Testbed Experiments for Improving the Cost-Effectiveness of the Conservation Reserve Program

[preliminary - do not circulate]

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Abstract

The Conservation Reserve Program (CRP), the world's largest conservation program, pays farmers to voluntarily establish conservation cover on approximately 30 million acres of environmentally sensitive cropland. Theory and evidence from other government-led market design exercises suggest that the CRP auctions can be redesigned to increase its efficiency and cost-effectiveness. We conduct a laboratory study of several auction alternatives for the CRP. We focus on the current price cap format using two different degrees of cap "tightness", and on two alternative formats based on reference prices; one in which the reference is determined exogenously and another in which it is determined endogenously. Our laboratory evidence indicates that once the price cap is minimally profitable for most bidders, relaxing the cap further does not increase participation or price competition. Only rents get bigger and, therefore, cost-effectiveness can be hurt. The *exogenous* reference price format generates a behavior by which buyer picks a costly set of sellers more frequently than in the other auctions, causing this format to perform poorly in terms of cost-effectiveness. The *endogenous* reference price, on the other hand, performs satisfactorily in terms of cost-effectiveness by increasing participation. Due to its informational properties, price cap format is optimal only if the precision of cost estimation is well understood. Otherwise, the endogenous reference price auction is an adequate alternative.

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1. Introduction

The Conservation Reserve Program (CRP), the world's largest conservation program, spent \$1.9 billion in fiscal year 2012 to pay farmers to voluntarily establish conservation cover on 29.6 million acres of environmentally sensitive cropland. The program relies on two approaches to enroll land: a competitive system known as *General Signup* and a first-come, first-served system called *Continuous Signup*. General Signup is a competitive auction through which offers to enroll land are ranked according to an index of environmental benefit and a cost metric. Each bid is constrained by a parcel-specific *bid cap*. In contrast, Continuous Signup focuses on enrolling land in targeted geographic regions or for sets of high-value conservation practices, delivering fixed payments to offers that meet fairly strict eligibility criteria.

Economic theory and practical experience from other types of government auctions (e.g.: timber sales, toxic asset purchase, and communication spectrum sales) suggest that a modified auction structure could make CRP more cost-effective. This paper reports on a laboratory study of alternative auction mechanisms and how perform in controlling costs and achieving efficiency. We focus on the current price cap format using two different degrees of cap "tightness" as well as on two alternative formats based on reference prices; one in which the reference is determined exogenously and another in which it is determined endogenously.

In our experimental setting, there are 16 bidders each with an object (parcel), and one buyer (the program) who has a goal to buy (enroll) eight objects (parcels). Opportunity costs per object (representing rental price of parcels) are assigned randomly and distributed privately. In the price cap treatments, bidders are restricted to submit offers up to an object-specific cap based on an unbiased estimate of opportunity costs plus a *markup* μ. The buyer buys from the bidders with eight lowest bids and pays each of them what they ask. In the *tight price cap* format (TPC) the markup is chosen to be minimal provided that non-participation is never dominant. In the *relaxed price cap (RPC),* μ is three times as big as in TPC. In the exogenous reference price auction (ExogRP), there is no cap in terms of bidding. Instead, a scoring system is used to determine the winners of the auction. The score has two additive components: one that normalizes the bid relative to a *reference* set equal to the estimated opportunity cost; and another that penalizes the bidder for having an estimated higher cost. The first component aims to generate price competition among bidders of different costs, the second aims to reduce allocative inefficiencies. In the endogenous reference price auction (EndoRP), the score function is the same, except that the reference is set equal to the average bid of other bidders with similar estimated costs. Because the score in this format depends on the behavior of others (therefore "endogenous"), bidders do not know with certainty their score at the time of bidding. All implemented formats are pay-as-bid type.

We study these formats in terms of participation rates, bidding behavior, allocative efficiency and cost-effectiveness. In terms of participation, both price cap treatments (tight and relaxed) as well as the exogenous reference price all have participation rates in the range of 80% to 84% (statistically equal). The endogenous reference price has a participation rate of 90.8% (statistically higher than the other three treatments). Our evidence suggest that prospects of null profits are definitely the main source of non-participation. As expected. this happens when the cap that is too tight, but also happens when a exogenous reference that is clearly unfavorable. In terms of bidding behavior, TCP does understandably best in keeping offers low as it mechanically enforces low rents. Relaxing price cap does not increase participation therefore price competition. As consequence, winning bids under RPC are actually the highest of all formats. In the exogenous reference price, typical low-and-medium-cost bidders aim to the same target score, when attainable. This implies that the auctioneer picks a costly set of bidders more often than in other auctions, making winning offers to be nearly as high as in RPC. In the endogenous reference price, higher participation promotes bid competition and winning offers are the lowest after TPC.

In terms of efficiency, measured as percentage of objects (parcels) that are allocated efficiently by the auction (sold/enrolled if and only if they are among the eight lowest costs) both price cap formats perform equally well (93% and 93.1%, respectively) and significantly better than the exogenous reference price (88.2%). Statistically, the endogenous reference price (91.5%) performs as we well as the price cap formats.

To study cost-effectiveness, we calculate the cost of achieving the target purchase level of eight objects (in the context of the CRP, a target extension of enrolled land) relative to the efficient payment (the sum of the eight lowest costs). This is what the buyer (program) would pay if he had full information on the actual costs. Obviously, tight price cap performs best in this measure of cost effectiveness (over cost of 18.3%). Relaxed price cap format performs worst in this metric (37.6%) mainly because it allows bidders to extract high rents compared to TPC. Exogenous reference price (35.1%) performs similarly to the RPC. Finally, the endogenous reference price (EndoRP) auction performs better relative to RPC and ExoRP with an over cost index of 30.8%.

We also discuss the informational properties of different formats. Namely that the price cap formats crucially depend on the quality and precision of the estimations the program has of the opportunity costs. This dependency in information quality still prevails, although to a lesser degree, in the exogenous reference price format. In contrast, the endogenous reference price is invariant to certain types of bias and more robust to variance than the other three formats. Our evidence is informative of the main formats being currently considered for the redesign of the CRP. In particular, our results reveal potential issues that mechanisms based on reference prices might face. However, further laboratory work and field research is recommended to study other potential formats and optimal specification of the chosen formats.

The rest of the paper is organized as follows. Section 2 describes the Conservation Reserve Program (CRP) and its currently known issues. Section 3 presents the alternative auction formats we study (relaxed price caps, exogenous reference price and endogenous reference price). Section 4 describes the experiment design, setting, sessions and protocols. In Section 5 we present and discuss our laboratory results. Section 6 presents a market design discussion and Section 7 concludes.

2. The Conservation Reserve Program (CRP)

The CRP pays farmers to voluntarily take environmentally sensitive cropland out of production for a contract period of 10-15 years and instead establish a conservation cover of grass or trees. The program's main objectives are to minimize soil erosion, enhance water quality, and create wildlife habitat. There are many CRP practices, ranging from relatively straightforward native grasses or tree plantings, to structural practices such as grassed waterways and constructed wetlands.[7]

[7] Practices can vary by region and state. For examples of eligible practice, see the Michigan state NRCS office website for a detailed description of common practices:
http://www.nrcs.usda.gov/wps/portal/nrcs/detail/mi/programs/?cid=nrcs141p2_024527,
and the Pennsylvania state NRCS office:
http://www.nrcs.usda.gov/wps/portal/nrcs/detail/pa/programs/?cid=nrcs142p2_018173.

Producers are provided an annual rental payment, as well as assistance paying for practice establishment costs ("cost share"). Which producers enroll and how their annual payments are set determine overall program cost.

The program enrolls land using two types mechanisms: a competitive system called *General Signup* and a first-come, first-served system called *Continuous Signup*. General Signup is a competitive auction through which offers to enroll land are ranked according to an index of environmental benefit and a cost metric. Some version of competitive General Signup has been utilized since the program began in 1985. General Signups have tended to take place annually and usually last four weeks. During this time, the USDA Farm Service Agency (FSA) maintains an open call for bids from landowners. The Continuous Signup focuses on enrolling land in targeted geographic regions or for sets of high-value conservation practices, delivering fixed payments to offers that meet minimum criteria.

An offer to enroll in General Signup specifies the conservation practice that the producer seeks to establish, the parcel on which the practice is proposed, and the annual payment that the producer proposes to receive, i.e., the bid. The bid can be no greater than a parcel-specific estimate that USDA generates. This estimate is designed to be equal to the (minimum) annual payment the producer will be willing to accept to enroll in CRP – his willingness to accept (WTA). This *bid cap* can also be referred to as the estimated opportunity cost of – or reservation value for – participation.

Since 1996, the General Signup has ranked offers on the basis of a multi-dimensional index (the Environmental Benefits Index, or EBI) that reflects both cost (the bid) and anticipated environmental benefits. Offers are ranked according to the EBI; those above a cutoff set by the Secretary of Agriculture are enrolled.

Also since 1996, Continuous Signup has been used to encourage establishment of relatively intensive practices to address serious conservation concerns. This signup is year-round and non-competitive, with eligible offers enrolled on a first-come, first served basis. Continuous signup acreage often qualifies for extra payments (such as Signup Incentive Payments and Practice Incentive Payments), hence are typically above the parcel's bid cap.

Total enrollment in CRP is subject to acreage caps at the practice[8], county[9], and national levels. The acres signed up in a given year cannot exceed the national cap set by the Farm Bill, less the active contract acres that will not be expiring at the end of the year. Accordingly, this constraint varies considerably from year to year.

As of December 2013 approximately 260,000 contracts covering almost 20 million acres had entered the program through General Signup, and about 410,000 contracts covering nearly 6 million acres had entered the program through Continuous Signup.[10] The average size of an enrollment is 75 acres and 14 acres, respectively, reflecting the fact that General Signup tends to enroll whole fields while Continuous Signup tends to enroll parts of fields (a consequence of the practices encouraged by Continuous Signup).

2.1. Known Issues of the Current CRP Auction

General Signup operates as a procurement auction, and, as such, the CRP can they utilize competition to control costs. That is, costs can be driven down because bidders might want to reduce their asking prices in order to increase their chances of being selected -- winning the auction. In pay-as-bid auctions like the CRP, participants will want to submit a bid that is low enough to be accepted, yet high enough to be profitable.

In the CRP, like in other auctions, some participants are very certain of their prospects of winning if, other things equal, their opportunity cost is low. In this way, those bidders are able to extract relatively large profits from the auction. Similarly, other auction participants who are certain to be rejected are unlikely to make any offer to enroll.

In the General Signup of the CRP, the piece of information which farmers can use to predict the likelihood that their offer will be accepted is the EBI. By having particularly environmentally valuable land, or of having land with unusually low productive value, or both, CRP bidders know that they can ask for an annual payment significantly higher than their opportunity cost and still be confident that their offer will be accepted. The fact that General Signup is a *repeated* auction

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[8] Practice caps only apply to continuous signups—since many continuous signup acres enroll under "initiatives" (such as the State Acres for wildlife enhancement initiative) that set aside a fixed number of acres that must use a limited set of conservation practices.

[9] CRP's enabling legislation limits per-county CRP enrollment to be less that 25% of cropland acres.

[10] http://www.fsa.usda.gov/Internet/FSA_File/julysummary13.pdf

may exacerbate the situation. Potential participants in General Signup auctions can observe past auction outcomes to determine the size of payments that they can ask for and still be confident that their bid will be accepted. In fact, empirical examinations of CRP signups generally find there are substantial differences between farmer bids and their "reserve rents". Kirwan, Lubowski and Roberts (2005) find that landowners are, on average, paid 20% above their opportunity costs. Similarly, Horowitz, Lynch and Stocking (2009) find that bids in an auction where the state purchases farmland development rights are 5-15% above landowner opportunity costs.

USDA has implemented price controls in the form of bid caps for the General Signup precisely to prevent excessive payments to bidders. The particular intent is to limit farmers' annual rental payments to an *estimate* of their opportunity costs. This is why the bid caps are based on *soil rental rates* (SRRs). SRR are in turn based on county-average dryland cash-rent estimates, soil-specific adjustment factors, and professional judgment.[11] The key feature of these bid caps, however, is that they are inherently imprecise and, possibly, subject to bias. Unobserved heterogeneity in land quality and limited number of observations with cash rental agreements are likely sources of error.[12] Moreover, the fact that SRRs estimates include cropland that does not qualify for the program and treat some types of grassland differently is a likely source of bias.

Despite its goal to lower the costs of the program the parcel-specific price caps are likely having counterproductive consequences. Under imprecise and possibly biased estimates of the SRRs, the bid caps may be causing higher costs the General Signup auction due to their negative impact on participation rates. Even small imprecisions in the opportunity cost estimates can drive a mass of potential bidders to an unprofitable region (receiving a bid cap below actual opportunity costs), inducing them out of the auction. And, with fewer participants, the cost effectiveness of the program is negatively affected via two channels. First, in order to satisfy an acreage target, the program needs to accept parcels with high opportunity costs to replace the dissuaded (possibly lower-cost) bidders. Second, strategic, non-dissuaded bidders can exploit the lack competition,

[11] "FSA bases rental rates on the productivity of the soils within each county and the average dryland cash rent" http://sustainableagriculture.net/publications/grassrootsguide/conservation-environment/conservation-reserve-program/

[12] In regions where share rents predominate, imprecise formulae that map share fractions to cash rentals are often used.

that gives them good chances to win the auction, by submitting higher offers than they would do otherwise. In Appendix A, a simple simulation illustrates this point more in detail.

Relaxing the cap (setting each bid cap equal to the estimated opportunity plus a "markup") is an obvious way to reduce its negative effects on participation. However, the more relaxed they are, the less binding caps become, and so the cost-reducing potential of the bid caps vanishes. There is an optimal cap that balances the participation effects discussed with the potential for bid reduction. However, as discussed in (Hellerstein and Higgins, 2010), in our own simulations and experimental data, striking the right balance is difficult and to a large extent unlikely.[13] Balancing the price cap effect for the good, requires: i) a precise measure of the accuracy of the SRRs estimates, and ii) using that information in a careful manner to set the correct markup.

3. Alternative Auction Formats

Looking for an adequate price cap, by carefully using available information on the accuracy of the SRRs estimates is a natural alternative. However, as argued above, the precision of the opportunity costs is key to such a policy and, therefore, its performance is vulnerable to errors in precision measures. In this context it is necessary to study other formats that, while use using the available costs estimates, are more robust to their imprecision. We consider two alternatives to replace the price caps: one with format based on an *exogenous reference price* and another with an *endogenous reference price*. Reference price auctions have been successfully implemented in other contexts. For example, the U.S. Treasury used reference price auction to purchase toxic assets under TARP legislation, following the 2008 financial crisis. Reference price auctions allowed the Treasury to compare bids on securities of different values. In the CRP context, this type of auction could help reduce the rents extracted from farmers with lower opportunity cost, by incentivizing all farms to participate and bid competitively. Experimental work on auctions with reference price can be found in Ausubel et. al. (2013), Armantier, Holt, and Plott (2013).

[13] Hellerstein and Higgins (2010) find that auction efficiency peaks in the neighborhood of the tight cap. They compare observed payments to the cost of a feasible Vickrey auction, and bid caps 20 percent above or below cost perform relatively worse than caps around participant cost. However, the role of participation is not explicitly studied here.

3.1. Relaxed price caps

This alternative is a modest departure from the current General Signup: Set bid caps equal to an opportunity cost estimate, plus an allowed "markup" intended to overcome the inherent imprecision in the estimate. If the effect of increased participation from the relaxed bid cap outweighs the increase in price paid to existing participants, this approach will reduce program costs. This alternative has been applied in other natural resource contexts: British Columbia calculates what they call an *upset price* (an estimate of value) for timber stands that they wish to sell at auction. Athey, Cramton, and Ingraham (2002) find that using a limit price equal to about 70% of this value is optimal. This limit price represents a 30% "rollback" from the estimated value – the analog in a reverse auction like the CRP would be setting bid caps at 130% of estimated opportunity cost.

3.2. Exogenous Reference Price

Point estimates of opportunity costs could also be used to normalize bids instead of serving as caps. That is, they can serve as *reference prices*. Relative bids can form scores and be ranked in the similar fashion that do raw bids in the current format. In that sense, it would use a similar information infrastructure as the current system.[14]

Theoretically, in this context, reference prices can have contrasting effects. On one hand, the reference price mechanism, unlike the bid cap, makes bids above the soil rental rate admissible and pushes no one out of the auction. This must increase price competition and cost-effectiveness. On the other hand, however, ranking bidders by the attractiveness of their offers relative to their reference price (or estimated SRRs) is a powerful equalizing force across the cost range. This can make undesirably high cost bidders to win the auction often, impacting cost-effectiveness negatively.

One alternative to reduce the second negative effect is to set a scoring function that uses as inputs bidders offers relative to SRRs <u>and</u> a penalty increasing with the likelihood of being a high cost bidder. As discussed below, this modification of the pure relative offer seems to help cost sorting among bidders improving the cost effectiveness.

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[14] The current CRP offer ranking already includes a *cost factor* that provides improved ranking for offers that bid down to a greater extent relative to their bid cap.

In sum, the benefit of a reference price mechanism is that no one is dissuaded from participating but other present incentives could partly offset this benefit. Finally, an operational benefit of the reference prices is that references (based on SRRs) could be announced to farmers before they submit a bid as it currently happens with bid caps.

3.3. Endogenous Reference Price

An even less direct way to use SRRs estimates is to have them as inputs of a mechanism with *endogenous reference* prices. The way an endogenous reference price works is similar to the exogenous reference price (presented above) except that the reference price is now an average bid of a set of similar, comparable or neighboring parcels with respect to the information available to the Program. Furthermore, the set of similar or neighboring bidders can be constructed at random although this could add another source of error. In this mechanism, the reference price for each parcel would not be known to the farmers at the time of the auction, but would be calculated after all bids are submitted.

Making reference unknown and uncertain to bidders, may reduce asking prices and rents. However, not announcing a reference price upon which to base their bid could be unsettling to some bidders and cause them to opt of the auction. Also, endogenous references might suffer from collusion, and attempts to minimize collusive forces (larger, less obvious matching) could exacerbate or generate other issues.

As in the case of exogenous reference prices, a penalty that is increasing with the likelihood of being a high cost bidder can be included in this mechanism as well in order to attenuate the equalizing forces of a reference price mechanism.

Participation effects and collusion in reference price settings are not straightforward to model and therefore the laboratory evidence can be particularly insightful on those regards; even more so when the scoring formulae are not simple ratios as it is our case.

4. Laboratory Experiment

We study the auction alternatives described in the previous section (and several variants detailed in Appendix D) in a laboratory setting. These experiments aim to inform the discussion and redesign of the CRP auctions by shedding light on the virtues of (and issues raised by) the potential new formats. It is expected that field work will be a next, intermediate step towards the redesign. A field experiment will provide more precise measures of the impact of the final candidate formats.

4.1. Experiment Design

4.1.1. Setting

In a given period, each of the $N > 1$ bidders holds an *object* which he might or might not aim to put for sale. Bidder $i \in \{1,2,\dots,N\}$ privately observes the a signal c_i representing his value or *opportunity cost* of the object. If bidder i sells the object to the buyer for *price* p_i, he forgoes the private value of the object and receives the price p_i, instead. Bidders' *costs* are i.i.d. draws from a uniform distribution with all integers from 10 to 100 as support.

$$c_i \sim_{iid} U[10, 100]$$

That is, we are in an independent private cost model setup. There is a single buyer with a fixed demand $Q^d < N$ that sets up a mechanism to buy as many units as possible up to Q^d. In all experiments reported in this paper, $N = 16$ and $Q^d = 8$. In the context of the Program, bidders represent farmers, objects represent parcels, the buyer represents the CRP.

In the laboratory implementation subjects collected profits based on their economic profits. That is, i's profit is the difference between the price p_i and c_i if i is able to sell the object and zero otherwise. However, all formats we study in this paper are pay-as-bid. That is, if i sells, the price will always be equal to i's bid b_i. Therefore, profits can always we represented as:

$$\Pi_i = 1_{\{i\ sells\}}(b_i - c_i)$$

and different formats will simply change the conditions under which bidder i sells or does not sell his object.

There is an imprecise estimate of each bidder's opportunity cost $\widehat{c_i}$ available to the buyer. This estimate follows this process.

$$\widehat{c_i} = c_i + \epsilon_i$$

where:

$$\epsilon_i \sim_{iid} U[-5, +5]$$

Finally, since players (representing farmers) in this environment can only have one direction of transaction, *sell*, we use the terms "bid" and "offer" interchangeably to refer to their stated/asked minimum compensation to part with their corresponding objects; i.e., their stated WTA.

4.1.2. Auction Formats

Tight price cap (TPC)

The buyer sets bidder-specific price caps. Bidder i's price cap equals the estimated cost $\widehat{c_i}$ plus a "markup" of 5 experimental currency units (ECUs):

$$Cap_i \ = \ \widehat{c_i} + 5$$

At the beginning of the auction bidder i privately observes his own c_i and his specific Cap_i, an then decides whether to participate in the auction or not. If he decides to participate, he then submits a bid (offer). The buyer accepts the eight lowest offers and rejects the remaining participating offers. If less than eight offers are submitted, the buyer accepts all offers. Sellers makes profit of $(b_i - c_i)$ and non-seller make null profit.

The configuration of the tight price cap format we study here can be thought of the ideal cap implementation. This is because in this configuration the markup (5ECUs) satisfies a simple condition: it is the minimum markup such that it is always individually rational to participate for the given precision of the estimated cost, $\widehat{c_i}$.

Predicted (equilibrium) bidding behavior under price cap can be obtained numerically and takes a relatively simple form:

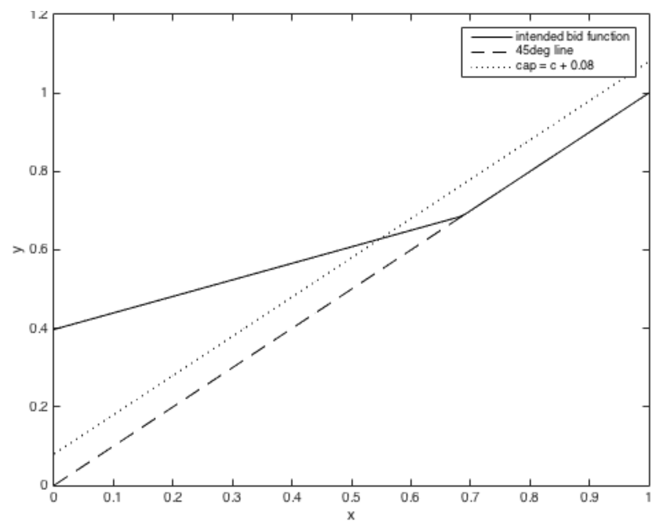
$$b_i(c_i, Cap_i) = \begin{cases} Cap_i & \text{if} \quad c_i < \tilde{b}^{-1}(Cap_i) \\ c_i & \text{if} \quad c_i > \tilde{b}(c_i) \\ \tilde{b}(c_i) & \text{if} \quad otherwise \end{cases}$$

where $\tilde{b}(c_i)$ is a *latent* bid function given by

$$\tilde{b}(c_i) = \alpha + \beta c_i$$

where $\alpha > 0$ is in the cost support, and $\beta < 1$. Figure 1 illustrates this bidding behavior from a numerical exercise where the cost support is the unitary interval.

Figure 1: Equilibrium Bidding Behavior of the Price Cap Format



Note: costs are represented in the x-axis and bids in the y-axis. c_i is iid uniformly distributed in [0,1] and ϵ_i is iid uniformly distributed in $[0, 0.1]$

Intuitively, this equilibrium bidding behavior works as follows. If bidder i has a low enough cost (below 0.7 in the figure), his intended bidding function, $\tilde{b}(c_i)$, will be above his cost, c_i, and i will submit $b_i = \tilde{b}(c_i)$, unless his cap_i is binding. If i's cap is binding, i will simply submit a bid equal to his cap. This bidding form predicts also that for very low-cost bidders the cap will always be binding so they will always bid the cap. Also, if i's cost is above a certain threshold τ (where $\alpha + \beta\tau_i = \tau_i$, 0.7 in the Figure) the bidder is indifferent between not participating and submitting $b_i = c_i$. If i's cost lies below such a threshold, i participates with certainty (as it is always profitable in expectation). Finally, the threshold is positively related to the tightness of the cap: the markup.

Relaxed price cap (RPC)

The buyer sets bidder-specific price caps in the same manner as in the tight price cap format except with a higher allowed markup. In particular, bidder i's price cap equals the estimated cost $\hat{c_i}$ plus a "markup" of 15 experimental currency units (ECUs):

$$Cap_i = \hat{c_i} + 15$$

The rest of the auction is identical to the tight price cap format.

The configuration of loose price cap format we study here can be thought of a cap implementation that, in order to avoid the negative effects of lower participation, provides a more relax cap with a higher markup. If higher participation generates enough pressure for competition, this auction should do better in terms of the cost effectiveness and allocation efficiency than a price cap with null markup.

Equilibrium bidding behavior of the RPC has the same structure as for the TPC format (see previous subsection and Appendix).

Exogenous reference price (ExogRP)

The buyer sets bidder-specific reference price based on estimated costs. Bidder i's reference price equals the estimated cost $\widehat{c_i}$. At the beginning of the auction bidder i privately observes his own c_i and his specific reference price (buyer's estimation of his cost), an then decides whether to participate in the auction or not. If he decides to participate, he then submits an offer. The buyer collects all offers from participating bidders and computes everyone's score following this rule:

$$\text{Score}_\text{i} = \frac{\text{Offer}_\text{i}}{\text{Reference Price}_\text{i}} + \frac{\text{Reference Price}_\text{i}}{50}$$

Where the $\text{Reference Price}_\text{i} = \widehat{c_i}$. The second term in the Score formula is the high-cost-bidder penalty discussed above. The buyer accepts the eight lowest scores and rejects the remaining participating offers. If less than eight offers are submitted, the buyer accepts all offers. As before, selling bidders make a profit of $(b_i - c_i)$; non-selling bidders make null profits.

Equilibrium Behavior in the exogenous reference price format does not take a semi-linear form with respect to the offer. However, it does take a simple form with respect to the score function. Equilibrium scores in this format always equal to a score value of $s_i^* = k$ when such value is attainable without violating individual rationality $(b(k) \geq c_i)$ with for a given pair (c_i, ϵ_i). When a score value of k is not possible, bidders are indifferent between not participating and submitting any bid at or above their cost (their chances of winning are negligible). The equilibrium value of k is determined by a condition that guarantees that, on average, only Q^d bidders (mainly low cost) can indeed achieve a score value of k.[15] This equilibrium bidding behavior follows this equation:

[15] See Appendix for further discussion in this equilibrium form.

$$b(c_i, \epsilon_i) = \max\{\, k(c_i + \epsilon_i) - \frac{(c_i + \epsilon_i)^2}{50}\ , c_i\}$$

which implies that bids are concave in costs up to a cost threshold that depends on ϵ_i and k. Equilibrium value of k is approximately 2.103.

Endogenous reference price (EndoRP)

At the beginning of the auction bidder i privately observes his own c_i and buyer's estimation of his opportunity cost $\widehat{c_i}$. He then decides whether to participate in the auction or not. If he decides to participate, he must submit an offer. The buyer collects all offers from participating bidders and computes everyone's score following the same rule as in the exogenous reference price (i.e. $\text{Score}_\text{i} = \text{Offer}_\text{i}/\text{Reference Price}_\text{i} + \text{Reference Price}_\text{i}/50$). Except now the $\text{Reference Price}_\text{i}$ is the average offer of the four bidders that are closest to i in terms of the estimated cost. The rest of the auction format is identical to the endogenous reference price.

Although we do not derive the theoretical (numerical) equilibrium predictions of this auction, two of its relevant conceptual features need to be noted. First, bidders in this format do not possess direct, precise information of their chances of winning, conditional on their (c_i, ϵ_i) pair, as they would do in all three other formats. This additional uncertainty could positively impact participation, because (as we document below) slim chances of winning are a major factor in non-participation decisions. Second, the bidding behavior set by this format is theoretically more robust to the moments of ϵ_i, the estimation error of the opportunity costs. In particular, equilibrium bidding is invariant to bias, $\mathbb{E}[\epsilon_i] = w \neq 0$, as this would not alter grouping therefore nor the neighbors' average bid faced by any bidder. Also, bidding behavior is affected to changes in $Var[\epsilon_i]$ only through the non-linearity of the bidding function with respect to cost.

4.2. Experimental Sessions and Protocols

We conducted eight sessions, each implementing three different auctions format in random order. Each auction format was studied in six different sessions which allowed us to implement six different draw vectors for cost and estimated costs. In the end the full set of draws is perfectly matched across auction formats. Of the six draws vectors, draws 1 through 3 had 15 periods, and draws 4 through 6 had 20 periods. That is, each format was run for a total of 105 independent auctions and therefore elicited 1680 individual bidder decision. Subjects are paid based on 6 randomly selected rounds, two for each type of auction in the session. The exchange rate between Experimental Currency Units (ECUs) to U.S. Dollars is 3; that is, 3ECUs = US$ 1.

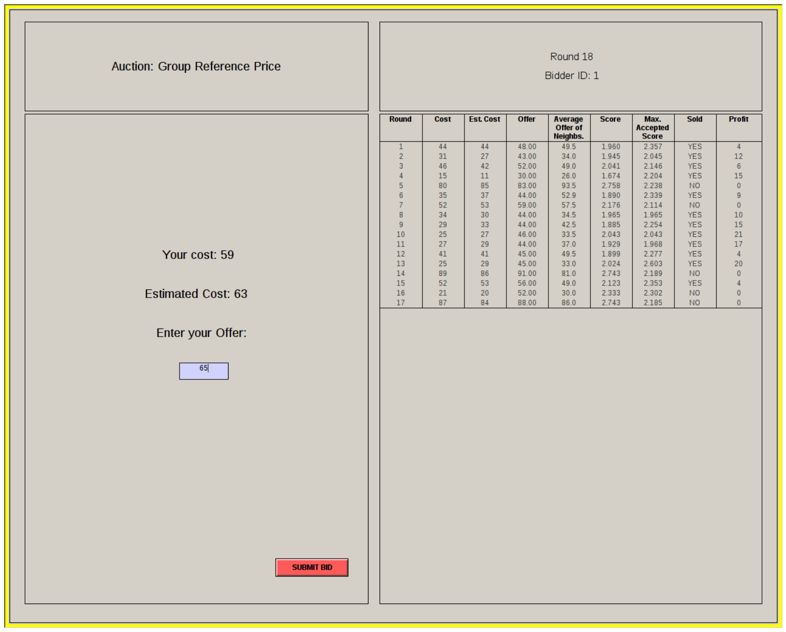
Table 1: Session Plan

Main Sessions	**Treatments (Draws)** [in order of implementation]	**Rounds per treatment**	**Number of participants**
1	ExoRP, RPC, EndoRP (4, 4, 4)	20	16
2	TPC, ExoRP, RPC (5, 5, 5)	20	16
3	EndoRP, TPC, ExoRP (6, 6, 6)	20	16
4	RPC, EndoRP, TPC (6, 5, 4)	20	16
5	EndoRP, TPC, ExoRP (2, 2, 2)	15	16
6	TPC, RPC, EndoRP (3, 2, 3)	15	16
7	RPC, ExoRP, RPC (1, 3, 3)	15	16
8	ExoRP, EndoRP, TPC (1, 1, 1)	15	16

Participants received a copy of written instructions at the beginning of each session. Once the session started, the experimenter provided general instructions. Before each auction type started, the experimented read the format-specific instructions aloud and provided numerical examples as well as a description of the computer interface. Individual questions from participants were allowed after the reading of each format-specific instructions.

All auction interfaces shared main features. As seen in Figure 1, the left side of the screen displayed bidder's private information for the current period. At the action stage this side of the screen also contain the corresponding buttons and fields where bidders could opt in or out of the auction. After submitting their decision, that side of the screen turned into a waiting screen. Once the results for the current period were processed, those were displayed in detail in that side of the side of the screen too. See Appendix _ for the full set of experimental interfaces. The right side of the screen permanently displays all the relevant information from previous periods.

Figure 1: Sample Experimental Interface



5. Experiment Results

This section details the findings from the main treatments discussed previously: Tight price cap (TPC), Relaxed price cap (RPC), Exogenous Reference Price (ExogRP) and Endogenous Reference Price (EndoRP). We also present results from robustness exercises that, among other things, illustrate how participation effects and rent extraction make the price cap formats vulnerable to the precision of the SRRs. Detail on the auxiliary experiments and treatments are provided in the Appendix.

Summary Results

This section summarizes our main findings. We study the auction formats in terms of the following metrics: participation rates, bidding behavior, allocative efficiency and cost-effectiveness. There is no strong evidence of learning: excluding the first five periods of every session-treatment conducted yields nearly identical results in most outcomes. Our report will be mostly based on all data-points and we will mention results from excluding the first 5 periods when appropriate.

Table 2, provides summary stats of the main studied outcomes. In terms of participation, despite the fact that participation is always individually rational, both price cap treatments (tight and loose) as well as the exogenous reference price all have participation rates in the range of 80% to 84% (statistically equal). The endogenous reference price, however, has a participation rate of 90.8% (statistically higher than the other three treatments). As it will be discussed below, this pattern illustrates a more general point on the features of these auctions: directly unprofitable auctions (e.g. price cap with null or too-tight markup) discourage participation, but so do auctions where a subset of bidders know they will lose the auction with high probability.[16]

Table 2: Summary Statistics

Auction Format	All Periods (averages)				Period > 5 (averages)			
	Parti-cipation	Winning Offers	Allocat. Effic.	Over-cost	Parti-cipation	Winning Offers	Allocat. Effic.	Over-cost
TCP	0.824	38.815	0.930	0.183	0.803	39.070	0.920	0.192
RPC	0.842	44.799	0.931	0.376	0.820	44.776	0.925	0.377
ExogRP	0.818	43.879	0.882	0.351	0.812	44.298	0.877	0.365
EndoRP	0.908	42.505	0.915	0.308	0.908	43.082	0.912	0.329

In terms of bidding behavior, TCP does understandably best in keeping offers low: it mechanically enforces low rents. However, as previously stated and further documented below, this is mainly because the specification of our TCP format corresponds to the most desirable implementation of a price cap format (it achieves minimal rents and individual rationality for all). Interestingly, loosening up the price cap does not increase participation, so no extra competition force drives down bids in the relaxed price cap treatment compared to TPC. As consequence, winning bids under RPC are actually the highest of all formats. In the exogenous reference price, the typical bidding behavior (detailed below) implies that the auctioneer picks high-cost bidder more often. This causes winning offers to be nearly as high as in RPC. Finally, in the endogenous reference price higher participation promotes bid competition and winning offers are lowest after TPC.

[16] There are several reasons for which this could happen: costly processing of optimal bidding and behavioral biases associated to perception of loss are two of them.

In terms of efficiency, we use a simple object-level efficiency indicator of whether an object (parcel) was efficiently allocated by the auction. That is, this indicator takes value of 1 for bidder i sells (does not sell) the object when i is among the eight lowest (highest) costs bidders in the market; and the indicator takes value 0 otherwise. Table 2, reports the mean of this allocation efficiency index. In this metric, both price cap formats perform equally well (93% and 93.1%, respectively) and significantly better than the exogenous reference price (88.2%). Statistically, the endogenous reference price (91.5%) performs as we well as the price cap formats.

We also calculated a measure of cost-effectiveness:

$$\text{Over Cost} = \frac{\text{Observed Payment}}{\text{Efficient Payment}} - 1$$

This metric captures the cost of achieving the target purchase level of eight objects (in the context of the CRP, a target extension of enrolled land) relative to the efficient payment. That is this a measure of *over cost* bounded below at zero and unbounded above. The efficient payment is assumed to be minimum feasible cost (the sum of the eight lowest costs), which is what the buyer (program) would pay if he had full information on the actual costs.[17] The tight price cap performs best in this measure of cost effectiveness (over cost of 18.3%), mainly because it mechanically enforces low rents and efficient participation. Relaxed price cap format performs worst in over cost (37.6%) mainly because it allows bidders to extract high rents compared to TPC. Exogenous reference price (35.1%) does perform slightly better than the relaxed price cap, but the difference is not statistically significant. Finally, the endogenous reference price auction performs well relative to RPC and ExoRP with an over cost index of 30.8%.

5.1. Main Results

Participation

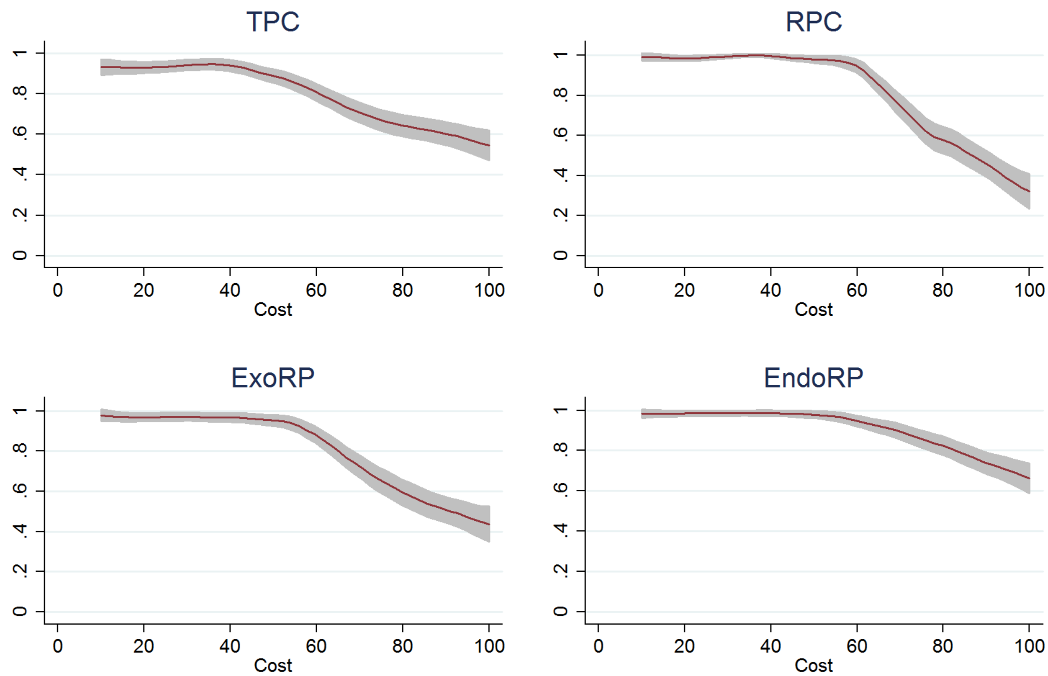
In every auction, participation was individually rational – bidding can never lead to losses. However, participation is far from complete in all auction formats (see Figure 2).

It is expected that participation in TPC is lower than in other formats: there is a 1/11 chance of getting a cap equal cost; in which case opting out or setting offer equal to cost both lead to the

[17] Other benchmarks of efficiency payments are discussed below.

same null profit. However, participation decisions do not simply obey (weak) individual rationality, but respond to the chances of winning and the size of the attainable profit. Consistent with equilibrium, participation rate when attainable profits are zero or one ECUs and costs are at or above 70 is less than 45%.

Figure 2: Mean Participation Rates by Auction Format



Note: Local polynomial estimation with 95% C.I.

In RPC, where it is always individually rational to opt in, participation rates sharply decline for costs over 60 ECUs. In particular, when attainable profits are zero or one ECUs and costs are at or above 70 ECUs, participation rate is only 49%.

With these forces in play, the level of overall participation in the "tight" and "relaxed" price caps are both similar 82.4% and 84.2%, respectively (80% and 82% excluding the first five periods). This is a relevant insight for the redesign of the CRP auction. It suggests that relaxing the markup has limited positive effects and only matters when the allowed markup is null or really low. Above the value that makes participation rational for enough bidders, further increases in the markup do not give any additional gains in participation rates.

Interesting, and to some degree unexpected, is the finding that participation rates are also low for the exogenous reference price format (81.8%). As discussed in the bidding behavior section, although there is no price cap that "forces" low cost bidders to win the auction, here again bidders observe a clear signal of their near null chances of winning and opt out (see Figure 2, bottom left panel). As explained previously when we discussed the predicted equilibrium, bidders that cannot attain an equilibrium score value loose the auction with near certainty. Those bidders, therefore, have a much higher tendency to opt out of the auction.

These points provide an additional insight for the redesign of the CRP: designing an auction where the information available to the bidder is not fully informative of his winning chances could, in some cases, be beneficial to encourage participation. In fact, that is the virtue of the last format: the endogenous reference price (EndoRP). In the EndoRP, bidders do not have a clear signal of their chances of winning (their exact score will depend on what other similar bidders do) and so they opt-in more often. See in Figure 2 (bottom right panel) that the EndoRP format has in fact the slowest decline of participation in cost. As a consequence, on average, this format has the highest participation rate: 90.8%.

These results are confirmed by our regression analysis reported in Table 3. Statistically, participation rates of all formats are equal, except for the endogenous reference price format that exhibits 8.2% (10.5% for Period>5) higher participation rates than in TPC. This finding is robust to a series of different specifications. Further analysis on the participation decisions (detailed in the Appendix) confirms that very tight caps in TPC (allowing profits of one or zero ECUs) lead to much higher non-participation rates. Also we see than in both price cap formats the participation rates decline after the fifth period. This is consistent with the idea that processing the bidding strategy is slightly costly and therefore when the chances of winning are sufficiently slim it is optimal to opt out.

Table 3: Participation Decisions – Probit Regression – Marginal Effects

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
RPC	0.0101 (0.0150)	0.0040 (0.0135)	0.0040 (0.0134)	-0.0016 (0.0129)	-0.0030 (0.01561)
ExogRP	0.0059 (0.0139)	0.0072 (0.0126)	0.0066 (0.0126)	0.0005 (0.0121)	0.0172 (0.0145)
EndoRP	0.0897*** (0.0120)	0.0882*** (0.0112)	0.0874*** (0.0111)	0.0825*** (0.0106)	0.1050*** (0.0127)
Cost		-0.0053*** (0.0002)	-0.0053*** (0.0002)	-0.0054*** (0.0002)	-0.0060*** (0.0002)
Controls for Individual Draw	NO	NO	YES	YES	YES
Controls for Period	NO	NO	NO	YES	YES
Only Period > 5	NO	NO	NO	NO	YES
Test: RPC = ExoRP prob > |t|	0.7671	0.7910	0.8313	0.8631	0.1624
Test: RPC = EndoRP prob > |t|	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
Test: ExoRP = EndoRP prob > |t|	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
Baseline probability	0.8235	0.8565	0.8576	0.8384	0.8294
Obs.	6720	6720	6720	6720	4800

All marginal effects are calcuaFor columns 2 through 5, baseline probability is for Cost = 55. All regressions include session fixed effects.

Bidding Behavior

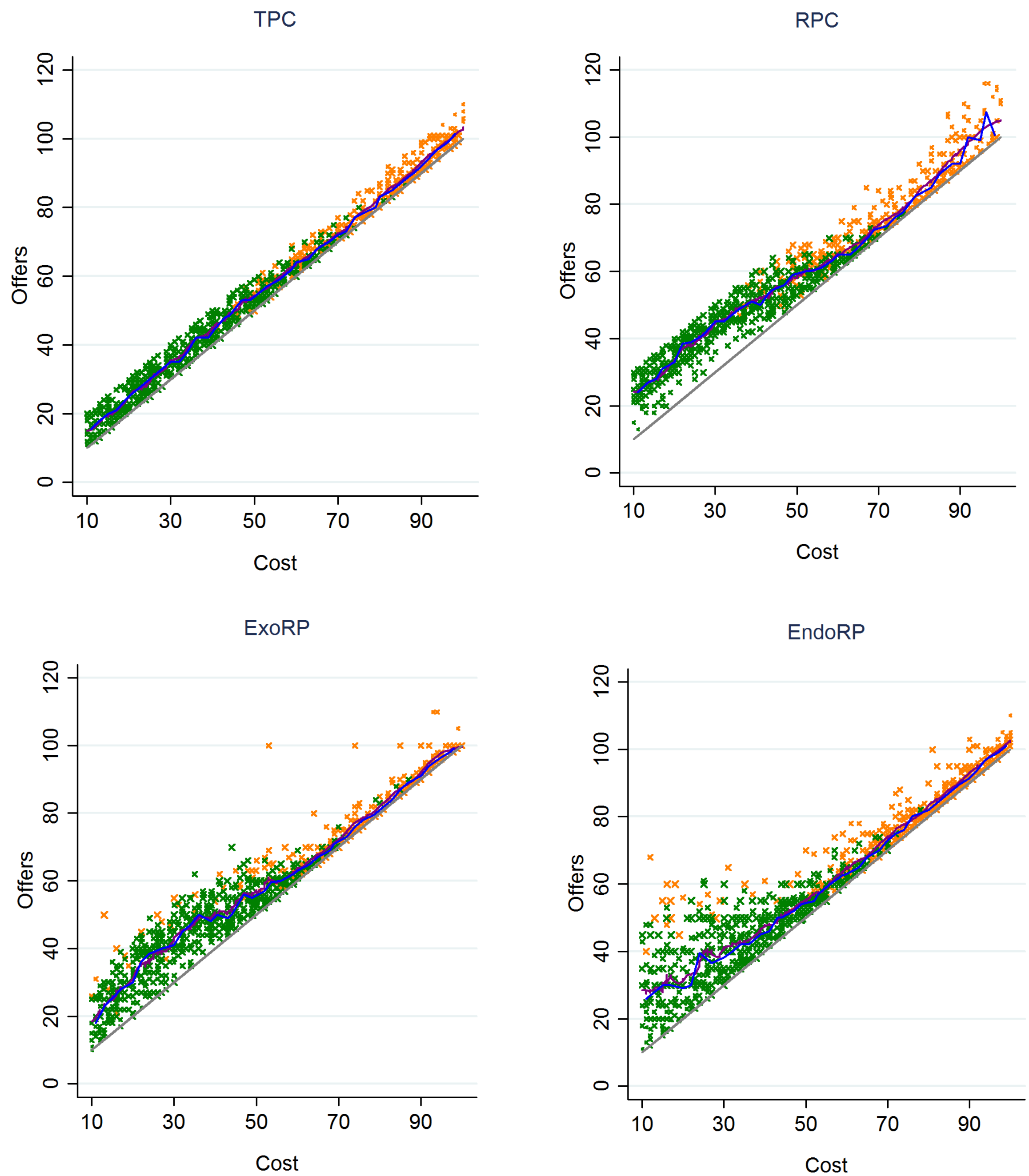
Observed behavior follows the patterns of theoretical predictions for the cap formats as well as for the exogenous reference price auction. The predicted bidding behavior in price cap formats states that the bidding function is based on a latent function $\tilde{b}(c_i)$ that determines the offer, except when the cap is binding ($cap_i < \tilde{b}(c_i)$) or when the latent bid is unprofitable ($\tilde{b}(c_i) < c_i$).[18] These patterns are observed in the laboratory. The two top panels of Figure 4 show bidding data from TPC and RPC. Indeed, low-cost bidders ($c_i \leq 40$) nearly always participate if their cap allows for profit and submit bids equal to their corresponding caps (71% in TPC and 70% RPC). And high-cost bidders ($c_i \geq 70$) either opted out or submitted bids with near null potential profits (2 ECUs or less) (72.5% in TPC and 69.1% RPC). Behavior for bidders with costs between the binding-cap and null-profit thresholds do follow the equilibrium pattern as well. The estimation of the latent bidding function (α and β coefficients) for TPC and RPC are reported in the Appendix. Consistent with equilibrium behavior, winning bids are much higher under RPC compared to TPC (p-value < 0.0001).

Observed bidding in the exogenous reference price (ExogRP) seems to follow predicted equilibrium too. Typical bidders in this format submit a bid that implies a score value of k if such value is attainable given their cost and reference price (the equilibrium value of k for our lab specification is 2.103). If that score value is not attainable given their realized cost and reference price, they either opt out of the auction, bid their cost or attempt a rather small markup (80.3% of bidders with $c_i \geq 70$ opt out of the auction or bid for a profit of 2 ECUs or less). This score pattern can be seen in the left panel of Figure 5 that plots score and cost data: average scores for bidders with $c_i \leq 50$ is flat around 2.06, and increasing for higher costs. Similarly, offers show a pattern congruent with the predicted behavior: $b(c_i, \epsilon_i) = \max\{\, k(c_i + \epsilon_i) - (c_i + \epsilon_i)^2/50\,, c_i\}$. Bidding data, displayed in the bottom-left panel of Figure 4, shows that winning offers are indeed concave in costs up to a cost threshold, as predicted. The non-parametric estimates of the conditional mean and median depicted alongside with the data show this concavity. Again, high-cost bidders exit the auction or submit bids that are close to their cost. The empirical estimate of k using simple

[18] See subsection of Auction Formats above for predicted equilibrium bidding.

non-linear least squares on our laboratory data is 2.059 (s.e. 0.0053). That is, observed data closely follows theoretical predictions.

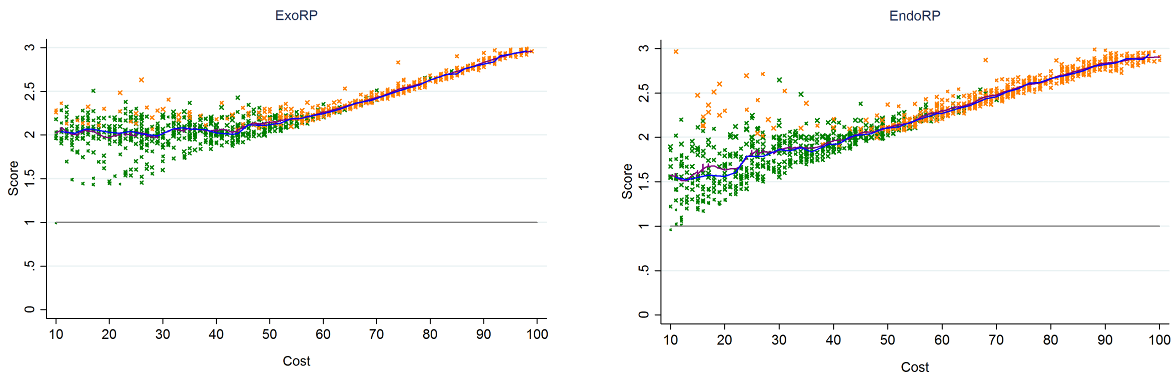
Figure 4: Data on Bidding Behavior



Note: green (orange) stars denote winning (losing) offers. Blue and purple lines depict a non-parametric estimation conditional mean and median, respectively.

Bidding behavior in the endogenous reference price is rather different than in the exogenous reference price. As expected, without information on their reference price (or scores), bidders focused more on making competitive offers. Compared to ExogRP, winning bids in EndoRP are lower (p-value < 0.001). Score behavior does not follow a flat pattern for low-cost bidders as it did for the exogenous reference price format (see bottom-right panel of Figure 5). Average score of winning bidders is 1.84, as opposed to 2.05 in the ExogRP format.

Figure 5: Score Behavior in Reference Price Formats



Note: green (orange) stars denote winning (losing) offers. Blue and purple lines depict a non-parametric estimation of conditional mean and median, respectively.

Efficiency and Cost Effectiveness

To measure allocation efficiency of the different formats, we define an object-level efficiency indicator that takes value of 1 for bidder i sells (does not sell) the object when i is (is not) among the eight lowest costs bidders in the market; and the indicator takes value 0 otherwise. A perfectly efficient format will buy from bidder i if and only if i is among the eight lowest cost bidders. So this indicator, on average, will be equal to one, always. This allocation efficiency index is reported in Table 2. In this metric, TPC and RPC formats perform similarly well (91.7% and 92.7%, respectively) and significantly better than the exogenous reference price (87.5%). The endogenous reference price (91.2%) performs as well as the price cap formats and clearly outperforms the exogenous reference price. Regression analyses that control for session and period effects are reported in Table 4 and confirm the result: all treatments perform equivalently, except ExogRP which underperforms all the other three. Although EndoRP seem to outperform RPC, this result is not robust to the exclusion of data from the first five periods.

In sum, i) in terms allocative efficiency the endogenous reference price performs are good as the ideal price cap (TPC) format; ii) relaxing price cap does not hurt allocative efficiency compared to the ideal price cap (TPC); iii) the exogenous reference price does worse than all the other studied formats. We discuss in the following subsection the sources of ExogRP underperformance in terms of allocative efficiency.

To study the cost-effectiveness of the different formats, we use a measure of "over cost" that measures the actual payments relative to the efficient payment ($\mathrm{OverCost} = \mathrm{ActualPayment}/\mathrm{EfficientPayment} - 1$). This measure compares the actual cost of achieving the desired purchase level (eight objects in the lab; enrolling a target size of land in real life) to the efficient payment; where the efficient payment is what the buyer (program) would have paid had it have full information on bidder's costs.

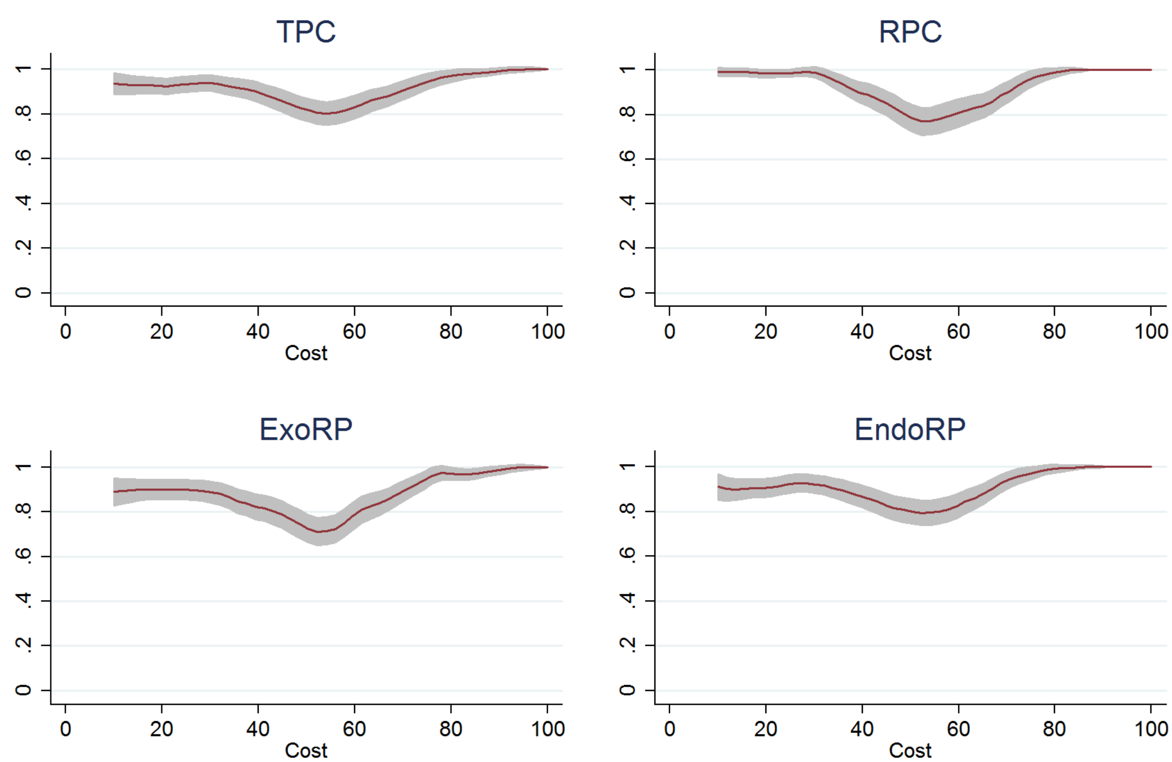
Table 4: Regression Analysis – Efficiency and Cost-Effectiveness

	Parcel-Level Efficiency (Probit – Marg. Effects)		**Auction-Level Over Cost** (Random Effects Model)	
	All Periods	Period > 5	All Periods	Period > 5
A2: Relaxed price cap	0.00404	0.00939	0.173***	0.162***
	(0.00884)	(0.0110)	(0.0294)	(0.0287)
A3: Exog. Ref Price	-0.0458***	-0.0411***	0.167***	0.172***
	(0.0100)	(0.0124)	(0.0323)	(0.0387)
A4: Endo. Ref Price	-0.0114	-0.00429	0.121***	0.131***
	(0.00921)	(0.0113)	(0.0371)	(0.0423)
Test: A2 = A3 prob > |t|	0.0000	0.0000	0.8408	0.7312
Test: A2 = A4 prob > |t|	0.0486	0.1212	0.0189	0.1981
Test: A3 = A4 prob > |t|	0.0008	0.0029	0.0475	0.1375
Controls for Cost	Yes	Yes	N/A	N/A
Controls for Period	Yes	Yes	Yes	Yes
N	6720	4800	420	300

Note: Comparison group is Auction 1: Tight Price Cap.
Standard errors in parentheses.
Significance levels: * 0.10 ** 0.05 *** 0.01

In terms of over costs, the tight price cap format performs best with an over cost of 18.3% while the loose price cap format performs worst with an over costs of 37.6%. It is important to note that although RPC performs highly in terms of allocative efficiency (comparably to the TPC), it performs rather poorly in terms of cost effectiveness. This is mainly because low-cost bidders in RPC are allowed to extract high rents without altering their chances of winning. Exogenous reference price (35.1%) perform slightly better than the loose price cap. The endogenous reference price auction exhibits an over cost of 30.8%, the second best after to TPC and outperforming RPC and ExoRP. Our regression analysis reported in the last two columns of Table 4 confirms this ordering.

Figure 6: Probability of being in the efficient allocation at different cost levels



Note: Local polynomial regressions and 95% confidence intervals.

It is important to further explore the sources of inefficiency in the ExogRP format. As figure 6 shows, this format performs all the other formats in the efficient allocation medium and low cost bidders. This is driven mainly because of the flat region of score behavior described previously. As predicted, in a typical auction of this format, there are on average eight bidders with the same score k, but quite often there are more than eight. Since ties are broken randomly, in many of such cases the buyer ends up selecting high cost bidders. This pattern can be observed in the bottom left panel of Figure 6. On the other hand, the EndoRP format is highly efficient because uncertainty in the final score gives bidders the incentive to focus on competitive offers. This causes the score behavior to be highly monotonic in cost. As it can be observed in the top left and bottom right panels of Figure 6, the efficiency pattern of TPC (in a sense our efficiency benchmark) and EndoRP are quite similar.

5.2. Robustness Treatments

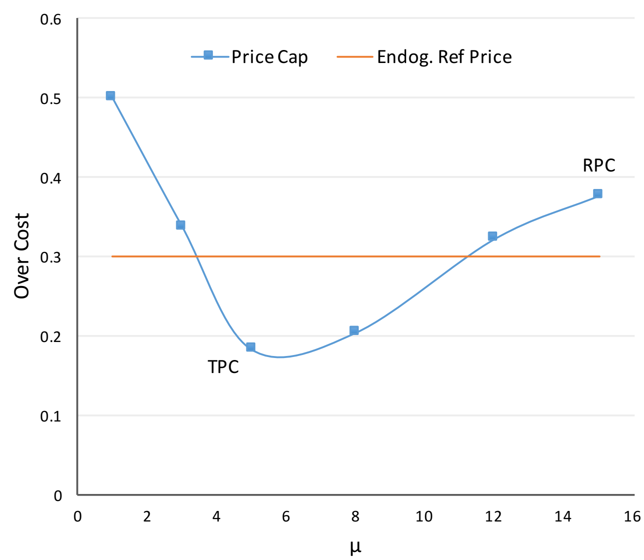
[placeholder]

6. Market Design Trade-Offs

Our laboratory exercise has provided relevant insights on the properties of different formats when implemented with actual bidders. The first, although expected, insight is that price cap can be an effective way to reduce costs if (i) information about SRRs is either of high quality or at least the properties and imprecision of these measures are well understood; and (ii) the Program is willing and able to adjust the allowed average markup (μ in this equation: $Cap_i = \widehat{c_i} + \mu$). Figure 6 shows how vulnerable this format is to changes in μ. This calculation is based on a small set of auxiliary sessions where we varied the tightness of the cap, μ. TCP ($\mu = 5$) and RPC ($\mu = 15$) are also displayed in the Figure. On the vertical axis we display the measure of over cost. As discussed previously, if μ is too small inefficient non-participation causes substantial over cost. On the other hand, after an optimal level in the vicinity of 4 to 6, loosening the cap only causes higher rents and over cost grows rapidly again. This format is also vulnerable to bias in estimation of $\widehat{c_i}$ (which would result in an unintended displacement of μ) and in the variance of such estimate (which would increase the chances of inefficient non participation at the same time that increases the rents of winning bidders – both hurting cost effectiveness.

If the estimates of the SRRs are sufficiently imprecise, it might be appropriate to rely on a format that is more robust to information imperfections. Such format seems to be the endogenous reference price. The EndoRP auction is, in theory, invariant to (flat) bias in cost estimates and it is less impacted by the variance of such estimates. Figure 6 depicts the level of over cost for the EndoRP format as found in our laboratory exercise. This figure shows that outside an optimal region [3>μ>11] the EndoRP performs better in terms of cost effectiveness. This area, however, will shrink if the cost estimates are less precise.

Figure 6 [7?]: Over Cost and Price Cap Tightness



7. Conclusions

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We find that once the price cap is minimally profitable, relaxing the cap further does not increase participation or price competition. Therefore, cost-effectiveness is hurt. The exogenous reference price format generates a behavior by which all low and medium cost bidders target the same score value. This implies that the buyer picks a costly set of sellers more frequently than in other auctions, causing this format to perform worst in terms of cost-efficiency. The endogenous reference price, on the other hand, promotes higher participation and price competition by not providing a clear signal of the chances of winning. As a result, this format performs satisfactorily in terms of cost-effectiveness.

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8. References

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