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ARTICLE

Spatially coordinated conservation auctions: A framed field experiment focusing on farmland wildlife conservation in China

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Abstract
How best to incentivize land managers to achieve conservation goals in an economically and ecologically effective manner is a key policy question that has gained increased relevance from the setting of ambitious new global targets for biodiversity conservation. Conservation (reverse) auctions are a policy tool for improving the environmental performance of agriculture, which has become well-established in the academic literature and in policy making in the US and Australia. However, little is known about the likely response of farmers to incentives within such an auction to (1) increase spatial connectivity and (2) encourage collective participation. This paper presents the first framed field experiment with farmers as participants that examines the effects of two features of conservation policy design: joint (collective) participation by farmers and the incentivization of spatial connectivity. The experiment employs farmers in China, a country making increasing use of payments for ecosystem services to achieve a range of environmental objectives. We investigate whether auction performance—both economic and ecological—can be improved by the introduction of agglomeration bonus and joint bidding bonus mechanisms. Our empirical results suggest that, compared to a baseline spatially coordinated conservation auction, the performance of an auction with an agglomeration bonus, a joint bidding bonus, or both, is inferior on two key metrics—the environmental benefits generated and cost effectiveness realized.

KEYWORDS
agglomeration bonus, Agri-environmental schemes, framed field experiment, joint bidding, payments for ecosystem services, spatially coordinated conservation auction

JEL CLASSIFICATION
C72, C93, D44, Q15, Q57

1 | INTRODUCTION

The past few decades have witnessed a rapid global proliferation of agriculture-related payments for ecosystem services (PES) programs, which provide payments for farmers to incentivize them to voluntarily undertake environmentally friendly land-use activities (Hanley et al., 2012; Wunder et al., 2020). In many countries, agricultural PES programs account for a substantial proportion of total public spending on agriculture (Nguyen et al., 2022). Both scientific and policymaking communities are actively considering novel design features of PES programs to achieve higher levels of conservation efficacy and cost effectiveness, particularly in the context of newly established targets for global biodiversity conservation (Convention on Biological Diversity, 2021). This study aims to contribute to this policy driven research agenda by conducting a framed field experiment with Chinese farmers to evaluate the performance of a novel design of PES featuring an auction mechanism that encourages participating farmers to bid jointly.

Such joint bidding can better account for supplementary ecological benefits arising from the spatial coordination of conservation practices on multiple farms (generating "edge" benefits), in addition to benefits from conservation practices on individual farms (producing "node" benefits) (Banerjee et al., 2021; Conte et al., 2023; Nguyen et al., 2022; Palm-Forster et al., 2016). This feature is especially relevant for preservation of natural habitats and many species in them that benefit more from having a favorable living environment at the landscape level (than at the farm level); although ecosystem service supply can also be increasing in connectivity (Albers et al., 2018, 2023; Engel, 2016; Haddad et al., 2015; Hanley et al., 2012; Nguyen et al., 2022; Reeling et al., 2019; Saura et al., 2018). Our work contributes to the literature that indicates that this spatial connectivity goal has been promoted with varying levels of cost effectiveness by auctions that either reward bids from adjacent farms on the landscape with additional points in the winner determination process (e.g., Banerjee et al., 2015; Krawczyk et al., 2016; Nguyen et al., 2023; Reeson et al., 2011) or pay auction winners a spatial bonus similar to the agglomeration bonus (AB) in addition to their bids (e.g., Fooks et al., 2016; Liu et al., 2019; Nguyen & Latacz-Lohmann, 2023).[1] The principal research question this paper asks is: When spatial coordination delivers environmental benefits, does encouraging joint bidding between different land managers improve the performance of a conservation auction?

The challenge is that, despite the potential cost effectiveness of conservation auctions, producers are often averse to participating, as noted by Howard et al. (2023). However, limited policy budgets devoted to conservation programs mean auctions still have appeal for policy makers (Grand et al., 2017). In this paper, we leverage the presence of close community social network ties between people in a real farming community to study a novel spatial auction that encourages joint bid submissions by neighboring auction participants. Individuals in rural farming communities routinely

[1]These studies constitute a more focused strand of literature specifically concerning spatial coordination in conservation auctions, which speaks to but also differs from a wider literature on conservation auctions that do not explicitly account for spatial coordination (e.g., Balmford et al., 2023; Cramton et al., 2021; Ferraro et al., 2022), or AB in nonauction contexts (e.g., Parkhurst & Shogren, 2007, 2008; Ward et al., 2021).

rely on their neighbors and other community members for managing different aspects of their operation such as renting machinery and hauling crops, and for information about improved management practices. For example, Sheremet et al. (2018) find that forest owners' willingness to participate in spatially coordinated PES programs depends positively on pre-existing experiences of collaborative forest management activities, which is a function of community social capital and attendant relationships. Our investigation into the performance of a joint bidding (JB)-based spatial auction presupposes that neighbors might be similarly disposed to working together in a conservation context especially if working together reduces the complexity associated with contract application process. Farmers' joint participation in PES programs can be even more preferable in cases where the target ecosystem service (e.g., biodiversity) is more observable across multiple farms rather than on an individual farm and/or where multiple farms are under joint management or even joint ownership arrangements (Engel, 2016). It is worth noting that our research agenda does not operate in a policy vacuum. The pilot Environmental Land Management Scheme in the UK, the Payments for Hydrological Services Program in Mexico (Sims et al., 2014), and many agri-environmental schemes in Europe (Limbach & Rozan, 2023; Westerink et al., 2017) encourage, require, or reward joint participation by farmers.

However, the evidence base for effective implementation of conservation auctions that incentivize both collective participation—JB—and spatial coordination is very limited. To the best of our knowledge, Banerjee et al. (2021) is the only laboratory experiment to study a joint bidding bonus (JBB) mechanism that provided bonus payments intended to account for both the ecological benefits of connectivity and the additional transaction costs of JB. That study finds that non-JB auctions outperform JB ones unless the latter are combined with multiple rounds of bid submissions (an efficiency enhancing feature, as per Windle et al., 2009, although more complicated and involving high transaction costs for bidders and the auctioneer alike). However, that study uses students rather than farmers as participants in a context-neutral environment, and while high on internal theoretical validity is limited in terms of externally valid conclusions regarding how farmers with their own personal and social contexts will behave in a JB auction. We thus know little about how actual farmers would behave in a JB environment. Evidence from real-world applications is also very limited: The Tiffin Watershed BMP (Best Management Practice) auctions in the US only had 10 bidders, and none of them bid jointly although given the option, which was likely due to the additional transaction costs of coordinating joint bids (Palm-Forster et al., 2016) that were not adequately addressed.[2] Yet, policy success requires a need for both laboratory and field testing prior to policy implementation. Thus, if a case has to be made for auctions in general and JB spatial auctions in particular to policymakers who are interested in findings drawn from the policy's target population (farmers, in our case), then an important gap exists in the evidence base (Cason & Wu, 2019; List, 2011).

To help fill this gap, drawing from Banerjee et al. (2021), we designed and implemented a JB auction framed field experiment to see how actual farmers in rural China would behave. Specifically, we investigated the extent to which auction cost effectiveness and environmental performance are impacted by including an AB or JBB mechanism separately or together. We employ two treatments: (1) presence and absence of JBB; and (2) presence and absence of AB payments. Our study is thus one of the very few to compare auction performance with an AB and/or JBB to a baseline spatially coordinated conservation auction with individual bidding that allocates contracts in such a way that maximizes the total environmental benefits under a fixed budget constraint, without paying any spatial bonuses. Our paper uses farmers in China as participants, rather than university students. Both of these features constitute our additions to Banerjee et al. (2021).

[2]Although this paper was being peer-reviewed and revised, Stenger et al. (2023) conducted another laboratory experiment study on JB, although they still used student subjects and focused on the difference between mandatory and voluntary JB. More broadly, several other studies also investigated the performance of JB in PES auctions, such as Calel (2012), Iftekhar and Latacz-Lohmann (2017), and Iftekhar and Tisdell (2016), but these are simulation-based studies. Chernomaz (2012) and Rondeau et al. (2016) conducted laboratory experiments on JB, but they did not concern PES and did not involve any spatial relations among bidders.

The Chinese context is relevant for two reasons. First, the country has been investing heavily in large-scale conservation programs that involve biodiversity hotspots and make financial transfers in various forms to local communities (Busch et al., 2021; Liu et al., 2018; Tuanmu et al., 2016; Yin et al., 2014). These conservation programs would benefit from the enrollment of more contiguous land plots in pursuit of enhanced ecological benefits. Thus, it might be expected that policy makers in China would be receptive to evidence regarding the performance of spatial auctions in general and JB based auctions in particular. Additionally, Chinese farmers are more familiar with mandatory conservation programs rather than voluntary auction-based ones. A field evaluation of a conservation auction would provide useful evidence for policy makers as well as establishing an understanding of whether farmers would be willing and capable to participate in these auctions. Second, China has been referred to as a relational society (Bulte et al., 2018; Zhang & Li, 2003) with people having low relational mobility represented by stable social connections that can be capitalized for different outcomes (Thomson et al., 2018). Additionally, there is extensive literature on the role of social capital in promoting Chinese farmers' environmentally friendly land-use activities in relation to PES (−akin) programs (e.g., Feng et al., 2023; Gong et al., 2010; Tu et al., 2011). Thus, if community social capital is to serve as a reason to motivate joint bidding by neighbors, agricultural communities in China provide an excellent testbed to evaluate the performance of spatial auctions with and without joint bidding.

Our results indicate that, compared to a baseline spatially coordinated conservation auction, performance of an auction with an AB, a JBB, or both is inferior on two key metrics: —the environmental benefits generated and cost effectiveness realized. This outcome is a function of the rewards paid for achieving spatial coordination either through the AB or JBB, or both. The key take-away message is thus that a budget constraint in a limited-sized auction group can restrict the efficacy of an agglomeration bonus and joint bidding bonus in promoting spatial connectivity and collective participation. Given that most if not all real-world conservation auctions run by the public sector will be budget constrained, this is important.

The remainder of this paper proceeds as follows. Section 2 describes the design and procedures of our experiment, which empirically assesses the effects of introducing AB and JBB in SC conservation auctions. Section 3 reports the data, analytical methods, and empirical results. Section 4 discusses the main findings and concludes.

2 | EXPERIMENTAL DESIGN AND FIELDWORK PROCEDURES

This section details the design (including treatments) and procedures of our experimental auctions. We adopted a balanced two-by-two full factorial experimental design. Participating farmers bid in auction groups, which were randomly divided into four between-subject treatments: (1) Treatment SC is the basic SC conservation auction, which allocates PES contracts in such a way that maximizes the total environmental benefits accounting for spatial coordination using both node and edge benefits, under a fixed budget constraint; it only allows individual bids and does not provide AB payments; (2) Treatment SC_AB is the SC conservation auction that provides AB payments but still only allows individual bids; (3) Treatment SC_JB is the SC conservation auction that allows both individual and joint bids but does not provide AB payments; (4) Treatment SC_AB_JB is the SC conservation auction that allows both individual and joint bids, and provides AB payments. Additionally for this treatment, whenever joint bids were selected as winners, they also provided an extra bonus proportional to the realized edge benefits to compensate for the higher transaction costs of submitting a joint bid and for the higher levels of uncertainty in the outcome of bidding jointly.

The experimental auctions in this study were set in the context of a hypothetical PES program.[3] Our subjects were told explicitly that they were in a study about a hypothetical PES program that had no connection to their actual land-use activities but would affect their payoffs from participation in the experiment. In all treatments, the experimental auction was a budget-constrained, sealed-bid PES auction that provided differentiated payments equal to winning farmers' bids. The auctions were repeated for multiple independent periods. Each auction period consisted of multiple bidding rounds, a feature that has been found to improve auction performance in field settings (Windle et al., 2009) as well as being essential for operationalizing a JB based auction in a comparable manner to the laboratory experimental results of Banerjee et al. (2021). All monetary values in the experiment (i.e. bids, bonus payments and cost parameters) had a one-for-one exchange rate with the local currency (CNY). Each participating farmer's payoffs from all the formal (non-practice) auction periods added up to their total earning that linked with the results of the experimental auction. In addition, upon the completion of their experimental session, each farmer received a fixed show-up fee, regardless of the results of the experimental auction. All auction sessions were run in farmers' villages with paper and pen. Each farmer received two handouts: an information sheet that contained the position and parameters of their own hypothetical farm (which they were asked not to share) and a bid sheet for each farmer to specify their bid. The experimenter read the instructions aloud to the farmers during the experiment.

2.1 | Auction context and features

Each auction group consisted of six farmers.[4] At the beginning of each auction session, the six participating farmers were seated randomly in a circle, at least 1 m apart from each other and facing the outside of the circle.[5] The farmers remained in the same seats (and thus had the same neighbors) throughout the auction session.

Each farmer was assumed to own one of the six farms on a circular network (as shown in Figure 1), and farmers' seats represented the spatial layout of their farms. Each farmer was assumed to grow fruit trees on their own farm using chemical pesticides that were harmful to birds and bees. The farmers were informed that there was a hypothetical PES auction intended to protect birds and bees. This program sought to select a subgroup of the six farmers as participants. If a farmer was selected into this program, they would be required to switch from using chemical pesticides to biological pesticides, which are less toxic to birds and bees but equally effective in terms of pest control

[3]Economics experiments conventionally employ context-free framing. Despite that, it is not uncommon in the conservation auction literature to conduct contextualized experiments (e.g., Fooks et al., 2016; Kits et al., 2014; Krawczyk et al., 2016; Liu et al., 2019; Reeson et al., 2011). Alekseev et al. (2017) argue that although context is likely to affect behavior, such influence is not always undesirable. For example, findings from a contextualized experiment can be more relevant if the research question focuses on a situation that involves specific context, which is the case of our study, where the research question is in the context of PES auctions. Moreover, contextualized instructions can help subjects better understand the experiment, which is particularly important in this study because our subjects are farmers who live in less developed regions and have limited education and market experience. Based on these considerations, we opted to provide context in our experimental auctions.

[4]Early research on independent private value auctions documented that collusion tends to emerge with three or fewer bidders but not for four or more bidders (Cox et al., 1982). Bidder numbers have not been studied systematically in spatially configured environments such as the type studied here. As documented later, the bidding behavior we observe does not appear to be collusive.

[5]This seating rule was intended to help prevent the participants from looking at each other's private information, including the information sheet that contained all the parameters about each participant's "farm" and the answer sheet with each participant's bids. Full details are provided in the experimental protocol in the online Appendix C. The participants might know each other's identity because they were seated next to each other without any partition screens between them. Laboratory auctions often prefer to keep bidders anonymous to each other because bidders' behavior is likely to change if they are aware of each other's identities (Lusk & Shogren, 2007). Some field experiment researchers argue that it can be helpful to investigate people's behavior in a less anonymous environment, because findings from a completely anonymous environment may be less applicable to those real-world situations that feature lower degrees of anonymity (Levitt & List, 2007). Our study focuses on a particular type of PES auction that targets neighboring farmers, who are likely to know each other. We therefore opted for a nonanonymous setting that resembles that situation in reality. Another reason behind this decision was that the vast majority of our subjects have extremely low levels of computer literacy and would not be able to independently complete the experiment (especially the communication process) in private on a computer or tablet, which adds to the logistical difficulty of ensuring anonymity.

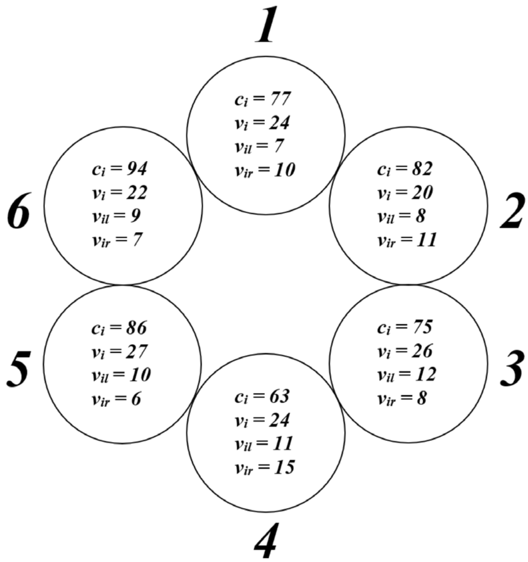

FIGURE 1 Spatial layout of farms and an example configuration of parameters in the experimental auction. c_i: farmer i's opportunity cost of switching pesticides; v_i: the node environmental benefit on farm i when i switches pesticides; v_{il} (v_{ir}): the supplementary edge environmental benefit on farm i when i and the left (right) neighbor both switch pesticides.

and would therefore ensure the same fruit yield. Biological pesticides are commercially available in our study area but are more expensive than chemical pesticides. Switching from chemical to biological pesticides incurs an additional cost c_i for each farmer i. The PES program would provide a farmer-specific payment b_i for each selected farmer to compensate for the additional cost of switching. The farmers' task in the experiment was to specify the amount of the payment they would be willing to accept to adopt this new pesticide.

In Treatment SC in the absence of JB or AB based spatial incentives, farmer i's net payoff from the experimental auction can be expressed as:

$$\Pi_i = w_i(b_i - c_i), \tag{1}$$

where w_i is a binary variable that takes the value one if farmer i is selected into the PES program and zero otherwise. (In the experiment, all rules were explained to farmers in a non-mathematical way accompanied by numerical examples.)

The experimenter then explained the selection rules of the PES auction. The six farmers were told that only a subgroup of them would be selected into the PES program, due to budget constraints. The program would select participants in such a way that would achieve the highest benefits for birds and bees. If farmer i "wins" the auction and enters a PES contract, they would switch to biological pesticides on their own farm, which provides an environmental benefit v_i (node benefit). If at least one of their neighbors also wins the auction and switches to biological pesticides, supplementary edge benefits v_{il} and/or v_{ir} would also be realized. The environmental benefit provided by each farmer i can be expressed as:

$$V_i = w_i(v_i + w_{il}v_{il} + w_{ir}v_{ir}), \tag{2}$$

where w_{il} (or w_{ir}) is a binary variable that indicates whether the left (or right) neighbor is selected. The amount of the budget was not announced to farmers.

At the beginning of each bidding round, farmers had a total of 3 min to communicate freely in private with the left and right neighbors separately.[6] Farmers then wrote their own bid on the bid sheet. The experimenter then came to each farmer to enter the bid into an Excel Solver algorithm to select a subset of farms that would maximize the total environmental benefit subject to the budget constraint M[7]:

$$\max_{w_i} \sum_i V_i, \\ s.t. \sum_i w_i B_i \leq M, \tag{3}$$

where B_i represents the total payment farmer i would receive if their farm was to be selected, which would equal to their bid b_i plus bonus payments if any. (The bonus payments are further explained in Section 2.2.) After that, the experimenter announced the (provisional) winners[8] to the entire group and returned to each farmer to write in private their own net payoff on the bid sheet. This process (from farmers' prebidding communication with neighbors to the experimenter communicating the results to farmers) was then repeated for a minimum of three and a maximum of six rounds.[9] In each new bidding round, farmers were allowed to freely revise their bids upward or downward on the basis of their bids in the previous round. The results of the final bidding round constituted the results of the auction period and determined farmers' payoffs. Following the third bidding round, the auction period concluded if the current bidding round had the same winners as in the previous round, despite possible changes of bids. If this stopping rule was not satisfied, the next round was conducted till the sixth round was conducted, at which point the auction ended. This stopping rule was not communicated to farmers.[10]

Each auction group undertook a total of three auction periods. In each period, farmers remained in the same seats but the parameters of their farms were reshuffled. As can be seen in Figure 1, the four parameters (c_i, v_i, v_{il} and v_{ir}) for one farm were always grouped as a single set of parameters. The same six sets of parameters were reshuffled for each auction period, and we did not redraw new parameters. The reshuffling process maintained the relative positions of the six sets of parameters. For instance, in one auction period, farms 1–6 could take parameter sets 1, 2, 3, 4, 5, and 6, respectively. In the next period, farms 1–6 could take parameter sets 4, 5, 6, 1, 2, and 3. In that case, the parameter sets are reshuffled in a way that maintains their relative positions, because the six farms

[6]In the experiment, allowing neighboring farmers to communicate in Treatments SC_JB and SC_AB_JB (where joint bidding is allowed) would be better in line with reality: If an actual PES auction allows joint bidding, it would be difficult to imagine farmers bidding jointly without any communication or coordination because the formation of joint bids requires mutual agreement among joint bidding partners. If communication is allowed only for joint bidding but not for individual bidding, the treatment effects of joint bidding would be confounded by the effects of allowing communication (Rondeau et al., 2016). Therefore, we allowed communication in all four treatments.

[7]The evaluation process was fast because the optimization problem in our experiment had only a small number of possible outcomes, conditional on bidders' choices of whether to bid individually and jointly (with whom), if applicable. Integer programming optimization can be applied to solve for surplus-maximizing allocations with hundreds of bidders (Plott et al., 2023).

[8]"Provisional winners" refer to the winners of all the bidding rounds preceding the last round in each formal auction period, and the winners of the last bidding round were the final winners of the auction period.

[9]We adopted multiple bidding rounds to allow bidders to learn and gain experience with the auction rules (Banerjee et al., 2015; Lusk & Shogren, 2007; Rolfe et al., 2009). This is particularly important in our study area, because an earlier study (Liu et al., 2019) that ran single-round experimental auctions on Chinese farmers found that a nontrivial proportion of the subjects had difficulty understanding the auction rules. Admittedly, multiple bidding rounds may lead to efficiency losses (compared to the single-round setting) for several reasons. For instance, bidders may become better positioned for rent-seeking due to the information and experience they have gained over multiple bidding rounds (Hellerstein, 2017; Schilizzi & Latacz-Lohmann, 2007). This study does not formally compare the performance of multiple- and single-round conservation auctions, which has been explored by several previous studies (e.g., Banerjee et al., 2021; Rolfe et al., 2009).

[10]If the last round was known to farmers in advance, there could be higher rent seeking (Reeson et al., 2011) and/or other changes in bidding behavior in the last round due to endgame effects (Banerjee et al., 2021). We thus chose not to inform our subjects about the stopping rule, following Banerjee et al. (2021). During our fieldwork, there was no sign that any participants were able to infer the stopping rule. The participants had only three opportunities to figure out the stopping rule because the stopping rule was used once for each nonpractice auction period, and there were only three such periods.

are on a circular network. We did not tell farmers how we reshuffled the parameters. At the beginning of each auction period, each farmer simply received a new information sheet that contained a new set of parameters. The parameters were adapted from Banerjee et al. (2021), although we reduced the auction group size to six and rescaled the parameters so that the costs approximate the actual price difference between chemical and biological pesticides (CNY per liter). The parameters and the budget were chosen such that if the PES program (the auctioneer) has perfect information about the parameters and sets the payments equal to the opportunity costs of conservation plus AB and/or JBB payments if applicable, it would allocate PES contracts to three contiguous farms (which would be farms 3–5 if the parameters are assigned as in Figure 1). The three farms are hereafter referred to as the first best farms. All the treatments had the same budget and the same first best farms, which were affordable after accounting for bonus payments.

At the end of each auction period, each farmer learned their own net payoff, although we did not make the actual payments until the completion of the last auction period (and a postexperiment questionnaire survey, which will be further described in the Fieldwork subsection).

Prior to the three formal auction periods, there was a practice auction period to improve farmers' understanding of the auction rules. The rules of the practice period were mostly the same as in the formal periods, except that: (1) the practice period had only two bidding rounds that both needed to be completed (and thus did not have the stopping rule), (2) farmers had 5 min to communicate before bidding in each practice round, and (3) the practice period did not provide real payments for winning farmers.

2.2 | Payments in the agglomeration bonus and joint bidding treatments

Treatment SC_AB introduced AB payments into the SC conservation auction described above. Each farmer i was required to tender an individual bid b_i for their own farm. If farmer i and at least one of their neighbors were simultaneously selected into the hypothetical PES program, farmer i would receive the basic PES payment they bid for (b_i) and an AB payment equal to the edge benefits (the additional connectivity-derived benefits to birds and bees when neighboring farms switch simultaneously to biological pesticides). For farmer i, the AB payment would be: (1) v_{il} if farmer i and the left neighbor were both selected; (2) v_{ir} if farmer i and the right neighbor were both selected; or (3) $v_{il} + v_{ir}$ if farmer i and both neighbors were all selected. Farmer i's net payoff from the experimental auction can be expressed as:

$$\widehat{\Pi}_i = w_i(b_i + w_{il}v_{il} + w_{ir}v_{ir} - c_i), \quad (4)$$

where w_i, w_{il}, and w_{ir} are binary variables indicating whether farmer i and their left and right neighbors are selected or not, respectively.

In Treatment SC_JB, each farmer could either bid individually or bid jointly with one or both neighbors.[11] Each farmer needed to specify on the bid sheet whether they would like to bid jointly, and if so, with which neighbor. In addition, each farmer i needed to specify the basic PES payment they would like to have for their own farm (b_i), regardless of whether they were bidding individually or jointly. If farmer i chose to bid individually, their situation would be the same as in Treatment SC. If farmer i chose to bid jointly, they and their joint bidding partner(s) would be considered by the PES program as one single bidder. The PES program still sought to select a subgroup of the six

[11]This feature is different from the auction design considered by Banerjee et al. (2021), which always required individual bid submission so that even if a subject did not win via a joint bid, they had a chance of winning the auction via their individual bid. However, this component led to significant complexity in the winner determination exercise, which although possible to handle in a computerized laboratory experiment poses complications for a field based one such as the current one. Moreover, in the field if farmers have opted to submit a joint bid, it can be confusing for them to also submit an individual bid.

farmers to maximize the total environmental benefit, although there was one additional restriction that farmers in a joint bid needed to be jointly selected or rejected. If farmer i was selected through a joint bid, they would receive the basic PES payment (b_i), plus a JBB payment equal to 1.5 times the edge benefits achieved.[12] Therefore, the performance impact of the joint bidding treatment is the combination of these bonuses and joint bidding. Farmer i's net payoff from the experimental auction can be expressed as:

$$\widetilde{\Pi}_i = w_i(b_i + 1.5x_{il}v_{il} + 1.5x_{ir}v_{ir} - c_i), \tag{5}$$

where x_{il} (or x_{ir}) is a binary variable which indicates whether farmer i bids jointly with the left (or right) neighbor.

Treatment SC_AB_JB combined the incentive mechanisms in Treatments SC_AB and SC_JB: AB payments were provided for neighboring farmers selected simultaneously through individual bids, and JBB payments were provided for successful joint bids. This implies that a farmer could have their joint bid accepted with one neighbor and have their other neighbor selected as well so they would receive the AB as well as the JBB. Farmer i's net payoff from the experimental auction can be expressed as:

$$\overline{\Pi}_i = w_i[(b_i + 1.5x_{il}v_{il} + (1 - x_{il})w_{il}v_{il} + 1.5x_{ir}v_{ir} + (1 - x_{ir})w_{ir}v_{ir} - c_i)]. \tag{6}$$

It is worth noting that for a particular pair of farms, AB and JBB payments were mutually exclusive, because one farm could be selected only once, through either an individual or a joint bid.

2.3 | Power analysis

We conducted experimental auctions with a total of 432 Chinese farmers divided equally into 72 auction groups. Each auction group was randomly assigned to one of the four treatments, giving rise to 108 farmers (18 groups) per treatment. We prepared a preregistration report that included power calculations that helped us determine the sample size at the auction group level, because the effects of the AB and JBB treatments were planned to be estimated at this level. The power calculations considered the six auction outcome variables listed in Table 1. The power calculations required reference values for the means and standard deviations of the auction outcome variables, which were derived from the data of the laboratory experiment of Banerjee et al. (2021). We attempted to find a sample size that would provide adequate statistical power (at the 80% level or higher) for the estimation of the treatment effects if they are at least 10% of the reference level means of the auction outcome variables, following the recommendations of Ferraro and Shukla (2020), and Ioannidis et al. (2017). We performed two sets of power calculations. One set adopted the formula recommended by Moffatt (2021), assuming that the treatment effects would be estimated using standard t-tests. The other set followed the simulation-based approach of Bellemare et al. (2016), assuming that the treatment effects would be estimated using nonparametric rank-sum tests. Both sets of power calculations corrected for the family-wise false positive error rate (associated with multiple hypothesis testing) using the Holm-Šidák procedure as described in Dinno (2015). Figure B1 in the online Appendix B in Data S1 presents the results of the power calculations. It can be seen that our sample size

[12]The payment rate of JBB was set 50% higher than that of AB, because joint bidding is likely to incur higher coordination/transaction costs (Banerjee et al., 2021) and higher levels of uncertainty in the outcome, a fact that was observed in the Tiffin Watershed Auction, which barely had any joint bid submissions. The two bonus levels, 50% and 150% higher than the edge benefits, were tested by the laboratory experiment of Banerjee et al. (2021) in comparable auction settings. The lower level was closer (in proportion) to the extra time needed to complete a typical session in Treatment SC_JB than that in Treatment SC_AB in our pilot sessions. Moreover, Banerjee et al. (2021) found that the lower level of the JBB outperformed the higher level. We therefore opted for the lower level of the JBB.

TABLE 1 Auction outcome variables: definition and descriptive statistics.

Variable	Definition	Descriptive statistics: Mean (SD)			
		SC	SCAB	SCJB	SC_AB_JB
Total benefit	Sum of node and edge environmental benefits achieved	123.02 (10.09)	119.37 (12.75)	103.37 (20.93)	108.44 (10.40)
Edge benefit	Sum of edge environmental benefits achieved	44.52 (5.03)	42.13 (6.88)	35.67 (8.71)	38.11 (6.14)
Bid cost difference	Sum of bid–cost differences for all winning bidders	41.85 (19.03)	24.80 (26.38)	18.00 (37.63)	9.62 (24.07)
Net payment	Sum of net payments (bids plus bonuses minus costs) for all winning bidders	41.85 (19.03)	66.93 (21.66)	54.76 (31.50)	62.61 (18.23)
Cost effectiveness	Environmental benefit procured per unit of payment	0.45 (0.04)	0.40 (0.04)	0.41 (0.07)	0.39 (0.05)
Farms conserved	Number of farms conserved	3.11 (0.26)	3.06 (0.31)	2.67 (0.43)	2.87 (0.17)
	Obs. (independent groups)	18	18	18	18

Note: The combinations of these acronyms refer to treatments with the corresponding auction mechanisms. The variables in this table were measured for each auction period and then averaged over the three auction periods conducted for each auction group.
Abbreviation: SC: spatially coordinated conservation auction; AB: agglomeration bonus; JB: joint bidding;

(18 auction groups per treatment) achieves the target statistical power for the two key variables ("total benefit" and "cost effectiveness") and for another indicator, "farms conserved." Our research budget did not allow for a sample size that would achieve the target statistical power for the other three variables.

2.4 | Fieldwork

Our subjects were recruited from 28 villages in three counties in Huangshan municipality, Anhui province, China. Figure B2 in the online Appendix B in Data S1 shows the locations. The municipality is mostly covered by Mount Huangshan, a conservation hotspot recognized as a UNESCO World Heritage Site and Biosphere Reserve for its unique landscape and extremely rich biodiversity. Mount Huangshan provides habitats for many endangered species on the IUCN red list, such as the oriental stork (Osipova et al., 2020). Moreover, the municipality's rural population is mostly farming actively and is familiar with PES programs such as the Sloping Land Conversion Program (SLCP), China's flagship PES program, which pays farmers to plant trees on highly sloped farmland. The municipality thus provides an ideal setting for our fieldwork.

Table 2 summarizes the demographic characteristics of the subjects (at the bidder level). It also presents the results of cross-treatment balance tests for these 12 covariates, which were selected on the basis of previous studies that involved the determinants of bidding behavior in conservation auctions (e.g., Jack, 2013; Liu et al., 2019). In particular, we included a measure of bidders' risk preferences using a five-level self-rating question and constructed the variable "risk averse," because risk

TABLE 2 Demographic variables: definition, description, and balance checks.

Variable	Definition	Descriptive statistics (bidder level) Mean (SD)				Balance checks (p-value)	
		SC	SC_AB	SC_JB	SC_AB_JB	Bidder level	Group level
Age	Age (years)	56.27 (11.63)	57.42 (11.96)	55.32 (11.19)	55.17 (13.38)	0.49	0.62
Cattle	Number of cattle in the past year	1.76 (7.68)	1.74 (14.43)	5.30 (24.92)	3.09 (15.33)	0.45	0.48
Collaboration	Whether a bidder had agricultural collaboration experiences with the left or right neighbor in the past 3 years (1 = yes, 0 = no)	0.17 (0.37)	0.18 (0.38)	0.23 (0.42)	0.14 (0.35)	0.37	0.48
Education	Years of education attended	6.94 (3.79)	6.80 (3.64)	7.51 (3.60)	7.23 (3.64)	0.47	0.58
Gender	Gender (1 = male, 0 = female)	0.61 (0.49)	0.73 (0.45)	0.66 (0.48)	0.63 (0.49)	0.35	0.53
Household head	Whether a bidder is the head of their household (1 = yes, 0 = no)	0.58 (0.50)	0.73 (0.45)	0.62 (0.49)	0.56 (0.50)	0.30	0.41
Household size	Number of household members	3.69 (1.67)	3.98 (1.59)	3.79 (1.86)	3.96 (2.49)	0.51	0.56
Land	Area (mu) of cropland and orchard	2.25 (2.60)	2.44 (2.53)	2.96 (3.44)	2.60 (2.67)	0.36	0.50
Leader/CCP	Whether a bidder is a village leader or a CCP (Chinese Communist Party) member (1 = yes, 0 = no)	0.28 (0.45)	0.37 (0.49)	0.39 (0.49)	0.27 (0.45)	0.32	0.43
Market experience	Whether a bidder ran businesses or had employments in urban areas in the past year (1 = yes, 0 = no)	0.48 (0.50)	0.51 (0.50)	0.52 (0.50)	0.55 (0.50)	0.60	0.65
Risk averse	Whether a bidder is risk averse (1 = yes, 0 = no) elicited from a 5-level self-rating question	0.57 (0.50)	0.54 (0.50)	0.53 (0.50)	0.60 (0.49)	0.48	0.60
Rooms	Number of rooms in a bidder's house(s)	5.17 (3.37)	5.18 (2.96)	6.01 (3.52)	5.19 (2.69)	0.51	0.56
	Obs.	108	108	108	108		

Note: SC: spatially coordinated conservation auction; AB: agglomeration bonus; JB: joint bidding; The combinations of these acronyms refer to treatments with the corresponding auction mechanisms. The p-values in this table were derived in the spirit of the Pitman Permutation Test described in Holt and Sullivan (2021). For each covariate, we first measured the differences in means between each of the six pairs of treatments using the original data. We then created 1000 permuted datasets by randomly reassigning the treatments 1000 times. We next used each permuted dataset to measure for each covariate the differences in means between treatments pairwise. The p-value of the permutation test was measured as the probability that the absolute value of a difference in means in the permuted data is not smaller than its counterpart in the original data.

preferences have been frequently found relevant to bidding behavior in conservation auctions (Banerjee et al., 2017) and other types of experimental auctions (Lusk & Shogren, 2007).[13]

The covariate balance tests were performed at both the bidder and the auction group levels. The *p*-values of the covariate balance tests were derived from permutation tests, which is preferable when the sample size is not large enough to justify strong distributional assumptions (Holt & Sullivan, 2021). As can be seen in Table 2, the *p*-values of the balance tests for the 12 covariates are all above 0.30. The magnitudes of the means are highly comparable across treatments for nearly all the covariates, except for "cattle," which contains two outlying bidders in Treatment SC_JB and one in Treatment SC_AB_JB who had large numbers of cattle.[14]

In preparation for the formal fieldwork, we tested the procedures and parameters of the experiment in five rounds of pilots, two with university students in Beijing and three with farmers in Beijing and Huangshan. The formal fieldwork was conducted in Huangshan in 2021. Winning bidders earned CNY 58.90 (USD 9.13) per person on average from the experimental auctions. In addition, each bidder received CNY 50 (USD 7.75) as a show-up fee regardless of the results of the experimental auctions. Winning bidders received a total of USD 16.88 per person on average, which was >2 days' minimum wage in our study area (CNY 78.67, USD 12.19). The show-up fee alone was >1 day's minimum wage. The typical duration of an auction session (consisting of one practice period and three formal periods) was 2–3 h, depending on the treatment. Upon the completion of the experiment, each bidder completed a face-to-face questionnaire that asked about their demographic and socio-economic details, risk attitudes, and social connections with other bidders in the same auction group. All payments were made in cash after the completion of the experiment and the questionnaire.

3 | DATA ANALYSIS AND RESULTS

Our data analysis starts with assessing the effects of the AB and JBB treatments on the performance of the experimental auctions. This part of the analysis was conducted at the auction group level. After that, we proceed to an analysis on how bidding behavior is affected by auction parameters (farm-specific costs and benefits of conservation), auction periods, and farmers' demographic and socioeconomic characteristics. Throughout this analysis we focus on data from the last bidding round of each auction period, because those data are directly associated with the final results of the auction period which determined farmers' payoffs. Results are qualitatively similar when including all auction rounds.

3.1 | Effects of the agglomeration bonus and joint bidding bonus treatments

We start with analyzing the effects of the AB and JBB treatments separately and in combination on the performance of the experimental auctions relative to when these features are absent. Auction

[13]Besides the three standard demographic variables "age," "gender," and "education," we sought to proxy bidders' income levels using four variables about bidders' assets and household size ("cattle", "land," "household size," and "rooms"). In less developed rural areas such as our study area, it can be difficult to accurately measure income levels without asking a large number of detailed questions about the input and output of a wide range of production activities, because most local households tend to be self-employed and engaged in multiple production activities. By comparison, data on assets and household size can better capture household income levels (Haughton & Khandker, 2009). The two variables "household head" and "market experience" account for the heterogeneity in bidders' experience in land-related decision making and market activities. Next we included the variable "collaboration," which indicates whether a bidder had real-life agricultural collaboration experiences with neighbors, a feature that we expect will promote neighbors to work toward joint bid submissions. Last, we accounted for bidders' within-village social status using the variable "leader," because higher status people may intentionally behave in a less self-interested way in economic experiments as a means to invest in their social capital in real life (Bulte et al., 2017).

[14]Aside from three outlier farmers, the mean of "cattle" is 2.57 in SC_JB and 1.72 in SC_AB_JB, which are highly comparable to the other two treatments. We did not observe any indication that the three outliers (out of a total of 432 bidders) might have been systematically assigned to SC_JB and SC_AB_JB. Therefore, the outlying values of "cattle" in those two treatments were likely caused by random sampling variability.

outcomes are characterized by the six variables listed in Table 1. The two environmental benefit variables refer to the total and edge environmental benefits achieved, respectively, with edge benefits reflecting the degree of connectivity achieved in farms switching to bio-pesticide use. The variables "cost effectiveness" and "net payment" indicate the economic performance of the auctions, where the former refers to the environmental benefit procured per unit of payment, and the latter represents the level of rent seeking by bidders (including bonus payments). The remaining two variables, "bid cost difference" and "farms conserved" measure bid markups and the total number of farms conserved.

The treatment effects were first estimated as differences in means using standard *t*-tests. In addition, we estimated another set of treatment effects as differences in the rank sums of the outcome variables, using Wilcoxon rank-sum tests, which do not rely on distributional assumptions and are less affected by outliers (Athey & Imbens, 2017; Moffatt, 2021). Moreover, we corrected the *p*-values for the family-wise false positive error rate using the Holm-Šidák procedure as per Dinno (2015). This is because the comparison of each pair of treatments involves the comparison of multiple outcome variables, or multiple hypothesis testing, which, if not accounted for, is likely to increase the probability of falsely rejecting true null hypotheses (Ferraro & Shukla, 2020; Ioannidis et al., 2017).

Figure 2 presents the treatment effect estimates and the *p*-values from the rank-sum tests. (Further details, including the *p*-values from the *t*-tests, are provided in Tables B1 and B2 in the online Appendix B in Data S1.) In each panel of Figure 2, the first box plot from the top shows the mean difference in the corresponding outcome variable between Treatments SC_AB and SC. It can be seen that the SC conservation auction has similar environmental performance no matter whether AB is provided (Treatment SC_AB) or not (Treatment SC). The two treatments' environmental benefit indicators are statistically indistinguishable, and the magnitudes of the differences in means are well below 10%. However, the cost effectiveness of the SC conservation auction is decreased by the introduction of AB, although the amount of the decrease is less than 10% (the *p*-values from both the *t*- and rank-sum tests are at most 0.01). This decrease is largely due to a sizable and statistically significant increase in the total net payment for winning bidders in the presence of AB (Treatment SC_AB), which is nearly 60% higher than that in the absence of AB (Treatment SC). Despite that, the two treatments' difference in "bid cost difference" suggest that farmers in SC_AB bid lower, due to potential AB payments, compared to farmers in SC.[15] The *p*-values of the difference are above the conventional threshold level of statistical significance (0.10), yet the size of the difference (41%) is considerable. These results suggest that some winning bidders in SC_AB bid lower in anticipation of receiving AB payments, although the decrease in their bids tended to be smaller in size than the AB payments they received, which led to a higher total net payment. Also, Treatments SC and SC_AB are statistically similar in terms of the number of farms conserved, which suggests that it was affordable for SC_AB to conserve a similar number of farms despite the increase in the total net payment. The average number of the first best farms (as defined in Section 2.1) conserved is also similar in SC_AB (2.76) and SC (2.78).

Our results so far suggest that SC conservation auctions with and without AB have similar environmental performance. Nonetheless, it might be worth considering whether such similarity is attributable to the spatial configuration of the first best farms (which are three neighboring farms). We investigated this question using simulated auctions where we randomly reshuffled the six sets of parameters and thus allowed the possibility that the first best farms to be conserved might be disconnected from each other. The simulated bids were predicted values from treatment-specific regressions of bid values on the cost, node benefit, and edge benefit parameters; two auction period dummies; and bidder fixed effects. The simulated bids were predicted by replacing the actual values of auction parameters with randomly reshuffled parameters. We next compared the simulated

[15]This was also found by Liu et al. (2019) who had Chinese farmers participate in experimental conservation auctions with and without AB. Their conservation auctions did not directly account for edge benefits when selecting winning bidders and therefore differed from the SC auction in this study.

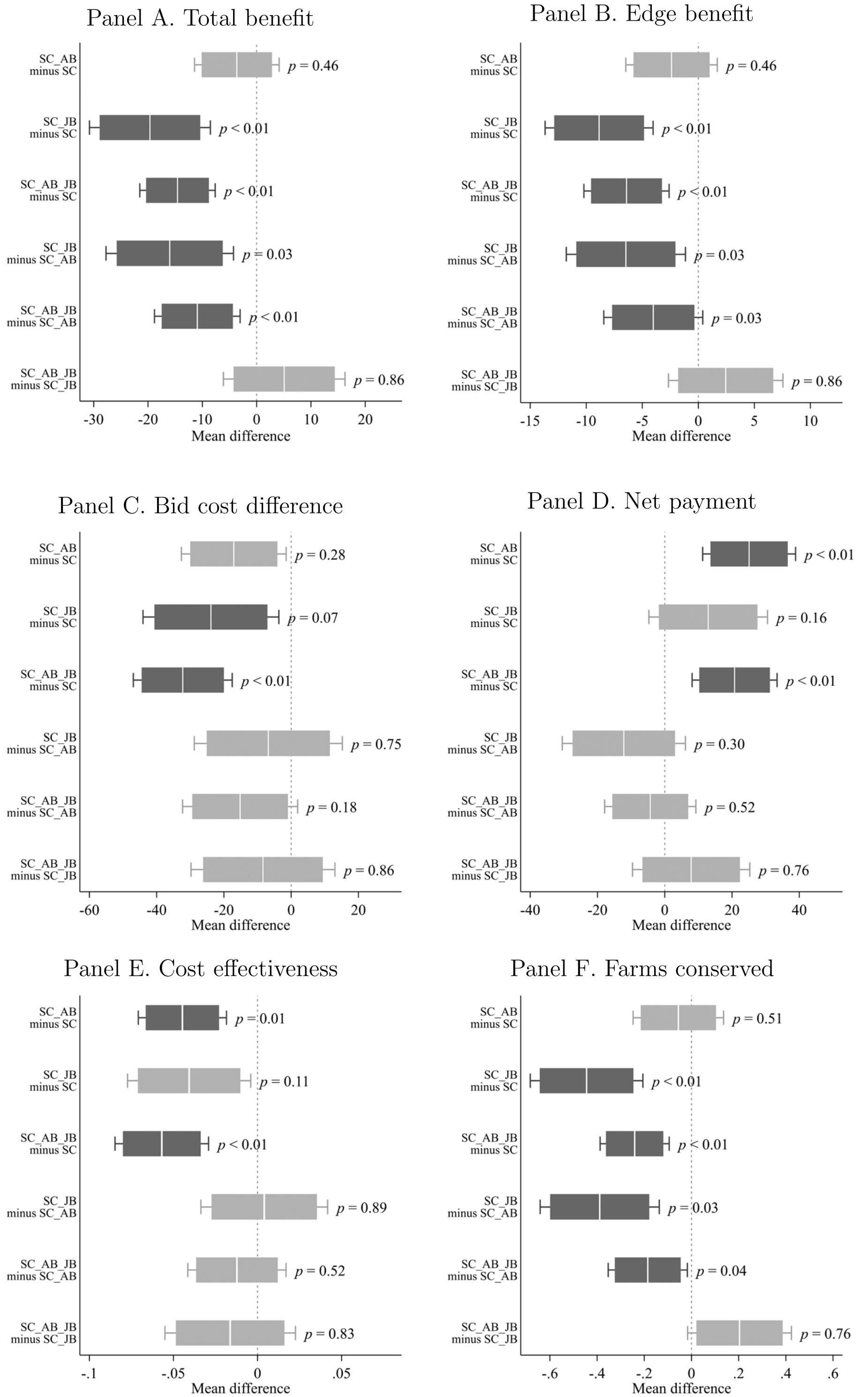

FIGURE 2 Effects of the agglomeration bonus and joint bidding bonus treatments. AB: agglomeration bonus; JB: joint bidding; SC: spatially coordinated conservation auction; The combinations of these acronyms refer to treatments with the corresponding auction mechanisms; darker gray box plots: $p < 0.10$; lighter gray box plots: $p > 0.10$; white bars in gray boxes: mean differences; gray boxes: 90% confidence intervals; capped spikes: 95% confidence intervals; the p-values were derived from Wilcoxon rank-sum tests and corrected for multiple hypothesis testing, and thus may differ from the statistical significance indicated by the confidence intervals.

outcomes between Treatments SC and SC_AB, using the same methods as described above. The results are reported in Table B3 in the online Appendix B in Data S1, and they show that the main findings are almost identical no matter whether the target farms are connected or not. In the simulated auctions, the total environmental benefit in SC_AB is lower than that in SC. This difference has a p-value close to the conventional threshold level of statistical significance (0.10), although the magnitude of the difference remains rather limited (4%).[16]

These results taken together suggest:

Result 1. The presence of the AB to reward spatial coordination in the SC conservation auction has no impact on environmental performance and negatively impacts economic performance relative to the baseline when this payment is not offered but spatial coordination is still a goal.

The second box plot from the top of each panel of Figure 2 concerns the effect of introducing the JBB mechanism into the SC conservation auction. The SC conservation auction has lower environmental performance under the JBB mechanism. The differences in the two environmental benefit indicators are both sizable (between 15% and 20%) and statistically significant (p-values <0.01). This is largely because most bidders in SC_JB chose to bid jointly in pursuit of higher JBB payments, and joint bids were less affordable to the PES program under the fixed budget constraint. The data reveal that 74% of the bids in SC_JB are joint bids (93% of these involve two bidders). Thus, the fact that most bidders in SC_JB chose to bid jointly rather than individually, and these were more expensive bids, reduced the number of farms affordable to the budget.[17] Further evidence is provided by the fact that the average number of farms conserved in SC_JB is 14% lower than that in SC, which is statistically significant at the 1% level. Moreover, SC_JB also conserved a smaller number of first-best farms (2.28 on average), compared to that in SC (2.78 on average), and this difference is statistically distinguishable at the 1% level based on a rank-sum and a t-test.

That said, it is worth noting that bidders in SC_JB bid substantially lower than those in SC, as shown by the difference in the variable "bid cost difference," and fewer bidders bid jointly in the last auction period than in the first two. Many bidders attempted to increase their probability of winning the auction by reducing their bids and switching between bidding jointly and individually. Last, the JBB mechanism slightly decreased the cost effectiveness of the experimental auctions (less than 10%) with the reduction being significant (p-value = 0.06). These findings are largely stable in the simulated auctions[18] that allowed disconnected first-best farms, as shown in Table B3 in the online Appendix B in Data S1.

These findings can be summarized as:

Result 2. Introducing the JBB mechanism into the SC conservation auction leads to (1) lower environmental performance through selection of fewer farms in general and fewer first-best farms; and (2) marginally lower cost effectiveness.

[16]We assessed whether our simulation procedure can generate auction outcomes that are comparable to the actual experimental auctions if the auction parameters are reshuffled in the same way (which maintains the relative positions of the six sets of parameters, so that the three target farms are always next to each other). The results of this assessment are presented in Table B4 in the online Appendix B. It can be seen that the means of the six auction outcome variables are almost identical between the simulated and actual auctions, and the p-values from rank-sum tests are nearly all greater than 0.50, which cannot reject the null hypothesis that the means of the six outcome variables are statistically equal between the simulated and actual auctions.

[17]For example, if one auction group tenders three joint bids from three pairs of bidders, the JBB mechanism would need to select or reject farms pair by pair, because the two farms in each joint bid need to be selected or rejected simultaneously. In that case, it is likely that the budget can afford only one of the three joint bids, or in other words, only two farms would be conserved, which would likely provide lower environmental benefits compared to a typical auction group in Treatment SC where the PES program is more likely to conserve three farms because all bidders bid individually.

[18]In the simulated auctions, the choice between bidding jointly or individually was simulated using treatment-specific binary logit models that explain the choice between bidding individually or jointly using the period-specific auction parameters, the averages of the auction parameters over the three auction periods, and the bidder-specific covariates listed in Table 2.

Moving down to the third box plot in each panel of Figure 2, we find that adding both the AB and JBB mechanisms to the SC conservation auction leads to systematically lower performance, for similar reasons as discussed above. In addition, the two treatments' notable difference in "bid cost difference" suggests that winning bidders in Treatment SC_AB_JB bid considerably lower than those in Treatment SC, although this difference was outweighed by the bonus payments received by winning bidders in SC_AB_JB. This explains the overall higher level of rent seeking in SC_AB_JB, as suggested by the large difference in "net payment" between Treatments SC_AB_JB and SC. The higher level of rent seeking in SC_AB_JB translated into lower cost effectiveness, which is roughly 13% lower than in SC. The simulated auctions with randomly reshuffled auction parameters have similar findings. We thus have:

Result 3. The SC conservation auction provides lower environmental benefits and is less cost effective in the presence of both the AB and JBB mechanisms relative to when these features are absent.

The remaining box plots in Figure 2 compare the performance of the treatments other than the baseline SC auction. The SC_AB auction outperforms both treatments that include JBB in terms of both the two environmental benefit indicators, by 10–18%, and the *p*-values of the differences are mostly lower than 0.10. This is because most bidders in those treatments chose to bid jointly (74% in SC_JB and 68% in SC_AB_JB), and joint bids tended to be less affordable to the fixed budget than individual bids, in part due to the JB bonus included to compensate for higher levels of transaction costs and uncertainty. This is evidenced by the differences in the variable "farms conserved", which suggests that SC_AB was able to afford a higher number of farms on average, 15% higher than that in SC_JB and 7% higher than in SC_AB_JB. Overall, the three treatments achieved similar levels of environmental benefits per unit of payment, as shown by the levels of "cost effectiveness" of the three treatments that have no statistically discernible difference.

Comparing the two treatments that allowed joint bidding (Treatments SC_JB and SC_AB_JB), we find that if an SC conservation auction has already adopted the JBB mechanism, providing AB for individual bids may slightly improve the environmental performance, although such improvement in our results is insignificant in terms of both the *p*-value and the size.

Overall, these analyses find evidence for:

Result 4. In the SC conservation auction setting, providing AB for individual bids leads to higher environmental performance and similar cost effectiveness compared to allowing JB and providing JBB.

3.2 | Analysis of bidding behavior

We next consider the factors potentially influencing farmers' bidding behavior. Model 1 in Table 3 reports the linear bid function regression, controlling for fixed effects distinguishing the 28 villages and six experimenters, and clustering standard errors by auction group.

The estimates of Model 1 suggest that farmers bid lower if AB was provided (about 10% lower than the average bid of all treatments) or if they chose to bid jointly with JBB being provided (about 7% lower than average). This is qualitatively in line with what we found from the cross-treatment comparison of bid markups as discussed above. On the one hand, the possibility of earning AB or JBB allowed farmers to bid lower while achieving the same expected payoff as in Treatment SC (in the absence of AB and JBB). On the other hand, farmers who could potentially earn AB or JBB needed to lower their bids to make them affordable to the fixed auction budget, which would be partly spent on bonus payments. Therefore, these farmers were likely to bid lower than those in Treatment SC, as formally discussed in the theoretical analysis in the online Appendix A in Data S1.

In this sense part of the bonus paid for edge benefits is capitalized into the bids. This resembles the finding of Liu et al. (2019), who compared the bid levels of PES auctions with and without AB.

Regarding the auction parameters (c_i, v_i, v_{il} and v_{ir}), Model 1 shows that the estimate on "cost" is positive and statistically significant. This finding is stable if we control for bidder fixed effects and estimate treatment-specific bid function models for individual and joint bids separately, as shown in Tables 4 and 5. This suggests that farmers bid for a lower PES payment when faced with lower opportunity costs for providing the environmental benefits, other conditions being equal, consistent with standard auction theory. The conservation auction mechanism is usually believed to be able to allow for differentiated payments for farmers with different opportunity costs, and thereby to achieve higher levels of cost effectiveness (Engel, 2016; Ferraro, 2008; Hanley et al., 2012). Our finding lends support to that postulation.

Moreover, we find that farmers tended to bid higher if they were able to provide higher environmental benefits, as shown by the positive and statistically significant estimates on "node benefit" and "edge benefit" in Model 1. This finding is consistent with a rent-seeking strategy. For farmers able to provide higher environmental benefits, the multiple bidding round setting might have allowed them to learn that their farms were prioritized by the PES program and were thus more likely to be selected. If so, those farmers may exploit that advantage and bid higher in an attempt to obtain higher payoffs. This echoes findings from previous studies on experimental and real-world conservation auctions (e.g., Banerjee et al., 2021; Hellerstein, 2017). As shown in Tables 4 and 5, this finding is particularly evident in Models 4 and 8, which were estimated using the bids in Treatment SC and the individual bids in Treatment SC_JB. This is likely because, for the bids in Models 4 and 8, the payoff of winning the auction depended entirely on the value of the bid (given the opportunity cost), because no bonus payments were provided for these bids. In those cases, bidding higher was the only possible way to further capitalize on the advantage of being able to provide higher environmental benefits. For the bids involved in the other models in Tables 4 and 5, the payoff of winning the auction depended on both the bid and bonus payments, where the rent-seeking strategy could be more complex and noisier.

Returning to Model 1, the estimates on the two auction period dummies are negative and sizable, although the p-value of the estimate on "Period 3" (0.13) is slightly above the conventional threshold of statistical significance. This suggests that farmers tended to bid lower in Periods 2 and 3 than in Period 1, indicating an improvement in auction cost effectiveness with increasing auction experience. Despite that, our estimates suggest that there is no evidence of further improvement in Period 3 in auction cost effectiveness, compared to Period 2.

The positive and statistically significant estimate on the variable "risk averse" suggests that risk averse farmers bid slightly higher (about 3% higher than average), which resembles qualitatively the finding of Banerjee et al. (2021). In conservation auctions without AB and JBB, risk averse bidders are typically expected to bid lower in an attempt to reduce the uncertainty of the expected payoff (Latacz-Lohmann & der Hamsvoort, 1997). However, the conservation auctions in this study provided bidders the opportunity of earning AB and/or JBB. In that case, risk-seeking bidders could obtain higher utility from the potential bonus payments, which had higher uncertainty, compared to risk averse bidders. Risk-seeking bidders could bid lower so as to enhance the probability of winning the auction and eventually to increase their overall expected payoff (Banerjee et al., 2021). This could explain our finding that more risk averse farmers bid a bit higher than risk-seeking farmers.

The findings discussed above can be summarized as:

Result 5. We found several factors that may affect how much a farmer is likely to bid in an SC conservation auction: (1) They tend to bid lower if AB is provided, or if they choose to bid jointly under the JBB mechanism. Therefore, the total payment (bid plus bonus) for a winning bid under the AB and JBB mechanisms is not necessarily higher than that in the basic SC conservation auction without AB and JBB. In our experimental auctions, the AB and JBB mechanisms have higher total payments for winning bids and

TABLE 3 Analysis of bidding behavior.

Explanatory variable	Model 1 dependent variable: bid amount; model: linear; data: all treatments	Model 2 dependent variable: bid jointly; model: binary logit; data: SC_JB, SC_AB_JB
AB provided	**−8.69** (4.37)**	**−0.67* (0.39)**
JB allowed	−2.23 (4.47)	
JB allowed x Bid jointly	**−6.44*** (2.22)**	
AB provided x JB allowed	2.63 (5.34)	
Cost	**0.91*** (0.12)**	0.03 (0.02)
Node benefit	**0.51* (0.26)**	0.07 (0.05)
Edge benefit	**0.93** (0.46)**	**0.19*** (0.07)**
Period 2	**−2.68*** (0.96)**	−0.22 (0.21)
Period 3	−2.50 (1.62)	**−0.75** (0.32)**
Won previous period	−1.97 (2.28)	**0.96** (0.43)**
Age	0.07 (0.25)	−0.01 (0.02)
Cattle	0.02 (0.04)	**0.02** (0.01)**
Collaboration	−3.02 (3.19)	**1.00** (0.48)**
Education	0.76 (0.89)	−0.03 (0.07)
Gender	−0.40 (2.80)	−0.31 (0.48)
Household head	0.82 (1.52)	0.08 (0.37)
Household size	−0.77 (0.94)	0.02 (0.06)
Land	0.63 (0.41)	−0.02 (0.05)
Leader/CCP	0.47 (4.55)	0.38 (0.39)
Market experience	−0.53 (2.50)	0.34 (0.31)
Risk averse	**3.08** (1.29)**	−0.38 (0.33)
Rooms	−0.26 (0.22)	0.01 (0.05)
Village dummies	Yes	Yes
Experimenter dummies	Yes	Yes
Clustered std. error	By auction group	By auction group
Model sig. (*p*-value)	<0.01	<0.01
(Pseudo) R2	0.22	0.20
Number of bids	1296	612
Number of bidders	432	204

Note: The combinations of these acronyms refer to treatments with the corresponding auction mechanisms. Standard errors are in parentheses. Estimates with a *p*-value lower than 0.10 are highlighted in bold.
Abbreviations: AB: agglomeration bonus; JB: joint bidding; SC: spatially coordinated conservation auction.
*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

TABLE 4 Dependence of bid amount on auction parameters and periods (fixed effects estimates).

Dependent variable: Bid amount explanatory variables	Model 3 (all bids)	Model 4 (SC, all bids)	Model 5 (SCAB, all bids)	Model 6 (SC_JB, all bids)	Model 7 (SC_AB_JB, all bids)
Cost	**0 72*** (0.10)**	**0.63** (0.26)**	**0 73*** (0.12)**	**0.90*** (0.15)**	**0.57** (0.23)**
Node benefit	**0.35* (0.21)**	**1.21*** (0.35)**	0.28 (0.23)	0.30 (0.25)	−0.39 (0.59)
Edge benefit	0.35 (0.26)	0.62 (0.46)	0.42 (0.32)	0.42 (0.39)	−0.18 (0.78)
Period 2	**−2.56*** (0.94)**	−2.99 (1.96)	−2.65 (1.74)	−1.62 (2.04)	−2.97 (1.97)
Period 3	**−4.88** (2.04)**	−7.76 (4.86)	**−5.68* (2.97)**	−3.40 (3.34)	−2.61 (4.84)
Won previous period	3.31 (1.99)	4.16 (4.77)	4.89 (3.47)	1.42 (3.64)	2.35 (3.87)
Bidder fixed effects	Yes	Yes	Yes	Yes	Yes
Clustered std. error (by auction group)	Yes	Yes	Yes	Yes	Yes
Model sig. (p-value)	<0.01	<0.01	<0.01	<0.01	<0.01
R2 (within)	0.22	0.14	0.37	0.34	0.19
Number of bids	1296	324	324	324	324
Number of bidders	432	108	108	108	108

Note: The combinations of these acronyms refer to treatments with the corresponding auction mechanisms. Standard errors are in parentheses. Estimates with a p-value lower than 0.10 are highlighted in bold.
Abbreviations: SC: spatially coordinated conservation auction; AB: agglomeration bonus; JB: joint bidding;
*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

thus underwhelming environmental performance. (2) A farmer is likely to bid lower if the conservation activity incurs lower opportunity costs for them, which confirms the theoretical expectation that conservation auctions allow for differentiated payments for farmers with different opportunity costs and are thus more cost effective than schemes that provide uniform payments. (3) A farmer is likely to bid higher if they can provide higher environmental benefits, especially in the baseline SC conservation auction, which does not provide bonus payments for the provision of edge benefits. This suggests a rent-seeking strategy that could potentially compromise the cost effectiveness of SC conservation auctions. (4) A farmer is likely to bid lower if they have greater auction experience, at least in the first two auction periods. (5) A risk-averse farmer tends to bid higher than a risk-seeking farmer.

Finally, we estimated a binary logit regression (Model 2 in Table 3) using data from Treatments SC_JB and SC_AB_JB to explore the determinants of the choice between bidding individually or jointly. The negative and statistically significant estimate on “AB provided” implies that farmers in SC_AB_JB were less likely to bid jointly than in SC_JB (11% less likely in absolute terms). Bidders in SC_AB_JB might have found individual bids more attractive than in SC_JB, because individual bids could receive AB in SC_AB_JB but not in SC_JB. This relates to our finding that SC_AB_JB provides slightly higher environmental benefits than SC_JB, as mentioned in Result 4, because farmers in SC_JB are more likely to bid jointly, and joint bids tend to be more expensive and less affordable to the fixed auction budget.

Furthermore, farmers who are able to provide higher edge benefits were more likely to bid jointly (3% more likely in absolute terms for a one-unit increase in edge benefits), which may represent another type of rent-seeking strategy to exploit advantageous environmental endowments.

In addition, fewer farmers bid jointly in the last auction period, perhaps because they learned from the previous periods that large joint bids of more than three farms would not win the auction.

TABLE 5 Dependence of bid amount on auction parameters and periods (switching regression estimates).

Dependent variable: Bid amount explanatory variables	Model 8 (SC_JB, indiv. Bids)	Model 9 (SC_JB, joint bids)	Model 10 (SC_AB_JB, indiv. Bids)	Model 11 (SC_AB_JB, joint bids)
Cost	**1.04*** (0.31)**	**0.82*** (0.19)**	0.22 (0.56)	**0.70*** (0.24)**
Node benefit	**1.72** (0.71)**	−0.01 (0.42)	−1.06 (1.20)	−0.05 (0.53)
Edge benefit	1.10 (0.99)	0.48 (0.57)	−1.34 (1.97)	0.29 (0.75)
Period 2	−4.51 (4.91)	0.01 (2.57)	−5.63 (5.45)	−0.12 (1.72)
Period 3	−1.76 (4.79)	−5.61 (3.93)	0.98 (9.03)	−7.15 (4.43)
Won previous period	4.07 (8.52)	4.18 (4.31)	5.20 (10.65)	5.71 (4.78)
Inverse Mills ratio	3.27 (4.00)	−0.36 (5.08)	−6.49 (6.59)	**10.94** (4.95)**
Cost and quality parameters (bidder level averages)	Yes	Yes	Yes	Yes
Won previous period (bidder level average)	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes
Bidder fixed effects	No	No	No	No
Bootstrapped std. error (clustered by auction group)	Yes	Yes	Yes	Yes
Model sig. (p-value)	<0.01	<0.01	0.12	<0.01
R2	0.53	0.32	0.26	0.30
Number of bids	84	240	104	220
Number of bidders	50	96	57	93

Note: The combinations of these acronyms refer to treatments with the corresponding auction mechanisms. Models 8–11 were estimated using the generalized panel data switching regression model as in Malikov and Kumbhakar (2014) and Tesfaye et al. (2021) to formally account for the sample selection process in Treatments SC_JB and SC_AB_JB where farmers self-selected into bidding individually or jointly. The switching regression models were estimated using the two-stage procedure as in Malikov and Kumbhakar (2014) and Tesfaye et al. (2021). In the first stage, we estimated for each auction period a binary selection model, which explains the choice between bidding individually or jointly using the auction parameters and the "won previous period" variable for each auction period, the averages of the auction parameters and the "won previous period" variable over the three auction periods, and the bidder-specific covariates listed in Table 2. The first-stage model was used to compute the inverse Mills ratio estimates for the correction of potential selection bias. In the second stage, we estimated a pooled least squares model (for individual and joint bids separately), which regressed bid values against all the regressors in the first-stage model, the inverse Mills ratio derived from the first-stage model, and the auction period dummies. Standard errors (in parentheses) were estimated using 1000 nonparametric bootstraps. Standard errors are in parentheses. Estimates with a p-value lower than 0.10 are highlighted in bold.
Abbreviations: AB: agglomeration bonus; JB: joint bidding; SC: spatially coordinated conservation auction.
*p < 0.10; **p < 0.05; ***p <0.01.

Our auction rules did not forbid bidders from submitting large joint bids, although these were not affordable due to the budget constraint and therefore bound to fail. In fact, such large joint bids rarely happened in our experimental auctions. The two treatments that allowed joint bids (SC_JB and SC_AB_JB) had a total of 410 bidding rounds, out of which there were only 17 joint bids of four farms, 2 joint bids of five farms, and 4 joint bids of six farms. None of those large joint bids were successful, of course. The two treatments had a total of 108 last bidding rounds that determined the final results of the auction periods, among which there were only two joint bids of four farms and no joint bids of more than four farms. This suggests that bidders were able to swiftly learn that large joint bids of more than three farms would not be successful and hence opted out of those.

We also find that farmers who won the previous auction period were more likely to bid jointly. Those successful bidders were perceived to have better bidding skills and/or farms with higher environmental significance. Therefore, others were more likely to bid jointly with those successful bidders as a means to increase the probability of winning the auction.

Last, farmers were more likely to bid jointly if they had real-life agricultural collaboration experiences with their neighbors in the experiment (15% more likely in absolute terms), which might imply that they were able to coordinate a joint bid more easily (with lower transaction costs). This speaks to the finding of previous studies (e.g., Sheremet et al., 2018) that pre-existing collaboration experiences tend to encourage landholders to participate in spatially coordinated PES programs and underscores our motivation to study the performance of a JB based auction leveraging social ties and capital within the community. Note that the regressor "collaboration" in Model 2 has some degree of exogenous variation, because farmers in each auction group were seated randomly and therefore had random neighbors within the group, although "collaboration" could potentially correlate with unobserved confounders specific to the auction group.

These findings lend support to:

Result 6. We found several factors underlying a farmer's decision as to whether to bid jointly or individually in an SC conservation auction. (1) A farmer is less likely to bid jointly if AB is provided, because individual bids could receive bonus payments and are thus more attractive than in the absence of AB. (2) A farmer is more likely to bid jointly if their farm could generate higher edge benefits, which may represent a rent-seeking strategy to capitalize on advantageous environmental endowments. (3) A farmer is more likely to bid individually after they have gained more auction experience. (4) A farmer who won the previous auction period is more likely to attract other bidders to bid jointly. (5) A farmer is more likely to bid jointly if they have pre-existing agricultural collaboration experiences with their neighbors.

4 | DISCUSSION AND CONCLUSIONS

Enhancing spatial connectivity of conserved land and encouraging collective participation are two ideas of growing importance in the PES community (Hasler et al., 2022; Runge et al., 2022). This paper presents the first framed field experiment study with actual farmers as participants that investigates whether the performance of a conservation auction can be improved by the introduction of agglomeration bonuses (AB) and joint bidding bonuses (JBB), either separately or together to achieve these two goals. This study conducted experimental conservation auctions in field settings using Chinese farmer subjects, which enriches the evidence base of the wider experimental literature on conservation auctions by studying the behavior of a potential participant group that could be targeted by auction-based PES policy. The findings of the current research is key in expanding the knowledge base on the effectiveness of conservation auctions, which has been studied mostly in the laboratory domain with student subjects.

Our empirical results suggest that the SC conservation auction has similar environmental performance no matter whether AB is provided or not, although the cost effectiveness is slightly higher when AB is *not* provided. Introducing the JBB mechanism into the SC auction leads to lower environmental performance and cost effectiveness. This is largely because a joint bid involves multiple farms, which are considered together by the PES program and are thus either accepted or rejected as a group. Therefore, joint bids tend to be less affordable given a fixed budget, compared to individual bids that only involve a single farm.

Focusing on bidding behavior, we find that farmers tend to bid lower in SC conservation auctions if an AB is provided or if the JBB mechanism is adopted and farmers choose to bid jointly. Conversely, farmers are likely to bid higher if the conservation activity incurs higher opportunity costs or if it provides higher environmental benefits. In SC conservation auctions with the JBB mechanism, farmers are more likely to bid jointly rather than individually if AB is not provided or if the conservation activity could generate higher edge benefits. In addition, we found that farmers typically bid lower and become less likely to submit large joint bids in later than in earlier auction periods. It is possible that the JBB mechanism could have achieved better environmental performance and cost -effectiveness if the bidders had undertaken more auction periods, which could have allowed them to further update their bidding strategies through adaptive learning.

Those findings are conditional on several key features of the experimental design. To start with, this study focuses on a JBB mechanism designed in a particular way, which is a combination of both allowing joint bidding and providing bonus payments intended to account for, (1) the edge benefits—representing the ecological benefits of higher connectivity—and (2) the higher levels of transaction costs and uncertainty of joint bidding. The joint bidding bonus offered to participants thus combines ecological benefits with compensation for higher levels of transactions costs and uncertainty. We opted to focus on such a JBB mechanism on account of its policy relevance, because policymakers are highly likely to consider making additional bonus payments available for joint bidding to compensate for the higher levels of transaction costs and uncertainty, and thereby to encourage participation. Otherwise, bidders may rarely bid jointly even if they are allowed to do so, as in the Tiffin Watershed BMP auctions. We do not seek to generalize our findings to joint bidding per se or to other types of joint bidding mechanisms, which could be further explored in future studies.

Moreover, farmers in our experiment did not have the option to withdraw from the auction in any round; thus, our experiment does not allow us to explore formally whether incentivizing joint bidding would increase or decrease participation rates in a conservation auction.

In addition, our experimental auctions allowed bidders to communicate, which was intended to better represent reality, as explained in Section 2.1. However, allowing communication has direct implications for the performance of auctions, through, for example, facilitating collusion (Krawczyk et al., 2016; Schilizzi, 2017), regardless of whether farmers bid jointly or individually. More generally speaking, preplay communication among players in coordination games tends to have considerable implications for players' ability to coordinate on equilibrium outcomes (Blume & Ortmann, 2007; Burton & Sefton, 2004; Ellingsen et al., 2018; Ellingsen & Östling, 2010). That said, because a real-world joint bidding scheme is bound to allow bidders to communicate and coordinate, policymakers would be keen to learn the performance of joint bidding in the presence of communication and coordination among bidders. If we forbid joint bidders to communicate in our experimental auctions, the findings would become less relevant to policymaking in practice.

Last, the edge benefits in our experimental auctions are substantial in magnitude relative to the node benefits. According to the ecological literature, the benefits of spatial coordination (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 very low (Dolman et al., 2007; Hofmeister et al., 2017; Terraube et al., 2016). Hence, there will be some conservation targets where the edge benefits are high and thus the policy designer would consider a high AB/JBB. In fact, the Oregon Conservation Reserve Enhancement Program (CREP) offers a one-off AB-akin bonus payment (Cumulative Impact Incentive Bonus) worth four times the annual rental payment of enrolled land (when at least 50% of any 5-mile section of streambed is put under conservation), in addition to annual rental payments for a 10–15 year contract period (USDA, 2021). In that case, the bonus payment accounts for up to 40% of the total base rental payment. Our findings are particularly relevant and informative for those cases.

The subjects of our experimental auctions are real farmers, who not only better represent the target population of the type of PES program we focus on but also have more diverse demographic and socioeconomic characteristics (compared to student subjects), which has allowed us to assess the impacts of those characteristics on farmers' bidding behavior. We found that risk-averse farmers tend to bid higher. Under the JBB mechanism, farmers are more likely to bid jointly rather than individually if they have pre-existing agricultural collaboration experiences with their neighbors. These findings provide useful insights for PES policymakers and can help them formulate expectations of farmers' bidding behavior according to their demographic and socioeconomic characteristics.

Our findings on auction performance and bidding behavior suggest that the efficacy of auction mechanisms and pecuniary incentives (AB and JBB) to promote spatially coordinated land uses will depend upon the budget available to procure projects. Rewarding spatial coordination because it generates benefits for society ultimately takes the form of a transfer of payments from the regulator to the farmer. However, this transfer can only be funded with an increase in budget. If budgets are the same regardless of whether pecuniary incentives rewarding coordination exist or not, environmental benefits procured might be the same but auction cost effectiveness will be lower. With scarce policy budgets, this might be difficult to justify.

If policy budgets are hard to increase, conservation auctions can be implemented with a focus on highlighting the benefits of spatial coordination and the goals of the regulator to the participants so that they bid in a way to ensure higher environmental benefits procurement through higher node and edge benefits generation. This strategy can also go a long way in increasing transparency and trust in the government, factors that conservation agencies consider of highest importance (even more than cost effectiveness) when implementing conservation programs (Grand et al., 2017; Messer et al., 2016). Yet in real world contexts, such as China where dominant social norms do not discourage collaboration, auctions promoting and rewarding spatial coordination and joint bidding, despite reducing cost effectiveness, may have other spill-over benefits. These include maintaining and improving community social capital (which we cannot capture with our data), which has been shown to positively influence ecosystem services provision (Bodin & Crona, 2008; Feng et al., 2023; Gong et al., 2010; Tu et al., 2011).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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