Show farmers the information sheet.]* But three things may have become different: the extra money you would need to spend on bio-herbicides if you are selected into the environmental programme, the environmental benefits to wildlife if you switch to bio-herbicides on your land, and the amount of bonus you would receive if you and your neighbours are simultaneously selected into the programme. *[Point at these details on the information sheet.]* Please read through these carefully. The answer sheet is the same as in the last game. *[Show farmers the answer sheet.]*

*[The remaining instructions for this auction period are the same as Sections 5.2–5.4.]*

***[7 Auction Period 3]***

*[The instructions for this auction period are the same as Section 6.]*

***[8 Closing remarks]***

OK. The game is now all over. Thank you very much for your participation! Please remain seated. We will come to you, collect your handouts and complete a short questionnaire with you. After that, we will give you the payments. Thank you!

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2. In ecological settings, edge effects refer instead to impacts on or responses of species and ecosystem functions to boundaries between two habitats (e.g., a forest fragment and surrounding agricultural fields). [↑](#footnote-ref-2)
3. There have been several recent field experiments on real farmers’ behaviour in conservation auctions, such as Balmford et al. (2023), Ferraro et al. (2024), Jack (2013) and Wallander et al. (2023), but these studies did not focus on the spatial coordination in conservation auctions. [↑](#footnote-ref-3)
4. At the national level, China’s total spending on the SLCP from 1999 to 2019 amounts to about half a per cent of the country’s GDP in 2020, all in current prices (National Forestry and Grassland Administration, 2020). [↑](#footnote-ref-4)
5. We opted for this hypothetical context based on our pilot fieldwork because this context was relevant to spatial coordination, understandable and plausible to farmers, and had yet to be regulated or affected by any real-world public policy/programme. [↑](#footnote-ref-5)
6. Liu et al. (2024) and Banerjee et al. (2021) used a different AB mechanism, where the contract allocation objective included both edge and node benefits, same as in Equation 2.1, and on top of that, bonus payments were offered as an additional source of incentive. In that setting, Liu et al. (2024) and Banerjee et al. (2021) found that the AB mechanism did not further improve auction performance because edge benefits had already been accounted for by the contract allocation rule. Therefore, this study adopted a different AB mechanism, as in Equations 2.3 and 2.4, where edge benefits were rewarded solely by bonus payments, not by the contract allocation objective. In that way, farmers who could potentially provide higher edge benefits would likely bid for lower base payments () in anticipation of higher bonus payments, and would thus have a better chance of receiving an AES contract (under the auction’s budget constraint), which would lead to higher edge benefits being achieved. [↑](#footnote-ref-6)
7. These villages were sampled randomly using a stratified approach, where we first sampled randomly four towns in total and then five villages per town. We piloted the experiment in July 2023 in another two villages in the study area, followed by the formal fieldwork in August–September 2023. [↑](#footnote-ref-7)
8. To assess whether this finding might be confined to the specific parameters adopted in our experimental auctions, we randomly drew 1,000 sets of edge benefits that have the same BF with under the SC mechanism, and another 1,000 sets that have different BF, representing 2,000 possibilities of the true edge benefits. We then repeated this procedure for , and , respectively. The 2,000 sets of the true edge benefits were drawn from the higher (lower) uniform distribution specified in Section 2 if the experimental parameters (, , or ) were from the lower (higher) uniform distribution. As shown in Figures A2 and A3 in Appendix A, auction performance is worse if the true edge benefits and the experimental parameters have different BF, compared to if they have the same BF, in terms of both ecological efficacy and cost-effectiveness. [↑](#footnote-ref-8)
9. We have qualitatively similar findings in Figures A2 and A3 for other randomly drawn true edge benefits. [↑](#footnote-ref-9)
10. For this reason, we were unable to repeat the analysis in Figures A2 and A3 for AB auctions, because redrawing edge benefit parameters would not give rise to different BF under the AB mechanism designed in this study. [↑](#footnote-ref-10)