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When can lotteries improve public procurement processes?

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When can lotteries improve public procurement processes?*

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Abstract:

We study the feasibility, challenges, and potential benefits of adding a lottery component to standard negotiated and rule-based procurement procedures. For negotiated procedures, we introduce a "discrete lottery" in which local bureaucrats negotiate with a small number of selected bidders and a lottery decides who is awarded the contract. We show that the discrete lottery performs better than a standard negotiated procedure when the pool of firms to choose from is large and corruption is high. For rule-based auction procedures, we introduce a "third-price lottery" in which the two highest bidders are selected with equal probability and the project is contracted at a price corresponding to the third highest bid. We show that the third-price lottery reduces the risks from limited liability and renegotiation. It performs better than a standard second-price or ascending auction when the suppliers' pool size, the risk of cost overrun, delays and non-delivery of the project are high. The choice between a second-price auction, a third price lottery and a lottery amongst all bidders also depends on the weight placed on producer surplus, including for instance the desire to increase the participation of local SMEs in public sector services markets.

Keywords: rules, discretion, procurement, lotteries, corruption, auctions

JEL: D44, D73, H57

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1. Introduction

For Procurement Agencies (PA), identifying and selecting the right contractor to deliver the goods and services expected to meet needs ranging from basic (surgical masks, roads, water pumps,…) to sophisticated (medication, planes, nuclear plants…) keeps being more of a challenge in practice than procurement theory may suggest. The long record of related empirical literature provides detailed evidence on recurring outcome weaknesses such as cost overruns or mistargeting of quality. There is thus a case for improving common (and popular) procurement procedures.

Simplifying somewhat, PA around the world usually pick between two main approaches: (i) *discrete* and (ii) *rule-based* procedures. Direct negotiations between a selected firm and a local bureaucrat are an example of the former. In practice, local bureaucrats and politicians use their specific knowledge of the region and project characteristics to select the most suitable bidder and agree on a way to cover their costs. Auctions in which firms bid to offer discounts over a reserve price to deliver a project are a prime example of the latter.[4]

Somewhere, from the design to the implementation stages, the selection processes under either approach often seem to fail, as evidenced by the number of dysfunctional contract renegotiations (Guasch, 2004; Guasch et al., 2017; Beuve et al. , 2018), and the large number of cases in which cost overruns tend to be the norm rather than the exception (Flyvbjerg et al., 2018). The debates on the extent to which these outcomes are the results of project design defects, incompetence of the implementation agencies or simply corruption are recurring topics in academic research and in international agencies (Bandiera, Prat & Valletti, 2009 ; Estache & Iimi, 2011; OECD 2016; Estache & Foucart, 2018; Fazekas & Blum, 2021). [5]

This paper suggests that, in environments characterized by various types of governance weaknesses and when the potential pool of contractors to pick from is large enough, adding a lottery component in the selection processes may help related issues including corruption and default risks. These benefits involve a trade-off however. They always come at the cost of allocating the contract to a firm that is, on expectation, less cost-efficient.

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[4] See for instance Bajari et al. (2009) for a detailed comparison.

[5] The negative image associated with renegotiation has recently been challenged by Beuve and Saussier (2021) in their study of the French parking sector.

The novelty of our approach is to focus on simple procedures, combining features from standard processes and lotteries. While the main trade-off between complete randomization and rule-based procedure has already been established in different contexts (Chillemi and Mezzetti; 2011; Burguet et al., 2012; Decarolis, 2018), our results show that hybrid procedures can often perform better than those polar cases.

This conclusion holds whether the PA's preferred procedure is discrete or rule-based. In the case of discrete procedures, we show that adding a final lottery stage amongst a subset of selected bidders – a procedure we call "discrete lottery" - lowers the risk of corruption. In rule-based procedures, we propose a "third-price lottery" in which the two highest bidders are selected with equal probability and deliver at a price corresponding to the third highest bid. This procedure decreases the risk of default and renegotiation while remaining more efficient in selecting low-cost firms than standard lotteries. Third-price lotteries offer an alternative to the widespread basic first price auctions observed in procurement processes involving large public goods and service, including those that can be unbundled into smaller projects (Hortaçsu and Perrigne, 2021), and to the kind of "English" auctions typically used in e-procurement.

The evidence on the margin to improve on standard rule and price based procedures, with somewhat discretionary complements has been available for some time, in particular for the delivery of infrastructures. In the transport sector for instance, rule-based procedure that do not directly aim at selecting the highest or lowest bidder have been followed since the 1990s in a wide range of countries (Asian Development Bank, 2018).

A popular example among practitioners concerns routine rehabilitation and maintenance projects. CREMA contracts (Contratos de Reabilitacao e Manutencao in Brazil or Contratos para Rehabilitacion y Mantenimiento in the rest of Latin America, i.e. Rehabilitation and Maintenance Contracts) adopted since the late 1990s in Latin America have been delivering very positive outcomes in terms of efficiency and other performance measures.[6] They require firms to maintain relatively short stretches (30 to 50km) of roads usually for a period of 3 to

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[6] ADB (2018) provides an overview of the evidence comparing CREMA to alternative procurement processes and Pérez et al. (2020) for an econometric evaluation on the Uriguyan experience.

5 years.[7] What makes them stand out in the procurement processes of the sector is that contractors selection can be based both on both price and non-price criteria (Stankevich et al., 2009). The scores associated with these criteria can be weighted to reflect policy preferences, an approach we discuss further in Section 5.5. Bidders can be either pre-qualified or post-qualified and short-listed based on the joint evaluation of technical and cost dimensions. In practice, the pragmatic "best value" approach in selecting a winner has often delivered better and more sustainable road maintenance than standard "low bid" approaches because it did a better job at accounting for multiple dimensions, including various market and management characteristics of the sector.

The challenge is, however, still to minimize rather than simply reducing the efficiency cost of the institutional weaknesses characterizing each country and each market in which the procurement process is implemented. Despite their impressive achievements, this is a dimension that CREMAs have not always fully internalized. And this is where the lotteries discussed here could make a difference.

Section 2 briefly reviews the attractive and less attractive characteristics of standard procurement practices, describe our main results and explain their place in the literature. Section 3 explains how lotteries could maintain the attractive characteristics of discrete procedures while minimizing the risks of corruption. Section 4 does the same in the case of auctions (rule-based selection), in which lotteries help minimizing the costs stemming from the winner's curse and limited liability. Section 5 discusses the main practical implications of the conceptual modelling of sections 3 and 4. We conclude in Section 6.

2. **The good and the bad things about standard procurement practices**

In this section, we build on the collective knowledge on the advantages and disadvantages of standard public procurement practices when common institutional weaknesses identified by the literature are accounted for such as corruption or default risks. This discussion allows us

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[7] Lancelot, 2010, offers a detailed description of the Brazilian experience

to provide a first intuition on the potential payoffs to rely on lotteries to award certain types of contracts.

2.1 Discrete procedures vs Lotteries.

The main advantage of discrete procedures is to leverage the knowledge of local bureaucrats. In a negotiation for instance, they are ideally qualified to identify the best suppliers because they may have superior information over the actual cost and characteristics of a project and/or a better understanding of the firms bidding on the market. They are therefore often more capable to directly select the best firm and commit to reimbursing their costs with a mark-up (the so-called “cost-plus contracts”), without taking the risk of the firm defaulting. Moreover, since empirical evidence suggests that discretion in some cases empowers bureaucrats (Bandiera et al. 2021), the approach can lead these actors to devote more effort to their work, ultimately reducing the cost of the delivered projects.

The main risk with a discretionary procedure is corruption: the more direct power the law puts into the hands of local bureaucrats in a weak governance and accountability context, the higher the returns for a private firm corrupting them. When this is a concern, adding a final lottery stage to the procedure allows reducing the marginal benefit from corruption. Intuitively, this would work as follows in the simplest situation: a local bureaucrat selects two firms, and a lottery picks which of the two gets the contract. The bureaucrat’s knowledge is reflected in the first stage but is ignored in the second one. In other words, adding a lottery comes at the costs of giving up on the ability to use all the information available to the local bureaucrats.

Thus, whether the lottery is desirable or not depends on the assessment of the relative importance of the risks of corruption and those associated with the information loss. The challenge is to be able to inform the drivers of this trade-off between efficiency costs and corruption costs. In Section 3, we show that a key parameter to minimize the efficiency costs is the number of bidders: if the pool of potential applicants is high, the efficiency cost of possibly ending up with the second best offer to avoid corruption is likely to be less important than if the pool is of limited size.

2.2 Auction Vs Lotteries

The main advantages of rule-based procedures are transparency and information revelation: corruption is less likely when the selection criteria are clear, and an auction process leads bidders to reveal some information about their true cost. An important drawback (see for instance Decarolis, 2014) stems from the risk of default from the winner, either due to the "winner's curse" (by offering the highest bid, the winning firm discovers it overestimated the value of the project) or limited liability (the winning firm bids too aggressively, knowing that it will not deliver if the costs are too high).

In that context, adding a lottery stage allows screening away some firms more likely to default, as those are bidding more aggressively and are thus more likely – all other things held equal – to offer the best bid. However, this gain comes at the cost of losing some of the information benefits from running an auction.

In section 4, we show conceptually that lotteries are desirable when the risk of default or renegotiation by the winning firm is high. Intuitively, lotteries reduce the benefits from being the highest bidder. As the firms who bear the lowest cost from renegotiating or even defaulting are also more likely to bid aggressively, a lottery allows the PA to award fewer contracts to them. Lotteries are also more useful when the PA puts a sufficiently high weight on the producer surplus. One advantage of auctions over lotteries is to reduce prices and reduce the profit margin of the firms. A PA who wants to support the development of local SMEs in a context in which they compete with more experienced large international suppliers should be less worried about it than one focusing on getting the lowest possible price.

Depending on how important the cost heterogeneity among firms is, the lottery can be among all firms passing a pre-qualification stage for the project, or among a subset of the highest bidders. As an example of the latter, we introduce a "third-price lottery" auction: one of the two top bidders is selected at random and delivers the projects at the discount level corresponding to the third highest bid. In this auction, all firms bid their true willingness to bid. We then use this result to compare it to a standard second-price (or English) auction.

2.3 The link with trade-offs documented in the literature

The trade-offs we identify relate to the recent literature on rules vs. discretion in procurement (Coviello, Guglielmo & Spagnolo, 2018 ; Bosio et al., 2020). These authors find that while discretion would be preferable in a country with high-quality institutions, the risk of corruption makes the use of rules preferable in parts of the world with a lower quality of institutions. One reason that makes lottery procedures attractive is that they alleviate some of the main drawbacks of each procedure (always at a cost), and may increase the scope for using each of them.

The history of explicit lotteries in procurement design is very limited. Uruguay is the only one country we are aware of having carried a large-scale effort to implement a random allocation procedure: the *menor cuantia.* It applied to the procurement of relatively small public works, and all firms passing a pre-qualification phase had the same probability of being selected by a centralized algorithm. Fadic (2020) studies this project, focusing on its main stated objective of promoting the growth of local SME.

This goal is related to our finding in this paper that a complete lottery should only be a tool for a government putting a high value on producer surplus. In this specific case study, the author finds that, indeed, lotteries provide a short-term gain for the winning firms. However, this gain does not translate into a measurable long run benefit such as higher growth revenue or current assets. One thing that might have hindered that potential long run benefit is that all firms had the same probability of winning the contract, regardless of their costs. In the third-price lottery procedure we suggest, the lottery is combined with some sort of selection to ensure that the selected firm is amongst the most cost efficient.

While we are not aware of other explicit lottery procedures, a type of auction in which all firms are selected at random and pay the reserve price - the Average Bid Auction (ABA) – comes close. Indeed, while, in practice, ABAs are equivalent to a lottery, this property is never stated explicitly. The ABA is present in public procurement procedures in Chile, China, Colombia, Italy, Japan, Peru, Switzerland or Taiwan among others. In the US, it has been used in the past by the Florida DoT and the New-York State procurement agency (Decarolis, 2018).

Under one variant of the ABA procedure (there are many), all firms bid on discounts over a reserve price. Then, the firm whose bid is closest to the average is selected and delivers the project using the price defined by her own bid. As shown by Decarolis (2018), such procedures are in practice random. They also lead to very high prices: most of the ABA procedures and in particular the one used in Italy, offer firms incentives to bid at the reserve price.

To see the logic, assume a reserve price V and $N > 2$ firms. Assume all firms bid a discount of exactly *0*. In that case, all firms are selected with equal probability $1/N$ and deliver the project at the highest possible price *V.* Now, imagine that a firm *i* acts differently and offers a discount equal to $b_i > 0$. This firm is selected with probability zero since its bid will then be the furthest away from the average, the selection criteria under an ABA procedure. Hence, there is no incentive for anyone to bid more than the minimum.

Decarolis (2018) shows, using data from Italy, that this is what firms actually do. The results we find in Section 4 relate closely to one of the main tradeoffs identified by Decarolis (2018): the ABA can be desirable to the extent that it limits renegotiation and the risk of default. However, it comes at a high cost in terms of allocative efficiency (all firms win with the same probability) and consumer surplus (all firms charge the reserve price). We will show that our third-price lottery procedure allows finding an intermediary path into the two extremes of auctions with a high risk of default and lotteries or ABAs with a low surplus for the consumer.

3. Discretion

In this section, we present a simple model comparing a discrete procedure, a lottery, and an intermediary procedure combining both. We assume all our procedures to apply only to those firms passing the pre-qualification stage. We do not formally model this stage and make the assumption to allow reducing the pool of applicant only to those able to technically deliver the project.

Our discrete procedure works as follows. The PA delegates to a local bureaucrat with private knowledge of the firms the power to select the most efficient one and reimburse their costs using a “cost-plus” contract where we assume for simplicity the firm mark-up to be zero. There is no risk of default: the true cost is known and observed by the local bureaucrat and the selected firm. The main drawback is that there is a moral hazard problem between the local bureaucrat and the PA. Discretion leaves some room for corruption: the local bureaucrat and the firm could agree on a contract allowing them to report a higher cost than what is necessary and share the surplus.

As we assume cost-plus contracts, all legally acquired surplus of the firm is constant regardless of the cost (and, in our setup, equal to zero). We make the further assumption that the PA does not put any value on the surplus stemming from corruption, be it ultimately extracted by the firm or by the local bureaucrat. Hence, any weight the PA puts on legally acquired consumer surplus is irrelevant to the ranking of procedures. The objective of the PA in our discrete procedures is thus simply to minimize the cost it pays to the contracting firm.

There are N firms competing to procure a project of value V to the consumers. A firm *i* has a private cost of delivering the project c_i taken from a continuous log-concave distribution with density $f(x)$ over the interval $[l, h]$. This cost corresponds to what happens in the good state of the world. However, there is a probability θ that the state of the world is bad, in which case the firm bears an additional cost $D > 0$. The assumption of log-concavity is satisfied by most commonly used density functions (see Caplin and Nalebuff, 1991 and Anderson and Renault, 1999), and we need it to ensure that the presence of more participants to the auction decreases the expected difference between the lowest and the second-lowest cost amongst the participating firms.

3.1 The discrete procedure

The first procedure is fully discretionary. The local bureaucrat selects the firms with the lowest costs in the good state, denoted $c_{(1,N)}$. With probability $1 - \sigma$, there is no possibility of corruption, and the bureaucrat reimburses this cost plus the additional cost in case the state of the world is bad, an expected reimbursement of $c_{(1,N)} + \theta D$. Moreover, with an exogenous probability σ, the local bureaucrat and the firm enter a corruption pact in which costs are overestimated to always correspond to the worst-case scenario, so that D is repaid even when the state of the world is good, an expected reimbursement of $c_{(1,N)} + D$.

This form of corruption corresponds to the idea studied in Estache and Foucart (2018) that it is often difficult for an outsider to distinguish corruption from bad luck and incompetence, and that local bureaucrats and private firms can exploit this information asymmetry to extract a rent. Hence, it is possible for the bureaucrat and the firm to agree to report a high cost in the good state of the world, and to pocket the difference. As the bureaucrat has the power to select a firm, she could for instance make this selection conditional to a bribe corresponding to a share of this extra cost.

A first key assumption we make is that a corruption pact is agreed at the selection stage, when the cost-plus contract is written. After the firm is selected, we do not allow for further corruption. Relaxing this assumption would mean that corruption happens in all configurations, regardless of how the firm is selected. A second key assumption is that the local bureaucrat always selects the firm with the lowest cost. The bureaucrat maximizing consumer welfare, conditional on extracting rents from corruption, is consistent with this assumption. It could also correspond to the fact that it is easier to conceal higher costs due to corruption when the baseline is low. Relaxing that assumption would imply that the benefits from using the knowledge of a local bureaucrat disappear, and hence the extent to which a discrete procedure can be desirable in the first place.

In such a discrete procedure relying on a simple costs-plus contract, the expected surplus for the PA is therefore equal to

$$S_{d,s} = V - E\left(c_{(1,N)}\right) - \theta D - \sigma(1-\theta)D.$$

where V is the value of the project to the PA. The term $E\left(c_{(1,N)}\right)$ corresponds to the expected value of the first order statistic of the distribution of costs. The term D corresponds to the extra cost to the firm in case the state of the world is bad, with probability θ. The last term, $\sigma(1-\theta)D$, corresponds to the extra cost of corruption. It is decreasing in: (i) how often a corruption pact is possible σ and how important the additional cost is in case the state of the world is bad, D. It is also decreasing in how likely it is the high cost would have happened even in the absence of corruption pact θ.

The main tradeoff is thus that a discrete procedure allows selecting the best possible firm, at the risk of this efficiency gain being captured by the firm and local bureaucrat in the form of corruption.

3.2 The standard lottery

A first alternative to the discrete procedure is a standard lottery. In this approach, all the firms who passed the pre-qualification phase are selected with equal probability by a random draw to deliver the project under a costs-plus contract. In that case, the principal bypasses the local bureaucrat, and reimburses the actual cost incurred by the selected firm. Hence, since the procedure does not select the most cost efficient firm, the expected surplus of the PA is equal to

$$S_{d,l} = V - E(c_i) - \theta D.$$

The trade-off between discretion and lottery is thus that the latter solves the moral hazard problem of corruption observed in the discrete procedure. Avoiding corruption comes at the cost of increasing the adverse selection problem due to the firms having private knowledge of their expected cost, and the PA being unable to select the most efficient.

3.3 The discrete lottery

We suggest the following alternative to the standard lottery: the rule becomes that the PA asks the local bureaucrat to select the two most cost-efficient firms to benefit from his/her knowledge of the project. Then, a third party is asked to operate a lottery to select the winning bid out of those two. We label this a "discrete lottery".

We argue that this procedure should be sufficient to avoid the kind of corruption described in the basic discrete procedure presented earlier. Indeed, we study corrupt practices in which a firm pays or commit to pay a local bureaucrat in exchange for getting the contract. Such a corruption pact relies on making sure that all participants benefit from it. It would be too risky for the local bureaucrat to receive a bribe or commit to receiving a bribe from a firm who, after not being awarded the contract in the lottery stage, would have all the incentives to denounce corruption. Hence, corruption is not feasible.

In that procedure, the expected surplus of the PA is therefore equal to

$$S_{d,dl} = V - \frac{E\left(c_{(1,N)}\right) + E\left(c_{(2,N)}\right)}{2} - \theta D,$$

Where $\frac{E\left(c_{(1,N)}\right)+E\left(c_{(2,N)}\right)}{2}$ is the expected value of the average between the first and second order statistic of the distribution of costs amongst N participants.

3.4 Comparing procedures

Ranking the last two procedures in terms of the surplus they generate, we immediately see that $S_{d,dl}$>$S_{d,l}$for all values of the parameters. As neither the standard lottery nor the discrete lottery involves corruption, it is indeed never in the interest of the PA to run a full lottery and loose the benefit from the (partial) selection made by the local bureaucrat as they is nothing to gain in terms of reducing corruption.

Whether a discrete lottery yields higher surplus than a discrete procedure depends on whether the efficiency gain from awarding the contract to the firm with the lowest cost with certainty is higher than the cost of corruption.

Proposition 1. The expected surplus of the PA is higher under a discrete lottery than under a discrete procedure if and only if:

$$\sigma(1-\theta)D > \frac{E\left(c_{(2,N)}\right) - E\left(c_{(1,N)}\right)}{2},$$

where the right-hand side decreases with the number of bidders *N.*

The formal proof is in the Appendix. This expression simplifies in the uniform case with *l=0* and *h=1* to

$$\sigma(1-\theta)D > \frac{1}{2(N+1)}.$$

On the left-hand side is the additional cost from the moral hazard problem in the presence of corruption. On the right-hand side, the additional cost from the asymmetric information problem when the local knowledge of the bureaucrat is not fully exploited. A key parameter for the latter is thus the number of pre-qualified bidders N: if the PA manages to attract a sufficiently large pool of applicants, the risk of having to work with the firm with the second lowest cost instead of the lowest one is low. This risk is however much higher if the number of competing firms is limited.

4. Rules (auctions)

In this section, we compare a second-price auction, a lottery, and a novel intermediary procedure combining both, the “third price lottery.”

Most procurement auctions either use first-price sealed bid auctions or “English” ascending auctions in which sellers are free to increase their bids – expressed as discounts on a reserve price. Such auctions often come in the form of e-procurement in which the procedure happens on an online platform. In our context, a sealed-bid second price auction is equivalent to an English auction, as each seller knows her own cost (Milgrom & Weber, 1982). We use the second-price setting for expositional clarity, but all our results translate directly into the English auction setting.

4.1 Preliminaries

A procurement agency may sometimes prefer sealed-bid auctions for practical reasons, as they involve a single bid by all sellers. One concern with such auctions however is that sellers need to trust the procurement agency. An English auction does not have that problem, as bidders do not need to reveal the maximum they were willing to pay.

The trade-off we identify between the lottery and the auction procedure is similar to Decarolis (2018), who compares first-price and average-bid auctions. As our novel procedure combines features of the lottery and of the second-price auction, we focus our attention to those two polar cases and refer the reader interested in first-price auction results to Decarolis (2018). As in the previous Section, we assume all our procedures apply only to those firms passing the pre-qualification stage.

As before, firm *i* has a private cost of delivering the project c_i taken from a continuous log-concave distribution with density $f(x)$ over the interval $[l, h]$. With probability θ, the firm bears an additional cost D. The difference with the discrete procedure is that the contract is awarded at a given price, and the costs are only privately observed by the firm. We thus need to look at the incentives for the firm to deliver the project whenever the costs are higher than the contracted price, or whether they are willing to pay the cost of default or the reputation cost of a renegotiation.

In order to do so, we follow Decarolis (2018) and assume each firm has a private cost of bankruptcy (reputation, moral, legal), that is equal to either zero (type *L*) or $\tau > 0$ (type *H*). A firm is characterised by its type $\omega \in \{L, H\}$. A share μ of the firms is of type *H*. Only the firm knows its own type. There is also a cost for society if the project is not delivered because the selected firm has defaulted, needs a bailout or renegotiation. To keep the model tractable, we treat all events in which the winner needs to renegotiate as "defaults/bankruptcy" and assume a social cost equal to T for the consumers in that event. We assume that all firms are risk neutral and maximize their expected surplus.

The key to solve our auction procedures is to compute the maximum willingness to bid of a firm.

We first want to compute the expected payoff of a firm winning the auction and paying a bid b_i (expressed as a discount from the maximum price V, where V is the value of the project for the consumers) in different cases.

The expected surplus of a firm, of either type, who would never default, is:

$$\pi_{H,nd} = \pi_{L,nd} = V - b_i - c_i - \theta D$$

If a firm is of type *H,* it chooses not to default selectively when the state of the world is bad if the cost of default is sufficiently high,

$$\tau \geq D + b_i + c_i - V.$$

We follow Decarolis (2018) and assume this condition is always satisfied: the reputation cost for firms of type *H* is sufficiently high to ensure they always deliver. We however do not assume that a firm of type *L* always defaults, an assumption made by Decarolis (2018) in the context of a First Price Auction. The reason is that we want to keep the possibility for a firm with no reputation concern to deliver when, even in the bad state, their cost remains below the value of the contract. Note that we only look at the bad state of the world when considering a possible default. The reason is that if a firm defaults in the good state of the world, it also has an incentive to do so in the bad state of the world and would therefore make no profit regardless of the bid.

Lemma 1.

a) The maximum willingness to bid of a firm *j* of type *H* and cost c_j is $\overline{b}_{H,j} = V - c_j - \theta D$.

b) The maximum willingness to bid of a firm i of type *L* and cost c_i is $\overline{b}_{L,i} = V - c_i$.

The formal proof is in Appendix A2. The lower willingness to bid of the firm of type *H* comes from the fact that they internalize the risk of being in a bad state of the world, while the type *L* firm knows that in the worst case they always keep the possibility of defaulting and getting zero profit.

Given that this setup allows for the possibility of sellers receiving a rent that does not come from corruption, we also need to look at the objective function of the PA. We assume a function linear in consumer surplus and firm profit (Baron and Myerson, 1982),

$$W = CS + \alpha PS$$

with a weight 1 on consumer surplus and $\alpha \in (0,1)$ on producer surplus.

We consider three possible and easily comparable procedures to illustrate the pros and cons of a lottery in this setting: a second-price auction, a third-price lottery combining an auction with a random procedure, and a standard lottery. We represent these three possibilities in Figure 1. The first column shows the maximum willingness to bid of four firms, A, B, C and D, with A the firm willing to offer the highest discount over the reserve price. We do not consider at this point the type of the firms and simply take these valuations as given.

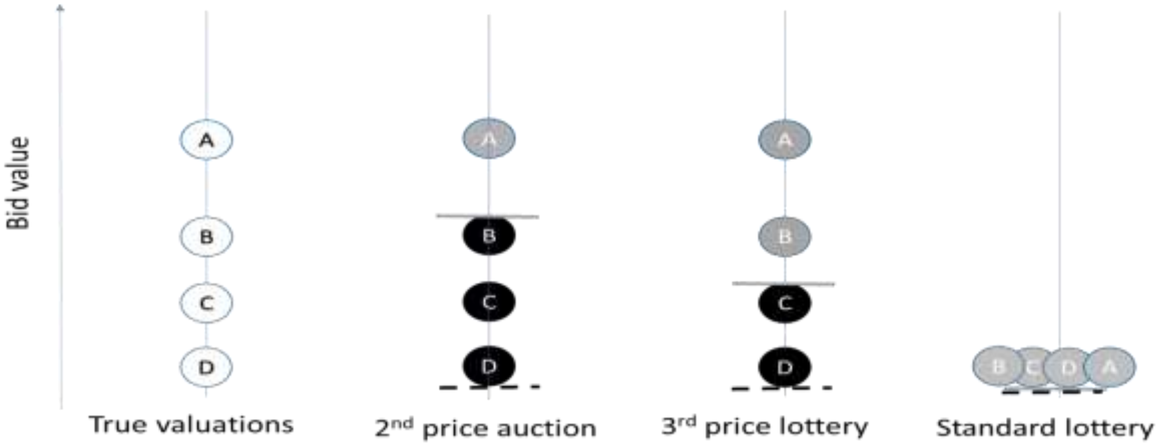

Figure 1: Three different rule-based procedures

4.2 The second-price and English auctions

Our first rule-based procedure is a standard Second Price (“Vickrey”) Auction. Firms submit written bids, without knowing what bids the other firms make. The highest bidder wins but the price paid is the second-highest bid. This auction is equivalent in our setting to the perhaps more familiar “English” auction, in which firms update their offered discounts until no one is willing to offer a higher one.

We illustrate the procedure in the second column of Figure 1. The horizontal (dashed) line at the bottom represents the lowest bid V the PA would accept, corresponding to a discount of zero. The horizontal grey line corresponds to the equilibrium bid at which a contract is agreed.

In this case, it is well known that bidding one’s maximum willingness to bid is a weakly dominant strategy, so that in the unique symmetric Bayesian Nash equilibrium the winner is the firm with the highest willingness to bid (in grey), and the contracted price corresponds to the second highest willingness to bid.

To see this, remember that the winner of the second price auction is the highest bidder, but she only has to pay the second highest bid. It is thus an equilibrium strategy for everyone to state his or her true valuation. For instance, firm A has nothing to gain from increasing or lowering its bid as long as it is above B. And it would lose out by bidding below B and not being selected. B has nothing to gain from increasing her bid below A, as she would still lose, and would lose out by bidding above A, as it would have to deliver the project for with a discount higher than her highest willingness to bid.

To measure the expected consumer surplus and profit of the selected firm, we need not only to look at the distribution of the costs, but also at the distribution of the bids and at the likelihood of default.

The existence of the more aggressive bidders of the low-reputation cost type *L* has the impact of making it more likely that the project does not happen. In such a case, the social cost for the consumer is equal to *T*. However, the existence of aggressive bidders also increases the expected value of the second highest bid, to be paid by the winner. Aggressive bidders guarantee a higher contracted price, but increase the probability that consumer bear the cost of default. In consequence, second-price auctions are more of a problem when *T* is high.

4.3 The third-price lottery

We introduce a novel procedure we denote as the “third price lottery.” It is similar to a second price auction, except for the fact that the two highest bidders (in grey in Figure 1) are selected with equal probability by a lottery. The contract is then agreed at a discount corresponding to the third highest bidder. A useful property of this procedure is that the firms’ bids are identical to the second-price auction. The third-price lottery is also equivalent to an ascending “English” auction in which the price is raised continuously until all but two bidders have left.

The winner is then selected at random among these two, and the discount corresponds at the point where the third highest bidder left.[8]

Lemma 2. In the third price lottery, in the unique symmetric perfect Bayesian equilibrium, each firm *i* bids the highest discount $\bar{b}_i$ they are willing to offer.

The formal proof is in Appendix A3. The result holds for reasons similar to the second price auction. We illustrate our reasoning in the third column of Figure 1. Neither A nor B could do better by bidding above or below their valuation (but above C), and both would lose out by bidding below C and being selected with probability zero. Both C and D would lose out from bidding above B. As we see from the grey line, this procedure yields a lower contracted discount than the auction without a lottery.

This lower discount yields the following trade-off: On the one hand, a third price lottery implies that the project is in expectation contracted with a lower discount than in the second-price one. Hence, conditional on the firm actually delivering the project, the third-price lottery decreases consumer surplus. On the other hand, the fact that the contracted discount is lower in the third price lottery makes it more likely that a firm with high reputation concerns is included in the lottery (as those bid less aggressively). It also makes it more likely that a firm with no reputation concern ends up in position of nonetheless delivering in the bad state, simply because the difference between its bid and the third highest one is sufficiently high to compensate for the extra production cost.

4.4 The standard lottery

The last procedure is a lottery among all participants. We assume that the highest possible cost *h* amongst those firms who passed the pre-selection phase is sufficiently low for their maximum willingness to bid to be positive (else, they would have no interest in joining the qualification phase in the first place). The selected firm signs a contract based on her stated

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[8] Our procedure is related to the hybrid auction described in Klemperer (1998), who suggested running an additional sealed-bid auction between the last two bidders.

bid. As for the Average Bid Auction (ABA), the equilibrium involves all firms bidding for a zero discount, and all of them selected with equal probability.

The equilibrium discount is therefore lower than in any of the two other procedures. The benefit is that the likelihood of a firm with reputation concerns (of type *H*) being selected is equivalent to its share in the population, while all other procedures gave an advantage to the more aggressive bidders of type *L*. Moreover, the zero discount ensures that as long as the cost is not too high, $V \geq D + c_i$, even firms of type L *d*o not default when the state of the world is bad.

4.5 Comparing outcomes

There are two reasons why the standard lottery yields the lowest discounts, and the third-price lottery yields lower discounts than the second-price auction.

The first is bad news: in a lottery, the PA loses at least part of the information benefit from the standard auction setting. In a second-price auction, the expected rent of the winning firm is the difference between her maximum willingness to bid and the second highest bid. In a full lottery, it is equal to her maximum willingness to bid.

The second is good news: our two lottery procedures discard some unrealistically high bids. In terms of surplus generated for the consumer, the contracted bid is indeed not the entire story. If the selected firm has no reputation concern (type L) and therefore defaults selectively, the project is only completed with probability $1 - \theta$. With probability θ, it is not completed, and society incurs a cost T, unless the contracted bid is a sufficiently low discount to ensure even a firm of type *L* delivers in the bad state of the world. This means that the highest price we observe in lotteries in simply more realistic: it reflects the cost of actually delivering the project, in contrast to the often-empty promises of the winner of an auction.

We first provide some general results:

Proposition 2.

a) The discount at which the project is contracted is highest in the second-price auction, then in the third-price lottery, then in the standard lottery.

b) The probability that the firm winning the contract has no reputation concerns (type L) is highest in the second-price auction, then in the third-price lottery, then in the standard lottery.

The proof is in Appendix A4 and follows directly from the equilibrium strategy under the different procedures. Intuitively, the lottery is attractive in cases where the cost of default for society T is very high, and so is the risk of default. The latter can come directly from a high probability of being in the bad state of the world $1-\theta$ or a low share of firms with reputation concerns H. It could also come indirectly from the size of the rent naturally occurring in the other procedures. If the rent of the winner is sufficiently high in an auction setting, be it because of a smaller number of bidders or a larger dispersion of the costs, the risk of default is lower.

To illustrate those ideas, the following figures display the outcome of 10 simulations of each time 1000 procurement outcomes with six bidders. We start by assuming costs are drawn from a uniform distribution, and use the following parameter values: $l=0, h=V=T=1, \theta=\mu=\frac{1}{2}, D=2/5$ and τ sufficiently high. This means that default has an additional cost equal to the value of the project, that half of the firms have reputation concerns, and that a cost overrun worth 40% of the value of the project happens with probability ½.

Figure 2 displays the average winning bid for each of the possible procedures. As expected, the procedure extracting the highest contracted discount, slightly above 0.6, is the second-price auction. By definition, the lottery does not lead to any discount, and the third-price lottery fares somewhere in between the two, slightly under 0.5. A key point here is the number of bidders and the dispersion of the cost function. Adding more bidders would make the two above lines closer to each other, while removing some would put them further away.

Figure 2

Figure 3 then shows the main advantage of the two procedures with a lottery component when compared to the second price auction is the fact that more firms actually deliver the project at the contracted price. In the standard lottery, the share of winners with no reputation concern and without cost of defaulting (type *L)* is equal to their share in the population, 50%. Of them, only those with the highest cost fail to deliver in the bad state, so that 80% of the winning firms always deliver. In the third price lottery, two-third of the selected firms have the undesirable type L, but around 50% of the firms always deliver nonetheless. In the second price auction, three-quarters of the selected firms are of type L, and only around 30% of the selected firms always deliver.

The first difference between a lottery procedure and the auction is thus that the latter is more likely to select a bidder without cost of defaulting (type *L*). Indeed, we have seen that this kind of firm bids more aggressively, and are therefore more likely to win a competitive tender. The second is that, by guaranteeing such a high price to the firm, procedures involving a lottery ensure that even those with a high cost often do not default. The exception is when the firm selected by the lottery is of type *L* and has such a high cost that delivering at the reserve price is too costly for her when the state is bad.

Figure 3

Figure 4 shows the expected consumer surplus from each of the procedures. For the chosen parameter values, the third-price lottery is superior in that dimension. The reason is that the difference between the second and the third highest bid is not very high, while the difference in the probability of default is important. The choice of parameter values is however crucial. For instance, with a lower cost of default for society *T=0.4* (instead of T=1), the second-price auction performs better. The same holds if we reduce the number of bidders (see Appendix A6). Consumer surplus is always negative with the Lottery, as the project is awarded without any discount, but society bears the expected cost of default.

Figure 4

Figure 5 shows that producer surplus, is the highest for the standard lottery. One reason is mechanical: the winning firm does not offer any discount, and thus charges the highest possible price. Another comes from the benefit from actually delivering the project in every state of the world. In comparison, there is a big loss of surplus in the second-price auction coming from the fact that the winning firm is likely to default and receive no surplus at all. Lotteries are however not perfect in that dimension, as there is an allocative efficiency problem: The winning firm is expected to have a highest cost than in all other procedures.

Figure 5

Which procedure is socially desirable therefore depends on the value of the parameters and on how much the PA values producer and consumer surplus. We summarize in Appendix A5 the results of the simulations for different values of the extra production cost to the firm in the bad state of the world (D), of the social cost for the consumer of the winning firm defaulting or renegotiating (T), and of the weight the PA puts on producer surplus α. As we would expect, when the damage for the firm and for the society of being in the bad state of the world are low, the standard second price auction becomes more desirable. The standard lottery is preferred for the largest weight on producer surplus, in particular when *D* and *T* are high. The third-price lottery is preferred in all the intermediary cases, in particular when the PA puts a strictly positive but moderate weight on producer surplus.

In Appendix A6, we look at the case with four bidders, keeping all parameters the same as in the main simulations. This case is more favourable to the second-price auction, for two reasons. As compared to the standard lottery, the difference in the probability of default is lower than in the presence of six bidders. The expected information rent is indeed higher with fewer bidders, and it therefore becomes more likely that a bidder with no reputation concerns delivers in the bad state of the world because it can still make positive profit. One of the advantages of the third-price lottery also becomes less important: the third highest discount is expected to be very low, so that this procedure becomes much closer to a standard lottery. Looking at the total welfare, in this example, the second-price auction is preferred when the PA only cares about consumer surplus ($\alpha = 0$), the third price lottery is preferred for intermediate values of α, and the standard lottery when consumer surplus is valued the same as producer surplus ($\alpha = 1$).

5. **Discussion and alternative procedures**

In this section, we review some risks, limitations and possible objections to lottery-based procedures, as well as some suggestions to mitigate these concerns.

5.1 Efficiency and subcontracting

We have shown that one of the main drawbacks of lotteries is that they fail to select the firm with the lowest cost. Branzoli and Decarolis (2015) however show that a mechanism failing to pick the most efficient firm does not imply the delivery of the project will not be efficient. As lotteries influence the nature of the firms selected ex-ante, they also affect the incentives to use sub-contracting ex-post. Assume the lottery selects a high cost firm: this firm could choose to subcontract all parts of the projects to the most efficient firm and pocket the difference. There is no loss of efficiency as compared to the case in which the procedure selects the best firm, but there is a clear question of redistribution. If subcontracting is perfectly efficient and the PA has no problem with the distributive outcomes it generates, standard lotteries are always optimal. Else, our intermediate third price lottery and discrete lottery procedures reduce this redistribution problem.

5.2 The value of control

One possible risk for the implementation of lotteries is the decreased benefits from the empowerment of local bureaucrats in discrete procedures (Bandiera et al. 2021): If instead of selecting the winning firm, they end up selecting two or more, bureaucrats may feel that their authority carries a lower weight. This feeling can be in part alleviated by giving bureaucrats formal control on all the stages of the procedure. This implies control of the ex-post negotiations - after the lottery has selected the winning firm, but also some form of control on running the public lottery allocating the project to one firm. Experimental research has shown that individuals have an intrinsic preference for control, even if it is in practice meaningless (Bartling et al., 2014 ; Owens et al., 2014), and this preferences extends to control over a lottery (Bouacida and Foucart, 2021).

5.3 The social acceptability of lotteries

Another possible difficulty in the implementation of lottery-based procedures is the reluctance of individuals to see their fate decided explicitly randomly (Bouacida and Foucart, 2021). Experimental evidence shows that such concerns can be alleviated by making the lottery less explicit, and letting it follow the *rituals of reason* (Elster, 1989). This kind of preference could explain why lotteries are so rare in practice, while the equivalent Average Bid Auction is so widespread: the latter does not look like a lottery, even if it is in practice equivalent to one.

If a PA aiming at implementing lotteries faces such concerns, it could look at alternatives that would be equivalent in practice to a lottery, without involving a formal randomization. One possible such alternative would be the use of an external, anonymous, engineer assessing the projects. In the case of auctions, this means providing the kind of “official estimate” of what a sustainable discount would look like typically used to screen out unrealistic bids. The procedures would then select the bid closest to this evaluation. In the case of discretion, the PA would select a very small subset of anonymized projects and let the final selection to a quick browse by an anonymous expert. Evidence from the allocation of research grants by expert panels shows indeed that that they tend to rank projects who meet a certain threshold (similar to pre-qualification in our setting) in a way that is undistinguishable from a lottery (Graves, 2001 ; Pier, 2018).

5.4 Optimal size of a discrete lottery

A fourth potential concern, in particular for discrete procedure, is that local bureaucrats could transmit information not only about which project is the best, but about how big of a difference there is between the best and the second best project. The local bureaucrat may want in some case in good faith to select only one “truly better” firm. In other cases, she may be fine to use a lottery to pick between more than two almost equivalent projects. Indeed, when indifferent, the local bureaucrat may actually sometimes prefer to randomize, and this is a widespread psychological trait (Agranov and Ortoleva, 2017 ; Dwenger et al., 2018). The somewhat rigid procedures we suggest in the previous sections do not allow such flexibility.

To incentivize further the local bureaucrat to choose between fewer firms only when it is beneficial to do so, a PA could combine the discrete lottery with a system of semi-random audits adapted from the Brazilian experience (Ferraz and Finan, 2008). In that case, the probability of being audited varies (such as the study of Zamboni and Litschig, 2018), and decreases with the number of bidders subject to randomization. If the local bureaucrat wants to pick a single winner, she is very likely to be audited and found if corrupt. If she selects a large pool of potential winners, the probability is lower. In both cases, corruption would be reduced and the PA would extract the desired information from the local bureaucrat.

5.5 An hybrid procedure: scoring rules

Finally, our dichotomy between discrete and rule-based procedures does not consider the many contracts using features of both. The same logic could however be applied to such hybrid procedures.

In cases in which the PA does not have enough information to directly quantify important parameters, such as dimensions of quality unobservable ex-ante or the reputation of bidders for keeping their promises, many agencies rely on scoring rules. With this procedure, the firm chosen to procure the good or the service is selected through a scoring of specific price and quality dimensions, usually weighted to reflect their relative importance in the overall assessment. The final score used to identify the desirable supplier is simply the weighted sum of the score assigned to each criteria. The difficulty is that the scores and the weights assigned to each criteria can be quite subjective. This is why procedures based on scoring rules are a hybrid between discretionary procedures and rule based procedures. If corruption is a risk, a firm could try to influence the weight put on each criterion.

In that case, the PA could build lottery procedure similar in spirit to our discrete lottery to randomize this weight within certain limits. An additional benefit of such a randomization is to encourage firms to offer the best project without focusing too much on the always-imperfect way its value is measured. If limited liability is a concern, randomizing amongst the two top bidders would have an effect similar to our third price lottery.

6. Conclusions

This paper identifies situations in which standard procurement procedures could be improved by the addition of a lottery component. The partial lotteries we suggest have the advantage of reducing the main risk from discrete and rule-based procedures, while keeping some of their informational advantage. This is in contrast with standard lottery procedures, in which the PA needs to give the entire surplus to the producers.

Putting the results of the paper in perspective with the recent literature on the choice between discrete and rule-based procedures offers us a rough guide of the circumstances in which some form of procurement lotteries is desirable.

Table 1 summarize those insights in the case of discrete procedure. Based on the result of Proposition 1, we know that the two key elements are the number of potential bidders and the quality of institutions: how corruptible the local bureaucrats are. When the pool of firms is small and corruption is low, a standard discrete procedure is more valuable, as it allows extracting the local knowledge of the bureaucrat without too much risk. With a larger pool, the information cost from asking the bureaucrat to provide the name of two firms instead of a single one gets smaller, so that a discrete lottery starts becoming an interesting option. The case of a large pool of bidders with high risk of corruption is the most obvious example where a discrete lottery is the optimal choice. Finally, the combination of a small pool of bidders and high risk of corruption makes both options less appealing, and a PA may consider instead switching to a rule-based procedure such as an auction.

Table 1: The choice of a discrete procedure

	Low Corruption	**High Corruption**
Small Pool	*Discrete Procedure*	*Consider rule-based*
Large Pool	*Discrete Procedure/Lottery*	*Discrete Lottery*

Table 2 looks at the choice of a rule-based procedure. We know from Proposition 2 that the main trade-off is between selecting the most cost-efficient bidder, and making sure that the selected bidder actually delivers even when the state of the world is bad. When the risk of default – the cost overrun in the bad state of the world and the social cost of the project not being delivered or being delayed - is low, the latter risk is minimized. When the pool of bidders is small, the information gain from a second-price auction is maximal. Hence, a classic second-price auction is the most desirable in this situation. A larger pool of bidders starts making the case for a third price lottery, as the difference between the second and the third highest willingness to bid starts decreasing. When the risk of default is higher, the lottery becomes even more appealing. With a large pool, for intermediate costs of default, the third price lottery is desirable. When this cost is even higher, in particular if the PA puts enough weight on the producer surplus, a standard lottery may prove being the optimal choice. Finally, the case with a small pool of bidders and a high risk of default is the one where rule-based procedures are the least appealing, and the PA may consider switching to a discrete procedure instead.

Table 2: The choice of a rule-based procedure

	Low Default Risk	**High Default Risk**
Small Pool	*2nd price Auction*	*Consider discretion*
Large Pool	*2nd price Auction / 3rd price Lottery*	*3rd price Lottery / Standard Lottery*

An important limitation of our study of rule-based procedures is that we make the assumption there is no collusion amongst bidders. Such cartels are however prevalent in practice (see for instance Kawai & Nakabayashi, 2022), and may limit the benefits from an auction procedure. However, they may also strengthen the case for our third-price lottery as, by limiting the maximum discount offered in practice, they make it more difficult to sustain cartels, a result found by Chassang & Ortner (2019) in the case of a PA setting a minimum price in auctions. Looking at the role of lotteries in bidding cartels and collusions would therefore be an interesting avenue for future research.

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Appendix

A1. Proof of Proposition 1

The condition $\sigma(1-\theta)D > \frac{E(c_{(2,N)})-E(c_{(1,N)})}{2}$ is straightforward from taking the expressions of $S_{d,dl}$ and $S_{d,d}$. We see immediately that the left-hand side increases with σ and D and decreases with θ. To see that the right-hand side is decreasing in N, we use the fact that

$$E\left(c_{(2,N)}\right)-E\left(c_{(1,N)}\right)=N\int_l^h F(x)\left(1-F(x)\right)^{N-1}dx,$$

Using the density function of the first and second order statistics (see Paul & Gutierrez, 2004, p.105). By Proposition 2.3 in Li (2005), we know that a condition for an increase the number of participants to reduce the cost difference,

$$E\left(c_{(2,N)}\right)-E\left(c_{(1,N)}\right)>E\left(c_{(2,N+1)}\right)-E\left(c_{(1,N+1)}\right),$$

is that the distribution of the costs has a decreasing reversed hazard rate (DRHR), a property shared by all log-concave distributions (see for instance Result 2.2 in Chandra and Roy, 2001).

A2. Proof of Lemma 1

The maximum willingness to bid of a firm *j* of type *H* and cost c_j is the amount that yields zero profit on expectation. It therefore has to consider both states, and is a discount equal to

$$\bar{b}_{H,j} = V - c_j - \theta D.$$

If a firm is of type *L,* it chooses not to default selectively when the state of the world is bad only if the additional cost, given the contracted bid, yields a positive profit

$$0 \geq D + b_i + c_i - V.$$

Denote by $\hat{b} = V - c_i - D$ the value of b_i such that for all $b_i > \hat{b}$ the condition is not satisfied, so that a firm of type *L* defaults selectively. Denote by $\pi_{L,d} = (1-\theta)(V - b_i - c_i)$ the expected surplus in case of partial default, the expected surplus of a firm of type *L* is thus,

$$\pi_L = \begin{cases} \pi_{L,nd}, & for\ b_i \leq \hat{b} \\ \pi_{L,d}, & for\ b_i > \hat{b} \end{cases}$$

Replacing $\hat{b}$ by its value, we see that for all $b_i \leq \hat{b}$, $\pi_{L,nd} > 0$, so that there is no bid below the threshold that yields zero or a strictly negative profit. Our only candidate for a maximum willingness to bid thus corresponds to the case $b_i > \hat{b}$ and is $\bar{b}_{L,i} = V - c_i > \hat{b} = V - c_i - D$.

A3. Proof of Lemma 2:

We establish that truth-telling – bidding one's maximum willingness to bid - is a weakly dominant strategy. Consider a firm *i* bidding b_i.

- *Assume first b_i is not part of the two highest bids*. The firm is then selected with probability zero and makes zero profit. Any lower bid does not affect the probability of winning. Any higher bid could mean the firm wins if it offers a bid higher than the current second highest bid. In that case, the current second highest bid b' would become the third highest and therefore the contracted discount under the procedure. If $b' > \bar{b}_i$, any discount higher than b' yields strictly negative profit, and it is not in the interest of the firm to do so. If $b' \leq \bar{b}_i$, all bids above b' yields identical positive profit. This includes the maximum willingness to bid $\bar{b}_i$.

- *Assume now b_i is part of the two highest bids*. If the third highest bid is $b' > \overline{b}_i$, firm *i* makes strictly negative expected profit and could get a higher surplus by bidding strictly less than the third highest bid. All $b_i < b'$ then yield identical zero profit, including the maximum willingness to bid $\overline{b}_i$. If the third highest bid is $b' \leq \overline{b}_i$, all bids above b' yields identical positive profit. This includes the maximum willingness to bid $\overline{b}_i$.

Similar to the standard second-price auction, this strategy thus constitutes the unique symmetric Perfect Bayesian Equilibrium. If all firms are expected to bid either less or more than their maximum willingness to bid with strictly positive probability, we know by the above reasoning that truth-telling becomes a strictly profitable deviation. There is no strictly profitable deviation if all firms are expected to bid exactly $\overline{b}_i$.

A4. Proof of Proposition 2

a) In the second price auction and in the third price lottery, firms bid $\overline{b}_i$. As the underlying cost structure is the same, and as the discount contracted in the third price lottery is the third highest bid, while it is the second highest in the second-price auction, the contracted discount is always higher in the latter for a given realization of the costs. The result for the lottery is straightforward as the discount is always zero.

b) Bidders of type *L* bid more aggressively. Hence, we can always expect the probability that the highest bidder is of type *L* to be higher than the probability that the second highest bidder is of type *L*, and the latter to be higher than the third highest bidder is of type *L.* The same logic applies until the lowest bid.

A5. Simulation tables

Consumer surplus in the form of (second-price auction, third-price lottery, standard lottery) for different values of T and D, average of 10,000 simulations. Highest value in bold.

D/T	0.5	0.75	1
0.1	**.53** ; .47 ; - .01	**.50** ; .45 ; -.02	**.47** ; .43 ; -.02
0.2	**.40** ; .35 ; -.03	**.34** ; .32 ; -.03	.26 ; **.28** ; -.05

0.3	**.30** ; .27 ; -.04	.21 ; **.21** ; -.05	.15 ; **.17** ; -.08
0.4	**.22** ; .20 ; -.05	.13 ; **.14** ; -.07	.06 ; **.09** ; -.10

Producer surplus in the form of (second-price auction, third-price lottery, standard lottery) for different values of T and D, average of 10,000 simulations. Highest value in bold.

D/T	0.5	0.75	1
0.1	.12 ; .19 ; **.47**	.10 ; .17 ; **.45**	.12 ; .18 ; **.47**
0.2	.11 ; .17 ; **.46**	.11 ; .17 ; **.44**	.11 ; .18 ; **.45**
0.3	.10 ; .15 ; **.42**	.11 ; .16 ; **.41**	.11 ; .16 ; **.41**
0.4	.10 ; .15 ; **.38**	.10 ; .16 ; **.37**	.10 ; .15 ; **.39**

Total welfare with $\alpha = 1/2$

D/T	0.5	0.75	1
0.1	**.59** ; .57 ; .23	**.55** ; .53 ; .28	**.53** ; .52 ; .21
0.2	**.45** ; .43 ; .23	.39 ; **.40** ; .19	.32 ; **.36** ; .17
0.3	**.35** ; .35 ; .21	.27 ; **.29** ; .16	.20 ; **.25** ; .12
0.4	.27 ; **.28** ; .19	.18 ; **.22** ; .9	.11 ; **.17** ; .10

Total welfare with $\alpha = 1$

D/T	0.5	0.75	1
0.1	.65 ; **.66** ; 46	.60 ; **.62** ; .43	.59 ; **.61** ; .45
0.2	.51 ; **.52** ; .43	.45 ; **.49** ; .41	.37 ; **.46** ; .40
0.3	.40 ; **.42** ; .38	.33 ; **.37** ; .36	.26 ; .33 ; **.33**
0.4	.32 ; **.35** ; .33	.23 ; .30 ; **.30**	.16 ; .24 ; **.29**

A.6 Simulations with 4 bidders, uniform cost distribution $l = 0, h = V = T = 1, \theta = \mu = \frac{1}{2}, D = 2/5$ and τ sufficiently high