**Evaluating the design efficiency of conservation auctions in payment for ecosystem services**

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1. **Introduction**

A payment for ecosystem services (PES) market has buyers and suppliers of environmental goods and services. For a successful implementation of an agri-environment scheme, hidden information (e.g. on market, opportunity costs, resources etc) and intentions between these market actors need to be revealed before a conservation contract is selected. This is because PES markets with imperfect information may lead to loss and degradation of environmental services, inefficient payments and budget allocations, and high information rents (Banerjee *et al.* 2015; Deng and Xu, 2015). If landholders fail to reveal their true minimum willingness to accept, the resulting implication is inefficient payment allocation, lowering cost-effectiveness of PES policies (Khalumba *et al.* 2014). Conservation auctions attempt to harness information from PES market players which is useful in revealing true opportunity costs and minimum willingness to accept, relying on competition in the auction to reduce information rents (Stoneham *et al.* 2003; Schilizzi and Latacz-Lohmann, 2007; Deng and Xu, 2015). Conservation auctions allocate resources to environmental protection against problems arising from agricultural practices such as watershed pollution (e.g. eutrophication arising from Nitrogen, phosphorus etc) (Cason and Gangadharan, 2004; Boxall *et al.* 2013), soil erosion (Leimona and Carrasco, 2017) and deforestation (Jindal *et al.* 2013). They are also used in allocating resources for stormwater detention (Thurston *et al.* 2010), reducing greenhouse gas emissions (Pant, 2014), creating new habitats (Khalumba *et al.* 2014) and conserving fish stocks (Schilizzi and Latacz-Lohmann, 2012).

A conservation auction entails sellers participating in a bidding process set up by buyer (s) of environmental goods or services in return for a conservation contract at either the lowest bid price (Ferraro, 2008) or an offer equal to the value of individuals’ bids (Lan *et al.* 2021) or based on the highest cost-benefit ratios (Fooks *et al.* 2015). Its implementation helps to expose the strategic behaviour which occurs when sellers get their buyers to reveal their willingness to pay without telling the conservation agency their true opportunity costs (Brown *et al.* 2011). Beyond the market actors, conservation auctions reveal information about the resource (i.e. land, irrigation water, fish etc), particularly its worth and value measured based on its description in the conservation contract without which it loses its worth in alternative uses (Santos *et al.* 2021). Different features of the auction design, such as the number of rounds, will affect the transactions costs to participants and thus the degree of participation (Rolfe *et al.* 2009).

Like any other PES mechanism, conservation auctions aim at delivering biodiversity cost-effectively. However, its design and implementation are typified by several limitations. Sellers as potential owners of the resource expect heterogeneous private benefits across landscapes, and thus generating variable levels of competition during bidding leading to increased rent-seeking particularly among those with higher private benefits (Conte and Griffin, 2019). If rent-seeking becomes persistent, then the resulting payment allocations become inefficient (Banerjee *et al.* 2015). The asset specificity of enrolled land may lead to high contracting costs especially when conservation agencies become opportunistic after sellers sign contracts (Santos *et al.* 2021). After a landholder signs a contract to make certain investments in a parcel of land, they may request to be safeguarded against the risk of agency opportunism through ex-ante payments particularly in developing countries where individuals may be unable to meet initial compliance costs (Santos *et al.* 2021). Such ex-ante payments may reduce the incentive of sellers to comply with contractual obligations leading to high monitoring and enforcement costs for long-term contracts (Santos *et al.* 2021). In the absence of a screening contract mechanism, the use of a especially when property rights are assigned to landholders with private information that may be useful to optimise each parcel leading to reduced efficiency resulting from the extraction of informational rents (Arnold *et al.* 2013). Higher transaction costs from multiple bidding may lead to further deterioration of cost-effectiveness resulting from participants’ learning and adaptation effects between bidding periods (Rolfe *et al.* 2009; Santos *et al.* 2021).

From the above analysis, two major concerns emerge from the design and implementation of conservation auctions: (i) information asymmetry and (ii) opportunistic behaviour. However, it is worth noting that, perfect information has the best performance in an opportunity cost offer scheme, higher participation and lower information rents but it is difficult to implement in reality thus the need for improved information revelation for better contract performance (Deng and Xu, 2015). It is also worth noting that lower bids are not always a sign of a higher willingness to accept the conservation contracts, but they can be an indicator of better compliance (Leimona and Carrasco, 2017). Further, even with asset specificity and information asymmetry, the cost-effectiveness of conservation auctions is achievable if asset liquidity and time preferences constraints are resolved through a trade-off between increased contract costs for stronger bilateral relationships (Santos *et al.* 2021).

Existing literature shows a focus on experimental conservation auctions designs in laboratories before implementing them in the real world. So far there are more laboratory experiment conservation auction designs (e.g. Banerjee *et al.* 2015; Boxall *et al.* 2017; Otto *et al.* 2021) compared to field experiments (e.g. Rolfe *et al.* 2017; Hellerstein, 2017). One of the reasons could be laboratory experiments are controlled and as such, they provide adequate incentive to reveal true opportunity costs while field-experiments reveal additional significant transaction costs (Conte and Griffin, 2017). An efficient conservation auction design needs to account for procurement costs and environmental benefits of the private landholders (Conte and Griffin, 2019). Further, the efficiency and cost-effectiveness of a conservation auction are also a function of sellers’ willingness to enrol into the scheme, implement the management practices and set their price through bidding (Rolfe *et al.* 2018). It is, therefore, important to synthesise existing literature with a central focus on further understanding the design efficiency of conservation auctions. Also important is the use of varying information during bidding, the pricing rule used to determine payment in the contracts, and the individual-specific and market design factors underlying bidder’s participation choices. We synthesise previous literature that has used data from laboratory and real-world experiments to meet the following objectives:

1. evaluate how different information treatments and feedback mechanisms impact auction outcomes,
2. assess the cost-effectiveness of different pricing auction rules in a single and multiple-round design formats,
3. understand the different factors influencing bidding behaviour, and
4. identify the research gaps emerging from existing literature

To fulfil the above objectives, we systematically synthesise peer-reviewed articles using a scoping review (Arksey and O’Malley, 2005). A previous review sought to understand the reasons behind the low participation in conservation auctions leading to loss of efficiency and cost-effectiveness (Rolfe *et al.* 2018). We build on this, and in our review, provide a detailed summary of existing literature while focusing on answering the following research questions.

1. How do different auction designs treat communication and feedback during bidding process and how does communication or no communication treatment affect bid outcomes?
2. How does the performance of different pricing rules compare under single or repeated bidding?
3. What factors influence bidders’ participation choices? and,
4. What are the research gaps that emerge from previous literature?
5. **Search strategy**

Conservation auctions have been used for several reasons use in previous time to allocate scarce resources, but we limit our review to its application in allocating resources in agri-environment schemes (see Cason and Gangadharan, 2005). Our keywords and alternative terms for conservation auctions were derived from existing studies that have implemented conservation auctions e.g. Cason and Gangadharan (2004), Ferraro (2007), Pant (2014), Conte and Griffin (2019), Otto et al*.* (2021) and Santos et al. (2021). We defined some terminologies that include “conservation auctions” or “reverse auctions”, “bidding” and “contract”. To further identify and synthesise the targeted studies we also defined “buyers/auctioneers” and “bidders/sellers”. We provide a summary of these definitions (see Table 1) without considering any geographical scope and time.

**Table 1: Definition of key terms in payment for ecosystem services (PES) conservation auctions**

|  |  |  |
| --- | --- | --- |
| **Term** | **Definition** | **Source (s)** |
| Reverse auction | A reverse auction (also known as conservation or procurement auction) involves a single buyer (auctioneer) and several sellers (bidders) who use bidding rules and market competition to make offers for compensating participants of the biodiversity conservation scheme | (Ferraro, 2007; Pant, 2014; Otto *et al.* 2021) |
| Conservation contract | It is an agreement that specifies the period a particular level of ecosystem services or a set of observable land uses are delivered in exchange for a payment | Ferraro (2007) |
| Bidding | It is the process of landowners/sellers deciding the most suitable payment offers which consist of a single or multiple units | Ferraro (2007) |
| Buyers/auctioneers | These are the entities or individuals, or agencies motivated to purchase credits for biodiversity conservation | USDA (2022) |
| Sellers | Defined as the landowners/resource owners who restore and improve or avert environmental degradation through adjusting to a set of management practices or creating new habitats | EEA (2021) |

* 1. **Database search process**

Our search was restricted to English language articles in Scopus and Web of Science using different key word combinations (see Table 2). We combined different words using Boolean “OR” and “AND”. An asterik (\*) sign was used to shorten words with several endings while “…” was used to limit search to a set of keywords.

**Table 2: Keywords and search strings**

|  |  |  |
| --- | --- | --- |
| **Conservation auctions** | | **Conservation auction related vocabularly** |
| “Conservation auctions”, OR  “auction bids”, OR “bidding”, OR  “land\* participat\*”, OR  “joint bidding”, OR “joint-bidding”, OR  “tender-based conservation” OR  “reverse auctions” | AND  “conser\*” OR, “agri-environ\*” OR  “participat\*” OR, “auctions”, OR  “contracts” OR  “auction\*” OR  “payment for ecosystem services” | |

* 1. **Selected studies**

Our study selection followed several steps. The first step involved transferring all relevant articles to Endnote software online followed by the removal of duplicates. Then it was followed by inclusion and exclusion criteria. Studies were included if (i), it involved either primary data collected from a laboratory or field experiment involving human subjects (i.e. hypothetical or real landowners), (ii) were on conservation auctions or procurement auctions or reverse auctions or conservation contracts or conservation tenders for securing biodiversity among private landholders or resource users for private benefits e.g. water or fish, or (iii) indicate joint-bidding for spatially connected biodiversity conservation, or (iv) was on factors influencing the participation behaviour of sellers or buyers in the bidding process. We excluded studies with theoretical experiments not involving human subjects, systematic reviews, book chapters, reports, editorials and commentaries, and studies not within the scope of auctions or tenders related to payment for ecosystem services.

**2.3 Data extraction process**

Our data extraction process consisted of six parts. The first part had study characteristics such as: name of the first author, year of publication, title, the objective of the study, study type, study area, and data type etc. The second part had data on the nature of the ecosystem services and the buyers and sellers. The third part contained the existing land use/management practices, desired land use types, auction type, basis for the auction and the eligibility criteria. The fourth part contained data bidding process, whether spatial targeting was considered, auction format/dimension, economic incentive, average bid price/earning, pricing mechanism, contract length and effect of duration on contract performance, scoring rule, number of submitted bids, final bid selection criteria, number of bids accepted, information/communication treatment, feedback on auction outcomes, within subject cost-benefit conditions and effect on cost-effectiveness. The fifth part contained information on factors influencing auction participation behaviour, main study findings study limitations and research gaps. The final part consisted of a list of references included in our literature synthesis. A detailed summary of this review is attached in form of an excel sheet (see supplementary material 1).

* 1. **Data analysis strategy**

We thematically and descriptively synthesized our literature to draw interpretations and conclusions.

1. **Results**

Results from Web of Science and Scopus gave us a total of 2038 articles out of which 51 met our set criteria for inclusion in our literature synthesis (see figure 1). Selected studies were carried out in developing and developed economies, specifically in United States, Canada, Australia, Malawi, Malaysia, China, Finland, Indonesia, Tanzania, Kenya, Bolivia, Peru, Nepal, United Kingdom, Japan and Germany. These studies were in both specific habitats (e.g. agricultural habitats [22%], watershed/water bodies [33%], grassland and wetland combined [2%], grassland [6%], forests [4%], cultural habitats [2%] and unclearly specified land and vegetation habitats [24%]). The basis of the conservation auctions included procurement of spatially adjacent land use projects, conservation of native habitats being converted into agricultural uses, to protect, maintain and establish new vegetation, pollution abatement (e.g. phosphorus), wetland restoration, carbon sequestration through conversion of marginal lands, social and cultural values preservation, prevention of fisheries degradation, soil conservation, determination of how participants respond to different levels of information, reduction of pesticide and fertilizer use and management of non-remnant vegetation. The economic incentive of about 6% of the studies was in-kind payment while 92% of the studies were monetary, and 4% had not specified the economic incentive. The pricing rules in the studies were as follows - discriminatory (43%), uniform (16%), both discriminatory and uniform (25%), combined discriminatory, uniform and cost-benefit ratio (2%) and not clearly specified pricing rules (8%). The auction dimension/format of most of the studies was iterative (59%) followed by single round and two round formats (24%) and combined single and iterative formats (6%) while for 10% of the studies it was not specified. Further, about 16% of the studies implicitly accounted for spatial targeting of ecological attributes on private land either by ensuring siting arrangements during bidding or a map was provided to participants to encourage coordination between neighbouring land parcels.

Total number of articles identified after using our search terms (n = 2038)

Articles selected after removal of duplicates, commentaries, books and book chapters, and those with no link or mention of conservation auctions (n = 155)

Articles (n = 1403) were excluded because they had no link to agri-environment schemes or payment for ecosystem services

Exlusion of articles with no mention or indication of bidding in PES or auctions in titles and abstracts (n = 101)

Full text articles were excluded because:

* Data was collected from experiments not involving human subjects or
* Had theoretical and hypothetical subjects or
* Had no mention of factors influencing bidder participation or
* Had no mention or indication of a potential bidder and an auctioneer or bidding process in PES market

Full-text screening and number of studies involving laboratory or field experiments with human subjects (n = 51)

Total number of studies that had relevance to agri-environment schemes or payment for ecosystem services (n = 635)

Articles (n = 480) were excluded because they were not peer reviewed articles

**Figure 1: Flow diagram demonstrating our search strategy and study selection**

**3.1 Communication treatment and feedback mechanisms in conservation auction design**

It is expensive and time-consuming to determine the opportunity costs of sellers of environmental services. Even if it was possible, there is risk and a tendency of sellers to overstate costs, because this is often in the best interests of sellers and opportunity costs are typically private information (Deng and Xu, 2015). Due to the problem of opportunism by PES actors, the design of a conservation auction is characterised by a careful restriction of information to avoid undue advantage to either actor which leads to different outcomes. Each actor is keen to make sure that they do not reveal information to the other that could lead to loss of benefits before establishing a suitable compensation package.

Information which is relevant in auction performance includes information on aspects of the auction design, and information on the behaviour of other bidders (other sellers). Therefore, during the bidding process, a conservation agency (auctioneer) can withhold information on the budget to prevent bidders from developing a particular price preference (Leimona *et al.* 2017) or asking for higher premiums if budgets are larger (Messer *et al.* 2017). Before the bidding process, the auctioneer can further withhold information on the underlying costs distributions (Conte and Griffin, 2019), land valuations used to reach target budgets (Horowitz *et al.* 2009), the environmental benefit index scores and methods of calculating benefits (Connor *et al.* 2008). During the bidding process the auctioneer can also withhold information on competing offers (Narloch *et al.* 2013) and the winning price (Jack *et al.* 2008). In the laboratories, the auctioneers can also restrict communication between participants (Jack *et al.* 2008; Fooks *et al.* 2015) to avoid collision resulting in reduced competition and increased rent-seeking (Cason *et al.* 2004; Connor *et al.* 2008; Palm-foster *et al.* 2016).

However, to improve information availability, the agency can decide to provide participants with information on the property (Thurston *et al.* 2010), the purpose of the auction (Palm-foster *et al.* 2016) and the technicalities of the new management practices (Wang *et al.* 2012). The auctioneer can also provide information on the conservation compliance type - whether single or joint (Narloch *et al.* 2017), market information (Messer *et al.* 2017), reserve price (Boxall *et al.* 2017), the selection rule (Narloch *et al.* 2017) and the winning score (Banerjee *et al.* 2015). If communication between participants is allowed, it is restricted to the discussion around the auction, previous and the new management practices and general familiarisation among participants (Jindal *et al.* 2013; Santos *et al.* 2021). Communication between participants is also important when spatial coordination between bidders in an auction is the target (Banerjee *et al.* 2021).

In between bidding rounds, the auctioneer typically provides feedback on auction outcomes. For instance, information on the number of provisional rounds before the final one so that the last offer reflects the willingness to accept the contract (Leimona and Carrasco, 2017). Additionally, bidders get feedback on (from preceding bidding rounds) market and sellers behaviour (Messer *et al.* 2017), whether offers are accepted or not, and their cumulative scores/earnings/profits (Vogt *et al.* 2013; Fooks e*t al.* 2015; Boxall *et al.* 2017; Conte and Griffin, 2019). This feedback occurs without revealing the identity of bidders (Khalumba *et al.* 2014) and without requiring the revision of offers in some cases (Otto *et al.* 2021). Feedback between rounds helps to improve the bidding strategies (Santo *et al.* 2021), provides an opportunity for participants to become familiar with the auction mechanism (Jack *et al.* 2008) and how the market operates (Lan *et al.* 2021), and for price discovery (Rolfe *et al.* 2009).

More specifically, exposure to information has been seen to increase benefits. For example, communication between bidders and auctioneers has been reported to lead to socially preferable outcomes in a competitive market with more equitable profits, trust and stronger bilateral relationships (Vogt *et al.* 2013). If sellers have access to quality information on ecosystem services (e.g. land quality etc), they may submit higher quality conservation auctions that do not lead to loss of efficiency (Conte and Griffin, 2017). Withholding quality information introduces an eroding effect across enrolled asset values (Conte and Griffin, 2017).

**3.2 Conservation auction pricing rules and auction formats**

There are three pricing rules used to determine the amount to be paid to sellers as compensation for meeting conservation requirements outlined in the contract – uniform, discriminatory, and a cost-benefit ratio (CBR) (Fooks *et al.* 2015). In a uniform pricing rule, bidders receive the same amounts of payments based on either the highest winning bid or the lowest rejected bid, while discriminatory price rule winning bids are paid as received and CBR pricing payments are based on the highest cost-benefit ratios (Narloch *et al.* 2013; Schilizz and Latacz-Lohmann, 2012; Fooks *et al.* 2015). Since offers in the CBR rule are made based on the largest cost-benefit ratios, they tend to out-perform other pricing mechanisms (Fooks *et al.* 2015). CBR attracts fewer offers that are competitive for high-quality land parcels while delaying those not attracted to the program for later competitive use (Fooks *et al.* 2015). Although the CBR secures significantly more benefits compared to the discriminatory pricing rule, it is characterised by a low participation rate and competition thus its limited use (Frooks *et al.* 2015). In a competitive bidding, participants compete for compensation by submitting their financial bids to a conservation agency indicating the amount of payments they want offered to meet the set contractual requirements (Schilizzi and Latacz-Lohmann, 2012). Both the discriminatory and uniform pricing rules are competitive, but their differences lie within their ability to reveal the bidders’ costs (Schilizzi and Latacz-Lohmann, 2012; Fooks *et al.* 2015). However, if both pricing rules are used, the first rejected offer rule for setting prices in the uniform-auctions may lead to higher prices per bidder resulting to efficiency loss compared to discriminative price sessions (Cason and Gangadharan, 2005).

The uniform pricing mechanism in most cases is used as a benchmark for comparison with different estimates of cost savings (Connor *et al.* 2008). This is because the strategy of the uniform pricing rule is to bid at the bidders’ opportunity cost making it a perfect cost revelation mechanism (Schilizzi and Latacz-Lohmann, 2012) for offers close to the true opportunity costs over discriminatory pricing mechanism (Cason and Gangadharan, 2005). For real world policy auctions resulting from lab experiments, sellers receive market-clearing prices that exceed their offers set by a seller not involved in the actual trading (Cason and Gangadharan, 2005). However, in some cases, uniform pricing rule leads to greater trade-offs between efficient and pro-poor targeting schemes (Jindal *et al.* 2013). When combined with an environmental-based index, it is more efficient in targeting measures (Iho *et al.* 2014). Boxall *et al.* (2013) report a superior performance for uniform pricing mechanism in a watershed experiment in Manitoba. However, on its own, it targets the cheapest land parcels which is less effective compared to aligning measures to the most suitable land parcels (Iho *et al.* 2014). It also leads to overcompensation and bid shading, resulting in lower participation rates and inefficient payment allocations (Connor *et al.* 2008; Jack *et al.* 2008).

Discriminatory pricing rules lead to significant cost-savings over uniform pricing even after accounting for administration and monitoring costs (Hill *et al.* 2011). It also leads to higher trade-offs of bid acceptance with higher trading surplus – where sellers bid higher amounts over the opportunity costs while risking not winning the bid (Cason and Gangadharan, 2005). Due to this, bidders in discriminant auctions face uncertainty about bid acceptance and not the price, since the offer that is paid is as bidded if the buyer accepts it (Cason and Gangadharan, 2005). Discriminant auctions offer higher additionality for contracted land with higher opportunity costs on average (Santos *et al.* 2021). It also determines the overall market performance of the measures bidded (Caso and Gangadharan, 2004). Although it does not lead to over-compensation, its efficiency depends on the amounts of information rents extracted (Iho *et al.* 2014). Further, in the discriminatory pricing rule bidders are presented with an incentive to shade their bids above costs (Schilizzi and Latacz-Lohmann, 2012). As a result, there is a high chance that accepted bids under the discriminatory price rule may contain an element of rent as they do not reflect true opportunity costs of bidders leading to reduced cost-effectiveness (Schilizzi and Latacz-Lohmann, 2012).

The bidding process has two dimensions – single round or multiple rounds/repeated/iterative auctions. Single round auctions understate the level of benefits across auction types particularly for CBR rule relative to discriminatory rule while at the same time hiding behaviour (Fooks *et al.* 2015). Nevertheless, single-round discriminant auctions perform better on cost-effectiveness than the uniform pricing equivalent (Schilizzi and Latacz-Lohmann, 2012). Multiple rounds reveal hidden behaviour and are valuable for price discovery but may lead to reduced efficiency gains owing to high transaction costs (Rolfe *et al.* 2009; Fooks *et al.* 2015). If multiple rounds are applied in real-world scenarios, any lengthy delays (e.g. 6 months) in between rounds could result to lower participation in successive turns due to withdrawal or death of participants or sale of land (Hill *et al.* 2011). Repeated auctions under discriminatory pricing rule increase cost-effectiveness in presence of asset specificity and higher additionality (Santos *et al.* 2021) and may increase the cost-effectiveness of conservation contracts (Deng and Xu, 2015). However, cost-effectiveness has been shown to deteriorate if auctions are repeated over time because bidders can learn and adapt their strategies (Santos *et al.* 2021).

**3.3 Factors underlying bidder participation behaviour**

Several factors determine how much bidders are motivated to participate in bidding. For instance, bidder behaviour depends on the amount of information about their costs known to the agency and the reputation of the agency (Santos *et al.* 2021). The absence of information about the agency (i.e. government) preferences may increase sellers’ participation while high information rents mean less funds are available for conservation (Ch’ng *et al.* 2013). In addition, whether the agency reveals information to sellers, the competitive edge created by the inclusion of private benefits in conservation and the pricing rule used to select the contract to determine bidders’ rent seeking behaviour (Cason and Gangadharan, 2004; Boxall *et al.* 2013; Conte and Griffin, 2019). If the agency exposes low-income bidders to high costs and uncertainty resulting from a switch between high and low-priced parcels during bidding, lower participation may occur (Boxall *et al.* 2017). Higher participation of bidders lead to low-cost contracts and lower conservation budgets and offers in future compensations (Santos *et al.* 2021). A competitive market determines bidder response behaviour to the inclusion of private benefits from costly or less costly conservation practices (Conte and Griffin, 2019). In the short-term, adverse selection may occur due to asset specificity and bidders may sign contracts to accrue certain private benefits e.g. planting trees targeting the benefits of firewood (Santos *et al.* 2021).

Further, the propensity of a bidder to retain higher markups rather than revise and resubmit a lower bid in an iteration is determined by whether they won a previous bid (Banerjee *et al.* 2015). For spatial considerations, bidder preferences for spatially adjacent procurements depend on their level of exposure to spatial information and how their choices may affect other participants’ outcomes (Banerjee *et al.* 2015). Some bidders’ willingness to participate may be discouraged by the length of the contracts, especially high-cost landowners who have lower probability of winning (Brown *et al.* 2011; Comerford, 2014)

Individual bidder-specific factors include education level where more educated participants especially in rural areas have a higher chance of bidding (Comerford, 2014). Younger participants are keener on the cos-effectiveness of the tender program than their counterparts (Doole *et al.* 2014). However, distrust between bidders and agency (i.e. government) decreases participation (Comerford, 2014). Trust is important in determining the effectiveness of auctions, communicating on the amount of wages and prices, and in defining contract relationship between an auctioneer and bidders (Vogt *et al.* 2013). It is also important to understand family historical development and ownership structures of land as participants may have intentionally set low value production land aside which they may present to seem important for enrolment in the scheme (DePiper, 2015; Bond et al. 2018). Further, if participants perceive an auction as unfair and characterised by collusion, they may not participate (Doole *et al.* 2014). Underfunding and lack of strong relationship between the agency and participants may negatively influence the participation of bidders (Doole *et al.* 2014).

1. **Research Knowledge Gaps**

Generally, our analysis reveals a lack of consensus on the amount and types of information provided to participants that is desirable for a more efficient conservation auction design without risking market competition. Further, it is not clear what factors determine whether conservation auction designs are effective PES mechanisms and if there are alternative ways of revealing hidden information between market players without opportunistic behaviour. Overall impression from the literature is that opportunistic behaviour in real-world scenario may also be impossible to eliminate given that communication does not occur in a vacuum.

Other gaps include limited literature establishing the performance of reserve price and budget-based targeting, how individual behaviour changes relative to costs and bid shading under different auction dimensions (Boxall *et al.* 2017). Opportunistic behaviour is a major concern in conservation auction design, it is, therefore, important in future research to incorporate a component in the model that accounts for the agency’s reputation and ability to enforce compliance with contracts (Santos *et al.* 2021). Further, future research should focus on expanding market design to consider how and whether economic incentives underlying auction participation align with desired conservation outcomes more broadly e.g. for fisheries (DePiper, 2015). Research should also focus on investigating the dynamic effects of different budget targets and understanding of how different entry points during bidding rounds require adjustments to alleviate adverse selection (Fooks *et al.* 2015).

Additionally, research should be undertaken to establish how different factors such as risk aversion and switching between different farm management scenarios may influence conservation auction outcomes (Iftekhar *et al.* 2013). Beyond efficiency, fairness in targeting should be incorporated through the inclusion of spatial attributes to discourage unfairness and inequality issues, especially for bidders who are not neighbours in the targeted location (Narloch *et al.* 2013; Lan *et al.* 2021). In addition to cost-effectiveness, fairness through establishing how land tenure and power relations between bidders and conservation agency shape conservation costs should be established (Narloch *et al.* 2013). Research is also required to address bilateralisation in reverse auction markets under incomplete information (Vogt *et al.* 2013).

Heterogeneous payments are considered more efficient, however there is need to carry out research to assess whether agricultural returns in homogenous farms are more cost-effective over those with heterogeneity in seller opportunity costs (Narloch *et al.* 2017). Research on the relation between cost and quality is limited, as a result, there is a need to establish their correlation, especially through the auction process and how this can lead to adjustments to the bidding strategy for higher quality bid submissions (Conte and Griffin, 2017). More specific to developing countries, it is important to carry out research more focused on understanding the advantages of using auctions to allocate payment for ecosystem contracts and explore the implication of ex-ante payments on compliance and enforcement costs, particularly in the long-term (Jindal et al. 2013).

Further, the political perspective of property rights on the effectiveness of reverse auction are understudied (Arnold *et al.* 2013). In countries where conservation auctions have been implemented, agencies have had to make choices between uniform and discriminatory pricing rules (Schilizzi and Latacz-Lohmann, 2012). However, the discriminatory price format is only suitable for political and transparency, but it is not necessarily because it is more cost-effective but because offers substantially exceed costs and each unit increase in cost is matched by a unit increase in the offer (Cason and Gangadharan, 2005; Schilizzi and Latacz-Lohmann, 2012). It is, therefore, important to quantify the differences in efficiency and cost-effectiveness under the two pricing rules and recommend the circumstances under which each is appropriate tool for policy making (Liu, 2021).

Participation is a key component of the cost-effectiveness of a conservation auction and there is need to carry out research that identifies (i) the specific participant group types, their motivations and disincentives to participate, (ii) factors and how the participation rates of absentee landowners and participants compare, and (iii) how information access, access to property and time constraints are addressed by the program (Bond *et al.* 2018). Further, most of the offers are determined in laboratories and attempts are made to mimic real world situations but there is a risk of loss of efficiency if bidders are drawn different population e.g., students’ population to represent landholders. Future research should enhance credibility of such auctions by drawing participants from the actual target population (Schilizzi and Latacz-Lohmann, 2012).

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