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Abstract

Conservation auctions are reverse auctions designed to allocate payments for environmental services. We perform an online experiment to study a reverse auction that combines both a budget and a target constraint, i.e., a double constraint auction. We compare the performance of this auction format to target and budget constraint formats according to three different criteria: the number of units purchased, the budget spent and the unit cost. Our results show that the performance of the double constraint auction, compared with announcing only a target constraint or a budget constraint, depends on the buyer's objective(s). Indeed, our main conclusion is that no ranking satisfies our three criteria simultaneously.

Keywords— Reverse auctions, Conservation auctions, Double constraint.

1 Introduction

Conservation auctions are a widely studied tool used to allocate agri-environmental payments to farmers (Schilizzi, 2017; Whitten et al., 2017; Bingham et al., 2021). The Conservation Reserve Program (CRP) (Hellerstein, 2017) in the US and eco-Tender in Australia (Stoneham et al., 2012) are well-known examples of large scale conservation auction applications. Competitive bidding is also encouraged by the European Common Agricultural Policy (CAP) to allocate agri-environmental contracts, yet the implementation of conservation auctions in Europe is not much

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widespread (e.g Ulber et al., 2011). Conservation auctions are reverse auctions because the auctioneer is the buyer (of environmental services), and the bidders are the sellers, or more precisely, the farmers who provide the environmental services. Conservation auctions are multi-unit auctions, as the auctioneer usually establishes agri-environmental contracts with several farmers. Thus, there are generally multiple winning bidders. For simplicity, we assume here that each farmer can offer a single contract and that each contract has the same value for the auctioneer. In other words, we assume that each farmer's contract provides the same value of environmental services. This is a very strong assumption, since many aspects of agri-environmental contracts may have an impact on the level of environmental services provided (number of hectares engaged in the contract, farm location, etc.). Without this simplifying assumption, the auctioneer would need to compute an environmental benefit index to weight price offers submitted by farmers (see Glebe, 2008). This aspect of conservation auctions is completely ignored in this paper, which allows us to consider a much simpler auction format, in which farmers have a single unit offer and thus compete only on the basis of price, and where the auctioneer simply selects the lowest bids.

In theory, because the auctioneer does not know the farmers' private costs of complying with the agri-environmental contract, auctions are more cost-effective than fixed payment schemes in allocating contracts (Ferraro, 2008; Viaggi et al., 2010). However, in practice, the implementation of conservation auctions varies significantly from auction theory models. For instance, in conservation auctions, the auctioneer generally announces his available budget as a constraint for the auction, i.e., he purchases the cheapest contracts until the budget is exhausted. As a result, the level of competition, which depends on the number of "winning" bids, is unknown before the auction. This makes it difficult for farmers to bid, which increases their transaction costs relative to those associated with fixed payment schemes (Palm-Forster et al., 2016).

Auction theory does not seem to consider the case of budget-constrained reverse auctions (hereafter Budget)[1]. Therefore, it is difficult to predict how farmers will bid in such situations. Wider theoretical knowledge is available when a target constraint is announced. As a matter of fact, announcing the quantity to be bought in a reverse auction corresponds to announcing the quantity to be sold in a multi-unit auction. In conservation auctions, the target is the amount of environmental services to be purchased. In our simplified context, where each farmer provides the same amount of environmental services, the target is simply the number of contracts or units, or even the number of winning farmers. Therefore, in a target-constrained reverse auction (hereafter Target) contracts are purchased from the cheapest bid until the target is met. The budget spent in such Target auctions can be very high (depending on the bid offers) and may exceed the maximum budget

[1] Latacz-Lohmann and Van der Hamsvoort (1997) proposed a decision theory bidding model in Budget auctions, but it requires introducing an exogenous parameter (i.e., bid caps).

available for the purchase of contracts (Viaggi et al., 2010). Indeed, in practice, any auctioneer's budget is limited.

To avoid exceeding his budget, the auctioneer may announce a reserve price beyond which offers cannot be accepted (Boxall et al., 2017). This reserve price may be kept secret (see Schilizzi, 2017). In this paper, we experimentally study an alternative possibility, which is to simultaneously announce both a target and a budget constraint (hereafter Double Constraint auction). In a Double Constraint auction, units are ranked by the auctioneer in ascending order of price and purchased from the cheapest bid until either the target or the budget constraint is exhausted.

Our main research question is how the Double Constraint auction performs compared to an auction in which only one constraint is announced (i.e., either the Target or Budget auction). To respond to this question, we use the experimental data obtained in Coiffard et al. (2023), which compares Target and Budget auctions, and we run new treatments using the same methodology. Three new treatments allow us to study the impact of adding a second constraint in both a Target and Budget auction, as well as to better understand the impact of announcing a higher budget prior to the bidding.

The experiment used in this paper is not contextualized to the case of conservation auctions. Indeed, our subjects are not farmers, so giving them instructions related to farmers and environment services may cause confusion. Thus, the instructions given to subjects only state that each of them has a unit to sell. To obtain the subjects' bidding function, our experiment relies on the strategy method: we ask subjects to fill out a decision table in which they indicate the amount of their bid corresponding to every possible cost. Both the subjects' costs used to compute the auction outcome and the subjects' payoff are randomly drawn afterwards. Thus, subjects do not need to participate in the experiment simultaneously, which allows us to conduct the experiment online.

The bidding strategies of all the subjects constitute a very rich data set, since from these bidding strategies we can simulate the auction outcome for any set of costs and for every group of bidders. In addition, by simulating the auction outcomes for all the possible cost sets of a group of bidders, we avoid the variation in auction outcomes due to the randomness of bidders' costs. Therefore, the combination of the strategy method with auction outcome simulations is very useful and allows us to obtain a large sample of independent auction data.

The paper is organized as follows. A literature review on conservation auctions is presented in Section 2. Next, the auction game and experimental design are presented in Section 3 along with the criteria we use to compare the different auction formats, our definition of the competition level, and information about the online implementation of the experiment and data. In Section 4, we present the results from our different experimental treatments. Finally, we discuss those results and conclude in Section 5.

2 Literature on conservation auctions

Conservation auctions are among the main areas of application of reverse auctions and are covered by an extensive literature. In practice, conservation auctions deviate significantly from theoretical auction models, and most research on conservation auctions uses an experimental approach.

A large body of the literature on conservation auctions has compared discriminatory and uniform payment rules (e.g Harris and Raviv, 1981; Cason and Gangadharan, 2005; Hailu and Thoyer, 2010; Duke et al., 2017; Iftekhar and Latacz-Lohmann, 2017; Liu, 2021). In a discriminatory auction, winning bidders receive their bid, whereas in a uniform price auction, all winning bidders receive the same price (generally the highest winning bid). Contrary to the discriminatory payment rule, in the uniform payment rule, the dominant strategy of bidders is to bid their cost. This auction type may therefore be more appropriate when the objective is to elicit farmers' opportunity costs. However, as bidders are paid at the highest accepted bid level (or the lowest rejected bid), the uniform price auction is often found in the literature to be less cost-effective than the discriminatory auction Cason and Gangadharan (2005); Iftekhar and Latacz-Lohmann (2017); Liu (2021). In this paper, we consider only the discriminatory payment rule.

Low participation and anti-competitive behaviors (collusion) are also major issues in auctions (Klemperer, 2002) and are equally important when implementing conservation auctions. Indeed, studies show that the cost-effectiveness of conservation auctions may be drastically reduced in the case of low participation (Palm-Forster et al., 2016; Rolfe et al., 2021). We assume here that the number of bidders is exogenous, common knowledge and the same in all auction formats, although in practice, the level of participation is endogenous and may depend on the auction format. Collusion between bidders is typically overlooked in laboratory experiments on conservation auctions, as subjects usually do not know the other bidders, which reduces collusion risk. Yet in practice, farmers are not monitored during the bidding process and may easily collude in some cases (Packman and Boxall, 2010).

However, what interests us more here is the impact of the auctioneer's announced constraint. Once the units are ranked, a stopping rule must be defined to indicate when the buyer stops purchasing the highest ranked units. In conservation auctions, typically the auctioneer has a limited budget available and tries to achieve the highest possible environmental target. Thus, in practice, the auctioneer usually purchases units in ascending order of price until this budget constraint is exhausted. Note that the level of the budget constraint may or may not be announced to the bidders (Messer et al., 2017). Nevertheless, when no constraint is announced, it is particularly difficult for bidders to define their bid. As explained in the introduction, an alternative, is to announce a target constraint, which means that the cheapest units are purchased until the environmental target is met.

To our knowledge, three experimental studies have compared Target and Budget reverse auctions (Schilizzi and Latacz-Lohmann, 2007; Boxall et al., 2017; Coiffard et al., 2023). Schilizzi and Latacz-Lohmann and Boxall et al. conducted laboratory experiments set in an agri-environmental context. They use a between-subject design in which student subjects submit bids in several auction periods to generate more observations. In contrast, Coiffard et al. (2023) uses the strategy method, which allows them to obtain the complete bidding strategy of all subjects and to carry out the experiment online. Furthermore, the experimental protocol is completely decontextualized. Schilizzi and Latacz-Lohmann and Boxall et al. found mixed results, as Target auctions performed equally or slightly better than Budget auctions in the early stages, whereas the auction performance deteriorates more slowly in Budget than in Target auctions after several auction periods. In a one-shot setting, Coiffard et al. (2023) found that for the same average budget spent, the Budget auction allows the auctioneer to buy significantly more units than does the Target auction. The issue (Target vs. Budget) is not only addressed in experiments but also with multi-agent models (Hailu et al., 2005; Lan et al., 2021). Hailu et al. (2005) found that both formats performed similarly, whereas Lan et al. (2021) found that the auction performance was equal or higher in Budget than in Target auctions. However, announcing a Target auction only is not completely credible in practice, because farmers know that the buyer's budget is generally quite limited. In conservation auctions, the auctioneer usually has an implicit reserve price (Schilizzi, 2017). Announcing the reserve price was found by Holmes (2010) (based on observational data) and by Boxall et al. (2017) (in an experimental study) to increase an auction's efficiency.

In this paper, instead of a reserve price, we study the impact of announcing both constraints (i.e., a target and a budget constraint) to bidders, which to our knowledge has never been considered in the context of conservation auctions. In this paper, we also investigate the impact of increasing the size of the budget announced in a Budget auction. Howard et al. (2023) showed that the performance of conservation auctions decreases with the budget size. In a study with objectives and methodology very different from ours, Howard et al. (2023) conducted a choice experiment survey with 430 farmers to elicit their home-grown values for different types of conservation contracts (different agricultural practices) and considering different types of policy interventions, including reverse auctions. Note that in their study, the budget constraint is not announced to the farmers, whereas in our experimental design, subjects might adjust their bids according to the announced budget constraint.

3 Methodology

3.1 The auction game and the different auction formats

The auction game considered here is the same as that presented in (Coiffard et al., 2023). Farmers are the bidders who want to win conservation contract payments. Conservation contracts are assimilated to units of a homogeneous good, which are assumed to be perfectly divisible for the auctioneer. Each bidder i proposes a bid b_i to sell his unit. The provision cost of the bidder's unit is identically and independently drawn from a uniform distribution in the interval $[\underline{c},\overline{c}]$, which is common knowledge. The number of bidders N who participate in the auction is exogenous and also common knowledge. The auctioneer ranks the N bids b_i in ascending order of price. Let $(r) = 1, ..., N$ denote the rank of ranked bids. The auctioneer purchases the cheapest units first. The number of winning bids is defined by the announced constraint(s)[2]. Three auction formats are considered. In a Target auction, the auctioneer announces the number of units to be purchased (M) and accepts the cheapest bids until this target is achieved. As bidders only bid for one unit, the target constraint is also the number of winning bidders. In a Budget auction, the auctioneer accepts the cheapest bids until a predetermined fixed budget (B) is exhausted. In a Double Constraint auction, the buyer announces both a target (M) and a budget constraint (B) and stops purchasing units as soon as one constraint is exhausted. In case of a tie, the buyer purchases the same fraction from each tied unit[3]. In Budget and Double Constraint auctions, the auctioneer may split up the last unit to fill the budget constraint. The payment rule considered in this paper is the discriminatory payment, i.e., winning bidders are paid their bid.

3.2 Experimental design

The experiment was conducted online using a between-subject design. Subjects are randomly assigned to a single treatment: either a Target, a Budget or a Double Constraint auction. For better control (e.g., heterogeneity of subjects' perceptions regarding the agri-environmental context), the protocol is completely decontextualized.

As in Coiffard et al. (2023), we use the strategy method of (Selten, 1967). This method allows us to obtain the entire bidding function of the subjects and to conduct the experiment online without requiring the subjects to be connected simultaneously. Subjects are told that groups of N bidders will be randomly made ex-post and that the cost used for their payment will also be randomly drawn

[2]The constraint(s) is(are) announced to the bidders before they submit their bid.

[3]In practice this tie rule is probably not the most pertinent, but it is easy to implement in the experiment and is the same as drawing a winner among the ties.

Your cost	Your selling price
0 €	€
5 €	€
10 €	€
15 €	€
20 €	€
25 €	€
30 €	€
35 €	€
40 €	€
45 €	€
50 €	€
55 €	€
60 €	€
65 €	€
70 €	€
75 €	€
80 €	€
85 €	€
90 €	€
95 €	€
100 €	€

Figure 1: Decision table

ex-post for each of them from a uniform distribution. More precisely, costs are multiples of five between 0 and €100 (21 possible cost values). The principle of the strategy method is to ask each subject what he would bid for every possible cost draw (see Figure 1).

3.3 Criteria to compare auction treatments

The auction results are computed in all the possible cost configurations. In other words, for each possible cost arrangement $k = 1, ...K$ within each auction group $g = 1, ...G$, we collect corresponding bids and compute auction outcomes. From these outcomes, we compute average values in each group g to be used as independent observations. Thus, the number of auction groups (G) is also the number of independent observations. This ensures that the observations are representative of the entire bidding functions of the bidders, unlike in most auction experiments that typically involve one or a few auction groups per treatment and several periods conducted with different cost draws in order to generate more (no longer independent) observations.

We use three criteria to measure the performance of auctions at the treatment level: the average number of units purchased, the average budget spent, and the average unit cost. To compute these criteria at the treatment level, we first define them at the auction level and then at the group level to finally compute the average at the treatment level.

• **The number of units purchased:** In a Target auction, the number of units purchased is always equal to the announced constraint (M). M_{gk}^{BC}, the quantity purchased in a Budget auction for a group g and a costs draw k, is given by

$$M_{gk}^{BC} = \begin{cases} N & \text{if } B \geq \sum_{r=1}^{N} b_{(r)gk} \\ t + \frac{B - \sum_{r=1}^{t} b_{(r)gk}}{b_{k(t+1)}} & \text{if } \sum_{r=1}^{t} b_{(r)gk} \leq B < \sum_{r=1}^{t+1} b_{(r)gk} \end{cases} \quad (1)$$

where t is a positive integer such as $0 < t < N$ and B is the announced budget constraint.

Similarly, M_{gk}^{DC}, the quantity purchased in a Double Constrained auction for a group g and a costs draw k, is given by

$$M_{gk}^{DC} = \begin{cases} M & \text{if } \sum_{r=1}^{M} b_{(r)gk} \leq B \\ t + \frac{B - \sum_{r=1}^{t} b_{(r)gk}}{b_{k(t+1)}} & \text{if } \sum_{r=1}^{t} b_{(r)gk} \leq B < \sum_{r=1}^{t+1} b_{(r)gk} \end{cases} \quad (2)$$

where t is a positive integer such as $0 < t < M$ and B is the announced budget constraint.

• **The budget spent:** The budget spent in a Target auction for a group g and a costs draw k is $B_{gk}^{TC} = \sum_{r=1}^{M} b_{(r)gk}$.
In a Budget auction, the budget spent is usually the announced constraint B. However, if B allows the auctioneer to buy all the units offered by the N bidders (i.e., no constraint is exhausted), there may be an excess budget E_{gk}

$$E_{gk} = \begin{cases} 0 & \text{if } B \leq \sum_{r=1}^{N} b_{(r)gk} \\ B - \sum_{r=1}^{N} b_{(r)gk} & \text{if } B > \sum_{r=1}^{N} b_{(r)gk} \end{cases}. \tag{3}$$

Thus, the budget spent in the Budget auction is $B_{gk}^{BC} = B - E_{gk}$.
The budget spent in a Double Constrained auction is computed as

$$B_{gk}^{DC} = \begin{cases} \sum_{r=1}^{M} b_{(r)gk} & \text{if } \sum_{r=1}^{M} b_{(r)gk} \leq B \\ B & \text{else} \end{cases}. \tag{4}$$

• **The unit cost:** Our last criteria is the unit cost[4]. For any auction treatment X ($X = TC$, BC or DC), the unit cost is defined at the auction level (group g and set of costs k) by

$$UC_{gk}^{X} = \frac{B_{gk}^{X}}{M_{gk}^{X}}. \tag{5}$$

Criteria are first averaged over all cost draws k at the level of each group g (M_g^X,B_g^X and UC_g^X). Thus, there is one value for each criteria per auction group. We use these values as independent observations from which all test statistics and standard deviations presented in the paper are computed. Finally, group-level values are averaged again over all groups ($g = 1, ..., G$) to provide treatment-level outcomes for each performance criteria (M^X, B^X, UC^X)[5].

3.4 Competition level

Here, we define the level of competition as N/M^X, where M^X designates the number of units purchased in any auction format X. In this paper, we assume that N is exogenous and constant in all auctions regardless of the constraint announced. As a result, the level of competition is known by the bidders before they bid, only in a Target auction, since M is announced. In a Budget auction, the level of competition is known only after the auction and is very difficult to estimate from the announced budget. In a Double Constraint auction, the announced target is the highest number of units that can be purchased, so it gives a minimum limit on the level of competition, but if the budget constraint is saturated, then the level of

[4]We use this terminology, as units are conservation contracts which generate a cost for farmers and ultimately for society.

[5]Here UC^X is not the ratio of average outcomes B^X/M^X, because the average of ratios is not the ratio of means.

Table 1: Sample description

Sample description	Value
Number of subjects	705
Age (mean, SD)	39.81 (12.8)
Income (proportion of €1,900 or more)	0.40
Gender (proportion of female)	0.51
Education (proportion of bachelor's degree or beyond)	0.47
Student (proportion of students)	0.09

competition can be much higher. These elements may provide insights to explain bidding behaviors and may be useful in interpreting our results.

3.5 Online implementation and experimental data

The protocol is completely decontextualized in order to avoid generating bias due to using a context with which subjects may not be familiar. Subjects are from the Foule Factory panel[6]. They are not only students, as in most lab experiments, but are also from the general population. A description of the subject sample is made in Table 1. Auction groups of four bidders ($N = 4$) are formed ex-post anonymously. Subjects received a lump sum payment of €2.5 based on an announced duration of 15 minutes to answer the survey. To compute the auction payoffs, we randomly drew one cost for each bidder among the 21 possible costs. The bid corresponding to that cost was used to determine whether a bidder succeeded in selling his unit according to the bids offered by the three other bidders of his group. Every winning bidder received an extra payment (his bid minus his cost). The subjects who did not succeed in selling their unit received no extra payment. They received only the lump sum participation payment. The average auction payoff per subject was €2.88.

We use data from five experimental treatments whose parameters are presented in Table 2. We use the Target and Budget treatments presented in Coiffard et al. (2023), here denoted as TC1 and BC1, respectively. In addition, three treatments are introduced in the current paper: BC2 (where the announced budget is increased), DC1 (with constraints from TC1 and BC1) and DC2 (with constraints from TC1 and BC2). The budget announced in BC1 (€72) is the average budget obtained in TC1 (see Coiffard et al. (2023)). To study the impact of the budget size, a larger budget is used in BC2 (€120), which corresponds to the theoretical budget obtained on average in a group of four bidders when they all bid, as in the equilibrium strategy in (Hailu et al., 2005). Instructions for the DC1 treatment

[6]Participants are paid to complete surveys. See https://www.wirk.io/en/50k-freelancers-in-france/ (former web address: https://www.foulefactory.com/en/)

can be found in the Appendix A.1. Some comprehension questions were also submitted to subjects before the experiment (see the Appendix A.2), and they had to fill out a final survey questionnaire after the experiment (see Appendix A.3).

Table 2: Experimental treatments

Treatment	Number of subjects*	Nb auction group	Target constraint	Budget constraint
TC1	131	32	2 units	-
BC1	198	49	-	€72
BC2	128	32	-	€120
DC1	120	30	2 units	€72
DC2	128	32	2 units	€120

* Some subjects were removed randomly in TC1 and BC1 to create groups of four subjects.

4 Results

4.1 Announcing both a target and a budget constraint

Here we investigate how announcing both a target and a budget constraint may impact the auction's performance, as compared to announcing only a target constraint or only a budget constraint. For this purpose, we conducted a treatment (DC1) which combines the constraint levels from TC1 and BC1.

In the DC1 treatment, subjects face the target constraint $M = 2$ and the budget constraint $B = 72$. Thus, we know that M_{gk}^{DC1} is at most two and B_{gk}^{DC1} is at most €72. Each constraint is likely to be saturated in a certain number of cases, which would lead to $M^{DC1} < 2$ and $B^{DC1} < 72$. In this case, no conclusion could be drawn about a difference in performance in DC1 vs. TC1 or in BC1 using M and B as performance criteria. Therefore, we also use the average unit cost UC, which is a common performance criteria in auction experiments.

Results given in Table 3 show that the average number of units purchased (outcome M) and the average budget spent (outcome B) are indeed lower in DC1 than in TC1 and BC1, and that these differences are significant (*Wilcoxon rank sum test*). The outcome UC is lower in DC1 than in BC1, but the difference is not significant between DC1 and TC1.

There is therefore a trade-off between M and B. As cheapest units are purchased first, fewer units purchased on average in DC1 may lead UC to be lower in DC1 than in both TC1 and BC1. However, this difference is not significant between DC1 and TC1[7]. In DC1, we observe that the target constraint is reached first in 51.65% of the auctions; in these cases, a part of the budget is not spent.

[7]This is not surprising as both B and M are lower in DC1.

Table 3:

Outcome	TC1 (1)	DC1 (2)	*Diff.* (2)-(1)	BC1 (3)	DC1 (4)	*Diff.* (4)-(3)
M	2	1.78	-0.22***	2.14	1.78	-0.36***
	(.)	(0.05)		(0.10)	(0.05)	
B	72.32	58.01	-14.31***	71.91	58.01	-13.9***
	(6.56)	(3.33)		(0.04)	(3.33)	
UC	36.16	35.00	-1.16	37.18	35.00	-2.18***
	(3.28)	(2.96)		(1.95)	(2.96)	

Standard deviations in parentheses.

Wilcoxon signed rank or *Wilcoxon rank sum* tests.

* p<0.1, ** p<0.05, *** p<0.01

Conversely, in 47.18% of the cases, the budget constraint is reached first, so the targeted number of units is not met. Finally, in 1.17% of the cases, both constraints are simultaneously exhausted. These proportions, close to 50/50, are not surprising, since both constraints are defined in Coiffard et al. to obtain a kind of equivalence between TC1 and BC1.

4.2 Announcing the same target but a larger budget constraint

In DC1, the budget spent on average is only €58. We consider another double constraint treatment (DC2) with the same target constraint, but with a higher budget constraint, in order to have an ex- post average spent budget closer to €72. As we have no insights to help us set a higher value for B in the DC2 treatment, we use the (theoretical) average empirical budget spent when all subjects adopt equilibrium bids in TC1[8]. This new budget constraint is $B = 120$€. Here we compare DC2 with TC1 and with a new budget treatment (BC2), where the constraint is set to $B = 120$ (as in DC2).

We are lucky, because as we had hoped, results given in Table 4 show that the average budget spent in DC2 (€73.92) is not significantly different from the €72.32 spent on average in TC1 (*Wilcoxon rank sum test*). More as expected, the average number of units purchased in DC2 is significantly lower than in TC1, but the difference is very small: only 0.04 units. Indeed, when the budget is large in the Double Constraint auction (DC2), it is very often the target constraint that

[8]This can be done, as the closed formula for the optimal bid is known (Hailu et al., 2005).

Table 4:

Outcome	TC1 (1)	DC2 (2)	***Diff.*** (2)-(1)	BC2 (3)	DC2 (4)	***Diff.*** (4)-(3)
M	2	1.96	-0.04***	2.74	1.96	-0.78***
	(.)	(0.01)		(0.13)	(0.01)	
B	72.32	73.92	1.60	119.09	73.92	-45.17***
	(6.56)	(6.22)		(0.45)	(6.22)	
UC	36.16	38.33	2.17**	46.18	38.33	-7.85***
	(3.28)	(3.54)		(2.41)	(3.54)	

Standard deviations in parentheses.

Wilcoxon signed rank or *Wilcoxon rank sum* tests.

* p<0.1, ** p<0.05, *** p<0.01

is reached first (85.53% of auctions), whereas it is the budget in only 13.70% of cases, and both constraints are met simultaneously in 0.77% of the cases. On the other hand, both M and B outcomes are significantly lower in DC2 than in BC2. Finally, the average unit cost is significantly lower in DC2 than in BC2. However, it is significantly higher in DC2 than in TC1. A possible explanation for this last observation would be that the high budget (€120) creates a cognitive bias among subjects, making them underestimate the competition level in DC2, although it is objectively higher in DC2 than in TC1. Thus, subjects would increase their bids in DC2 compared with those in TC1 but not compared to those in BC2, as the budget announced is the same in both DC2 and BC2. Here we find that the competition level is higher in DC2 than in TC1 or BC2.

Thus, announcing a much higher budget (€120) than €72 (which corresponds to the equivalent target constraint of $M = 2$), limits the risk for the buyer of spending too much, compared to the Target auction **TC1**, but at a significantly higher average unit cost. On the other hand, compared to only announcing a relatively high budget (BC2), the Double Constraint auction (DC2) prevents the average unit cost from increasing too much, thanks to the target limit.

4.3 Increasing the budget constraint

This section analyzes what happens when, in the Budget treatment, the budget announced is increased from €72 (BC1) to €120 (BC2). We also study the impact of such an increased budget in the Double Constraint treatment when the target announced does not change (from DC1 to DC2).

Results presented in Table 5 show that the quantity purchased (M) increases with the size of the announced budget. Nevertheless, in the Double Constraint

Table 5:

Outcome	BC1 (1)	BC2 (2)	***Diff.*** (2)-(1)	DC1 (3)	DC2 (4)	***Diff.*** (4)-(3)
M	2.14	2.74	0.60***	1.78	1.96	0.18***
	(0.10)	(0.13)		(0.05)	(0.01)	
B	71.91	119.09	47.18***	58.00	73.92	15.92***
	(0.04)	(0.45)		(3.33)	(6.22)	
UC	37.18	46.21	9.03***	35.00	38.33	3.33***
	(1.95)	(2.41)		(2.96)	(3.54)	

Standard deviations in parentheses.
Wilcoxon signed rank or *Wilcoxon rank sum* tests.
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

auctions (DC1 vs DC2), the difference is quite small (less than 0.2 units) and only significant at the 10% threshold. Therefore, increasing the announced budget increases the level of competition N/M in the Budget auctions, but not so much in the Double Constraint auctions, because the unchanged target constraint limits the increase of winning bidders. Table 5 also shows that average unit costs (UC) are higher in the treatments with the largest budgets (BC2 and DC2). As expected, the average budget spent is close to the announced budget in the Budget treatments, but in the Double Constraint treatments, the average budget spent is much less than the announced budget, since the binding constraint is often the target constraint, especially in DC2. Finally, we see that the competition level decreases with the budget size, which is not surprising.

It is not recommended to increase the announced budget in a Double Constraint auction that already combines equivalent target and budget constraints. Indeed, moving from DC1 to DC2, significantly increases the average budget spent and the average unit cost without significantly increasing the average number of units purchased.

5 Discussion and conclusion

We propose an auction format experiment that combines a budget constraint and a target constraint, i.e., a double constraint auction. To study the impact of announcing both the target and the maximum available budget in conservation auctions, we conducted an online decontextualized experiment with 705 subjects. Thanks to the strategy method and auction outcome simulations, we compared the performance of the different auction formats according to three criteria: the number of units purchased, the budget spent, and the unit cost.

Our results show that the performance of the Double Constraint auction compared with Target and Budget auctions depends on both the buyer's objective(s) and on the budget size. Indeed, our first conclusion is that there is no ranking that satisfies the three criteria simultaneously.

If the auctioneer primarily wants to achieve an environmental target, announcing this target only ensures that he will reach it, which is not the case with a Double Constrained auction. However, in practice, the buyer usually has a limited budget. In this case, announcing the two constraints ensures that he won't spend more than his maximum budget. Our results show that with equivalent target and budget constraints (each constraint has about a 50% chance of being the binding constraint), the average unit cost obtained in the Double Constrained auction (DC1) is not significantly different from the Target auction (TC1). However, a Double Constraint auction may not be advisable if the budget constraint is quite large, and it may not be saturated in most cases. Indeed, with the same target but an increased budget, the average unit cost obtained in DC2 is much higher than in TC1. Therefore, our second main conclusion is that it is beneficial to announce both constraints when they are equally constraining, but it is better to announce only the target when the budget available (to reach this target) is relatively high. Nevertheless, other experiments with more restrictive budgets need to be performed in order to reinforce these results.

The Double Constraint auction thus seems particularly beneficial when the funds dedicated to a conservation program are scarce and the auctioneer's objective is to get the highest environmental benefit for each euro spent. However, in practice, it is not always easy to determine ex-ante which constraint (target or budget) is the most binding.

We can only formulate a hypothesis to explain why the performance of the Double Constraint auction deteriorates (compared with a Target only) when the budget size increases. One possibility is that a larger budget creates a cognitive bias among bidders who, rather than lowering their bids considering that the level of competition is higher in Double Constraint auctions, for example, see the ratio of the announced budget and target constraints as a proxy for the unit cost, thus aligning their bids on this (relatively high) value and causing a deterioration in the auction's performance.

Finally, we find that increasing the budget in Budget auctions allows the auctioneer to purchase more units, on average, but strongly increases the average unit cost. This result is consistent with that of Howard et al. (2023) regarding the impact of a higher budget. However, note that we assumed that the number of bidders is the same in all our treatments, while in practice, a higher budget may increase participation by attracting more farmers. This may increase the competition level and may even reduce the ex-post average unit cost of the auction.

Similarly, announcing a target as a common environmental objective may encourage more farmers to participate in conservation auctions, because the procedure may appear more positive to farmers than competing to win the largest share of an announced budget. Considering that endogenous participation goes beyond the scope of this paper, it should be kept in mind when implementing conservation auctions, as should the question of the appropriate spatial scale of the conservation auction.

A Content of the experiment

A.1 Instructional video for DC1 treatment (Translated slides from French to English)

Welcome !

This **experiment** is being conducted by researchers as part of a public research project to study decision making.

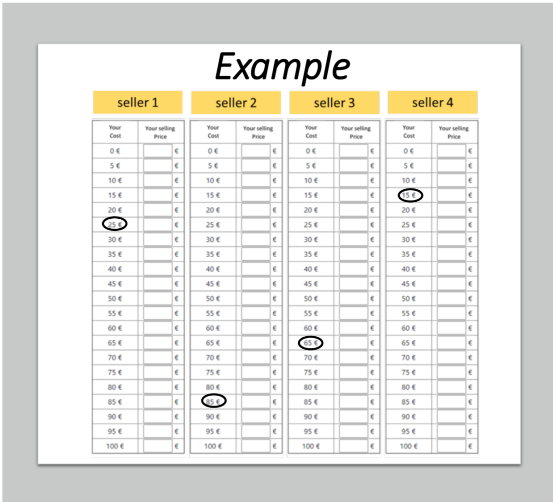
In this experiment you will have the **opportunity to earn money** in addition to the fixed participation payment.

The additional ***gain*** will depend on your decisions, as well as the decisions of other participants involved in this experiment.

We ask you to pay close attention to the instructions provided.
They should allow you to understand your role in the experiment.

Once all sellers have completed their table,

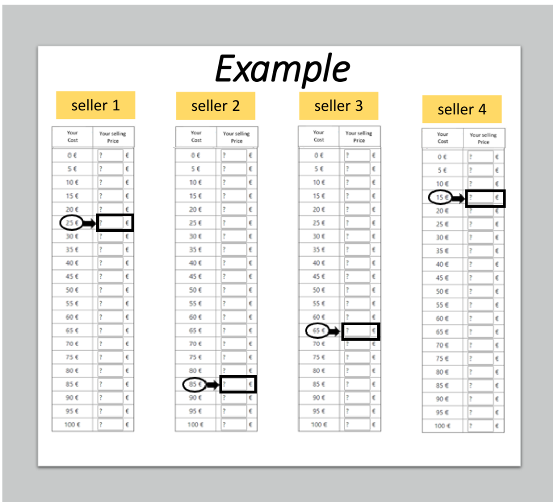
a production ***cost*** will be drawn randomly for each seller.



Once all sellers have completed their table,

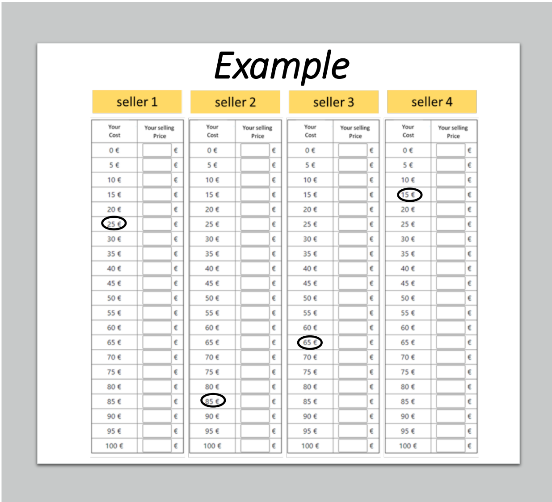
a production ***cost*** will be drawn randomly for each seller.

Then each seller's corresponding bid ***price*** for this ***cost*** will be looked up in their table.



Once all sellers have completed their table,

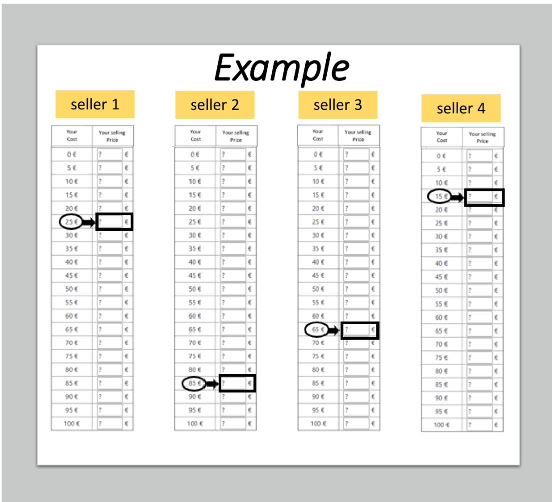
a production ***cost*** will be drawn randomly for each seller.



Once all sellers have completed their table,

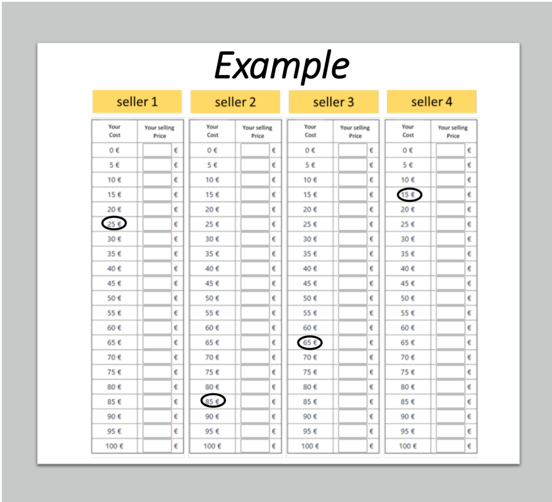
a production ***cost*** will be drawn randomly for each seller.

Then each seller's corresponding bid ***price*** for this ***cost*** will be looked up in their table.



Once all sellers have completed their table,

a production ***cost*** will be drawn randomly for each seller.



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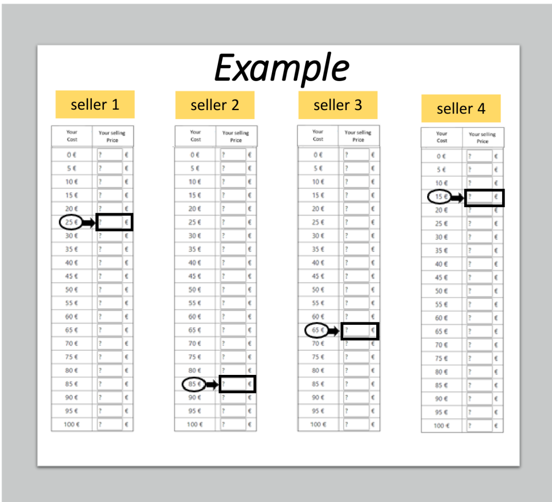
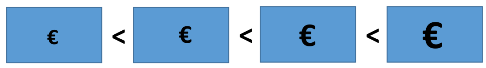


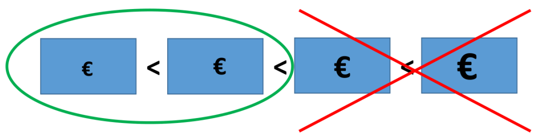
Game rules

The buyer will rank the 4 units offered in your group in ascending order of ***price*** (from lowest to highest).



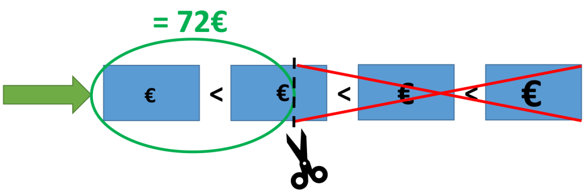
In each group, the buyer will purchase at most **2 units** with a maximum budget of **72€**.

<u>If the 72€ budget is sufficient</u> to purchase the 2 cheapest units, the buyer will purchase exactly **2 unit**.



The budget may not be spent entirely.

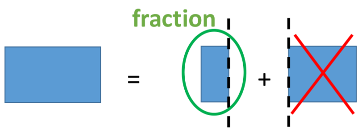
If the 72€ budget is not sufficient to purchase 2 units, the buyer will purchase units from the cheapest **until the 72€ budget is exhausted**.



*To spend **exactly 72€**, he can purchase only a fraction of the last unit selected.*

In case of a tie

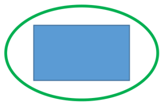
between several sales ***prices*** in the same group, these units will be divided by the buyer.



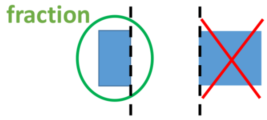
In this case, he will buy the same fraction of a unit from each of the ties.

Calculating your earnings

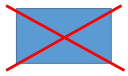
- If your entire unit is purchased:
  gain = price - cost



- If a fraction of your unit is purchased:
  gain = ***fraction*** **×** ***(price - cost)***



- If your unit is not purchased:
  gain **= 0€**



You don't need to pay the cost of producing your unit if you can't sell it.

Remarks

- The ***cost*** that will be drawn at the end of the experiment to calculate your earnings does not depend on the ***cost*** of the other sellers.

- Each production ***cost*** in the table has the same chance of being drawn.

For each possible production ***cost,*** you should ask yourself :

*« For this production **cost**, what is my selling **price**? »*

At this point, you do not know the production costs or the prices that the other 3 sellers will offer.

Each ***price*** should be rounded to the nearest euro and be greater than or equal to the ***cost*** of production.

Your Cost	Your selling Price	
0 €		€
5 €		€
10 €		€
15 €		€
20 €		€
25 €	?	€
30 €		€
35 €		€
40 €		€
45 €		€
50 €		€
55 €		€
60 €		€
65 €		€
70 €		€
75 €		€
80 €		€
85 €		€
90 €		€
95 €		€
100 €		€

Only those who succeed in selling their unit (or fraction of a unit) will receive their ***earnings***.

Before filling in the table,

please answer 3 questions in order to better understand the experiment.

Your answers to these questions will have no impact on your earnings!

After completing the table, you will be asked to answer a short final questionnaire.

During the experiment you can review the instructions at any time by clicking on this button:

See the instructions

A.2 Comprehension questions in DC1 (Translated from French to English)

True/False about the experiment

1. The production cost drawn at random will necessarily be the same for all of the 4 sellers in your group.

The answer is « **False** » because the production costs are randomly drawn independently for each seller. It is therefore highly unlikely that the 4 costs drawn within your group are identical.

2. When you must set a bid for each row in the table, you know the cost of producing your unit. However, you do not know the cost that will be used to calculate your profit.

The answer is « **True** » because when you set a selling price this price is necessarily associated with a production cost. However, only one cost (one row in the table) will be **drawn** to calculate your earnings.

3. You are in competition with the other sellers in your group.

The answer is « **True** » because if the other sellers in your group offer a lower price than yours, you will not be able to sell your unit and your gain will be 0€. Therefore, you have to make a trade-off according to your preferences between asking a higher price to potentially earn more or offering a lower price to increase your chances of winning (selling your unit).

A.3 Final questions

1. Was it easy for you to choose a price for each cost? From 0: Not at all (I chose randomly) to 10: Yes completely (I am sure of my choices)

2. Are you generally a risk-taker or do you try to avoid taking risks as much as possible? From 0: Avoid taking risks as much as possible, to 10: Very comfortable with the idea of taking risks

3. Age:

4. Gender:
Male
Female

5. What is your highest education level? (adapted from French education grade levels)
No high school diploma
High school diploma
Associate's degree
Bachelor's degree
Graduate studies

6. Individual monthly income before income tax:
Less than €1,100
Between €1,100 and €1,899
Between €1,900 and €2,299
Between €2,300 and €3,099
Between €3,100 and €3,999
Between €4,000 and €6,499
More than €6,500
Do not wish to answer

7. What is your socio-professional category?
Farmers
Craftsmen, retailers, entrepreneurs
Executives and higher intellectual professions
Employees
Students
Retired
Unemployed

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