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EXPERIMENTAL STUDIES OF OPTIMALITY AND EFFICIENCY OF INSTITUTIONAL INNOVATIONS IN THE CASE OF AUCTION RULES USED IN PROCUREMENT

Summary: Private, economic agents are free to modify the rules of auctions which they use to determine a contractor in a procurement. Such institutional innovations might gain popularity with time if they manage to improve the auctions' results. The paper discusses three modifications of a standard first-price sealed-bid auction, all consisting in starting an additional stage in which the second-best bidder is given a chance to improve his or her bid. The laboratory experiments showed that two of the analyzed innovations failed to improve the procurement auctions' results, as they led to higher prices and lower efficiency. One rule, though, being a sealed-bid auction with an additional stage of English auction, turned out to be significantly more efficient than the first-price sealed-bid auction, and so it appears an interesting alternative to it.

Key words: auction, procurement, efficiency, experiments.

1. Introduction

Auctions have been used for centuries to trade commodities ranging from agricultural produce to real estate. The auctions' rules were shaped by the traders who used them to sell and buy goods and with time evolved into a number of well-defined institutions, often bearing the names related to the places where they originated from, like the English auction, the Dutch auction, or the Amsterdam auction.

These trading institutions are still widely used in all types of markets, but in the case of the transactions made by privately owned companies they are by no means binding. Market participants can use whatever trading rules they wish to, in this way quite often designing new auction mechanisms. This process is particularly evident in the case of procurement, where auction is the most popular way of settling the transactions. Quite often procurers start with the well-defined auction institution and amend it by some additional rules, like extra stages, or additional negotiations. If such innovations turn out to work well in the long run (and not just because the procurers were surprised by a new rule, and they did not know how to react), they will gain popularity, and one day can form a separate, widely recognized market institution.

This paper is devoted to the analysis of a few such spontaneously created auction designs. Once there exists a number of auction designs, which can be implemented in a given market situation, there is a natural need to compare their properties and determine which of them are best suited to meet the auctioneer's goal. Of course, such an evaluation would depend on what is the main purpose for using the auction. In the case of procurement most of the time the goal is simply to minimize the costs, i.e. buy the good at the lowest possible price. An auction which leads to the lowest possible price is called optimal, and many studies in auction theory are devoted to the analysis of auctions' optimality. A construction of an optimal auction for the case of perfectly rational, risk-neutral bidders was first, independently presented by Myerson [1981] and Riley, Samuelson [1981].[1] But as most bidders are typically neither perfectly rational nor risk-neutral, the studies of optimality have to be continued empirically.

Optimality is by no means the only criterion used to evaluate and compare different auction designs. Quite often, especially in the case of public auctions, an important criterion taken into account is efficiency,[2] usually defined as Pareto efficiency. Efficiency guarantees that there are no wastes in economy, i.e. the auction matches the best traders (e.g., in case of procurement, with price being the only criterion, efficiency means that the lowest-cost firm wins the auction).

The issues of optimality and efficiency are especially important in the case of new, spontaneously created auction designs, which are not well tested or studied theoretically. This paper analyzes in this respect a few chosen auction designs, which can be observed on the Polish procurement market. Section 2 describes in detail the studied mechanisms. Section 3 explains why experiments are the most popular method used to analyze the properties of the auction rules and provides information on the experimental design used for these studies. Section 4 discusses the results and the last part summarizes the main conclusions.

2. Description of the auction designs under study

A potential number of auction designs is unlimited.[3] In this paper only a few of them are analyzed, all being a modification of a very popular auction design, called the first-price sealed-bid auction.[4]

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[1] Those papers actually showed that the type of auction design used does not matter for the expected level of prices once certain assumptions are made. This important finding is known in auction theory as a revenue equivalence principle.

[2] For a discussion on why efficiency is an important evaluation criterion see Kuśmierczyk [2010].

[3] For some other modifications of the first-price sealed-bid auction design see Kuśmierczyk [2011].

[4] Participants make sealed bids with the prices they offer. The auctioneer unseals them and determines the winner, being the participant who asked the best (in case of procurement: the lowest) price.

A modification which seems to be met the most often consists in giving the second-best bidder a chance to improve his or her bid once all the bids are disclosed. This means that after collecting all bids, the auctioneer does not finish the auction by announcing a winner, but instead he or she contacts the second-best bidder, giving him or her a chance to change his or her bid. This modification can be arranged in a number of ways, which lead to different auction rules. In this paper three modifications will be analyzed.

The first one was called a first-price sealed-bid auction with an outbid option (denoted as OUT). After collecting all the bids, the auctioneer contacts the second-best bidder, informs him or her about the best price and gives him or her a chance to outbid it by one unit. If he or she does so, he or she becomes the winner, as the best bidder is not given an opportunity of bidding again. If he or she does not (because outbidding is not profitable for him or her), the winner is the bidder who initially made the lowest bid. Observe that this design is very disadvantageous for the best bidder, because he or she might be outbid, without any chance to bid back. That, on the other hand, should force the best bidders to make as low bids as possible (so that it becomes unprofitable for the second-best bidders to outbid them).

The second one was called a first-price sealed-bid auction with a rebid option (denoted as REB). Similarly as in the OUT auction, the auctioneer contacts the second-best bidder, giving him or her the last chance to outbid his or her rival. But this time the lowest bid is not revealed to the second-best bidder, and so outbidding the best bidder is more difficult.

In both mechanisms described earlier, the best bidder was not given a chance to bid back, which might have a negative influence on the auction's efficiency. In a first-price sealed-bid auction with additional price negotiations (denoted as APN), this rule is changed. The auctioneer reveals to the second-best bidder the winning offer, but if he or she decides to outbid it, the auctioneer contacts the previously lowest price bidder, informing him or her that his or her price was outbid, and letting him or her outbid the new winning price. And so on, the auctioneer continues negotiating with both bidders, until one of them finally withdraws. It is then as if there was an additional English auction stage in which the best two participants from the first stage took part.[5] The optimality and efficiency of the aforementioned auction designs will be determined by comparing their results with the outcomes from the standard first-price sealed-bid auction (denoted as FPS).

3. Experimental methods

Laboratory experiments seem to be the only method which can be used to compare various auction designs empirically. This happens for a number of reasons. First of all, to analyze optimality and efficiency one needs to know which of the participating

[5] For an analysis of the theoretical properties of this auction design see Kuśmierczyk [2009].

bidders had the lowest costs, and what was their value. But this information is unavailable in real life, as firms would never reveal their true costs (or the minimal prices that they would accept). Second, to compare the results of two auctions a *ceteris paribus* rule must hold, i.e. no parameters other than the auction rules should differ. But it would be very difficult to obtain the results from two real procurement auctions with exactly the same number of companies, the same commodity, and so on, and differing only by the auction rules. Finally, third, experiments enable us to analyze the new designs even if they are not practiced in real life.[6]

All experiments were carried out at the Wroclaw University of Economics. The participants were the first-year students of bachelor studies. All students had lectures with the author and as an incentive to participate in the experiments (which took part in extra time, after the classes, and were not directly related to them), they were offered bonus points that were to be added to their exams' results.[7] In the analyzed experiments, a total number of 380 students took part, each of them participating in two different auction designs. Each auction design was repeated 8-10 times, which gives a total number of about 1120 auctions' results analyzed in this paper.

Students were informed that they took part in a procurement auction started by a buyer who wanted to buy a standardized product at the lowest possible price. In each auction there were four participants, who tried to maximize their profits, which in the case of winning the auction were calculated as a difference between the final price and their individual costs. The participants had no influence on their costs, which were independently drawn each round from a uniform distribution on the interval [200, 400]. The information on the distribution used for the cost randomization was common knowledge. Before a proper simulation was started, students first took part in a trial round, in which they could ask questions in case they did not understand some of the rules.[8]

All experiments were designed using zTree (Zurich Toolbox for Readymade Economic Experiments [Fischbacher 2007]) and conducted in computer laboratories.

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[6] For more on the pros and cons of the experimental methods in economics see Guala [2005]. Additionally, Kuśmierczyk [2009] discusses in more detail the application of experiments in the analyses of the auction designs.

[7] Students were offered two points for the participation and some additional points (no more than four), depending on their results. This was a substantial amount, as the total number of points from the exam was 40. Some time after the experiments students were asked a few questions concerning the incentives system in an anonymous questionnaire. In total, 61 responses were obtained. For the question "Did the incentive system motivate you to take the best decisions?" 38 students (62%) said "absolutely yes", and 19 (31%) said "rather yes". The students were also asked, what would be the minimal price for which they would agree to sell one point if a "point trade market" existed (it was strongly underlined that the question is purely hypothetical). The median answer was 50 PLN, which is yet another demonstration that bonus points were a highly valued commodity.

[8] Additionally, in some cases the data from the first rounds were omitted in the statistical analyses. This happened when the preliminary analyses showed symptoms of some learning process.

4. Results of experiments

As was mentioned before, the economic analysis focuses on two aspects of auctions – their optimality and efficiency.

Optimality. To analyze the optimality, the final prices reached in the three analyzed designs were compared with the prices from the first-price sealed-bid auction. An auction design is the better, the stronger it motivates the participants to lower their prices. But the prices themselves are not the best measure for comparisons – a higher price in a given auction might not necessarily be due to low competition, but it might result from the higher level of costs. Therefore, to evade this problem, a different measure was used for comparison – the difference between the final price and the minimal cost, as defined by (1):

$$\mu = p - k_{1:N} \tag{1}$$

where: p is the final price in the procurement, and $k_{1:N}$ is the lowest cost of the participants.

The more competitive is the auction design, the closer to 0 should be the value of μ, as bidders are forced to lower their prices more and more, closer and closer to their costs. As all the auction rules analyzed in this paper are the modification of a standard first-price sealed-bid mechanism, it serves as a benchmark model – the prices reached under the REB, OUT, and APN would be compared with prices from the FPS. A Mann-Whitney U-test can be used pairwise for this purpose[9] with the null hypotheses that values of μ are the same in both studied mechanisms and the alternative hypotheses that values of μ are smaller in the case of a modified auction (i.e., those modifications "work" by bringing the prices closer to the level of costs). Table 1 presents the average values of μ's in the four auction designs.

Table 1. Comparison of optimality of four auction designs

Auction	Average value of μ	p-values
FPS	15.58	–
OUT	21.5	2.7E-0.5
REB	17.05	0.2
APN	16.69	0.23

Comment: The p-values are presented for the one-tailed Mann-Whitney U-test, run pairwise, with an alternative hypothesis that price in case of FPS is lower than in the case of other mechanisms.

Source: author's own studies.

[9] See Domański [1979]. This test has to be used because the values of μ do not have a normal distribution.

The presented data demonstrate that the lowest values of μ were observed in the case of the classical first-price sealed-bid auction; i.e., this mechanism leads to the lowest level of prices.[10] Therefore, the modified mechanisms do not increase the optimality of the procurement auctions' results. The Mann-Whitney U-test was later run with a reversed alternative hypotheses to check if prices in the case of FPS are significantly lower than in the case of the modified mechanisms. The results (presented in Table 1) show that this is true in the case of the OUT rule, but in the case of the other rules there are no statistical grounds to reject the null hypothesis of equality of bidders' profit margins.

The analyses of optimality provide no arguments for introducing the modified mechanisms in the long run. In the short run, the participants, surprised by the new rules, might lower the prices in accordance with what the auctioneer hopes for, but once they get a chance to learn the new rules, they adapt to it. For example, it might seem at first glance that the APN rule (first-price sealed-bid auction with additional price negotiations) must improve the results, compared to the first-price sealed-bid auction, because additional price negotiations lower the price from its initial level, reached in a sealed-bid stage. Thus, if such negotiations were introduced as a surprising element for the bidders who initially made the optimal bids in the classical FPS mechanism, they would lead to final prices lower than in FPS. But the point is that once bidders know that there is going to be an additional negotiations stage, they start with higher initial prices, and so the final outcome is not necessarily an improvement. As the data in Table 1 demonstrate, actually, the final prices under the APN rule (as well as under OUT and REB rules) turn out to be higher than under the FPS mechanism.

Efficiency. As the analyses have demonstrated, there is no point in introducing the modified designs if one just counts on reaching the lower prices. But yet another important property of the auctions is their efficiency. We will use two measures to compare it among the analyzed mechanisms which are most widely met in theoretical literature:[11] the allocative efficiency and the Pareto efficiency. The allocative efficiency (denoted as EFF) is measured as the fraction of auctions which ended with the winning of the lowest cost producer. The EFF measure is easy to calculate and has an obvious economic interpretation, but it might be to some extent misleading. Let us say that two producers, A and B, have similar values of costs, with B's costs being higher than A's by just one unit. If B wins the auction, it is allocatively inefficient, but the actual loss of a total surplus is insignificant. Hence, a better way of measuring efficiency might be by comparing the realized surplus with the maximal surplus that

[10] It is worth noting that the values of μ are in all cases much smaller than the theoretical predictions, which in the case of FPS is 37.5, and so the results are more optimal than predictions for the "optimal auction" (as defined by Myerson [1981] and Riley, Samuelson [1981]). This is of course due to bidders' risk aversion and/or irrationality. This result shows why in the case of studies of optimality (and efficiency), apart from the theoretical analyses, experimental research is needed as well.

[11] See for instance Cox *et al*. [1982, pp. 26-28].

could be reached. Observe that the total surplus of both sides of the transaction (the buyer and the winning seller) is:

$$\mathrm{SUR} = (p - k) + (\overline{p} - p) = \overline{p} - k \tag{2}$$

where the first factor in the sum is the surplus of the seller (price minus costs), and the second one is the surplus of the buyer (a difference between the highest price $\overline{p}$ that he or she would accept and the final price that he or she actually pays). As (2) clearly demonstrates, the total surplus is not affected by the price at which the transaction is made and is maximized if the transaction is made with the lowest-cost supplier. A Pareto efficiency measure (denoted as PAR) is defined by (3), i.e., as the percentage of the realized surplus:

$$\mathrm{PAR} = \frac{\sum_i (p_i - k_i)}{\sum_i (p_i - k_{1:N})} \cdot 100\% \tag{3}$$

where: i is the index of the subsequent auctions, p_i is the price at which the i-th auction ended, and k_i is the costs of the winning bidder.

The PAR measure is based on the assumption that if the buyer makes a transaction at price $\overline{p}$, then his or her surplus is 0, and it increases linearly once the price decreases. But the problem is that the value of PAR is strongly affected by the arbitrary level of $\overline{p}$ – if it is much higher than the actual prices at which the procurement auctions end, then losses in surplus will be regarded as low. To demonstrate it, in this paper the PAR values were calculated for two cases: one with $\overline{p} = 400$ (the maximal price that could be bid in auctions) and $\overline{p} = 300$ (a price high enough so that it can be treated as a zero utility price for the buyer[12]).

It is worth mentioning that the English auction[13] should always have a 100% efficiency (both EFF and PAR[14]), as the lowest costs bidder is always able to outbid the other bidders and win the auction. In the case of the sealed-bid auctions, 100% efficiency is not guaranteed.

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[12] In all the experiments analyzed in this paper, a final price higher than 300 was observed in only 8% of cases.

[13] A dynamic bidding in which the bidding companies offer lower and lower prices in order to outbid the best bid made by their competitors.

[14] In the case of the one-criterion procurement auctions (price is the only criterion), there is a direct relationship between the EFF and PAR measures, because if the auction has EFF = 100%, then it must also have PAR = 100%, and *vice versa*. But this relationship is not that straightforward in the case of the multi-criteria auctions (not analyzed in this paper). A multi-criteria auction might have EFF = = 100% (the auction is won by the best bidder), but PAR < 100% (the best bidder did not offer the best combination of the quality parameters, and so the total surplus from transaction in not maximized).

Tables 2 and 3 show the efficiency reached in the experiments and the test statistics. As can be seen, the highest efficiency is observed in the case of APN design, which is due to the fact that the second stage takes the form of an English auction, and so if the lowest-cost supplier advances to the negotiations stage, he or she is guaranteed winning the auction. The lowest efficiency, as was to be expected, is observed in the case of the OUT design, which was the one in which the second--best bidder was given an option of outbidding the lowest price, with no reaction available for the best bidder.

Table 2. Comparison of EFF measures of four auction designs

Auction	EFF	*p*-values
FPS	90%	–
OUT	81%	0.002
REB	88%	0.26
APN	96.8%	3.5E-05

Comment: The *p*-values are presented for the one-tailed *U*-test, run pairwise to compare efficiency of FPS and other mechanisms. See Domański [1990, p. 122].

Source: author's own studies.

Table 3. Comparison of PAR measures of four auction designs

Auction	PAR, $\overline{p} = 400$	PAR, $\overline{p} = 300$
FPS	99.1%	98%
OUT	98.1%	94.9%
REB	99%	97.3%
APN	99.6%	98.7%

Source: author's own studies.

The differences in EFF measures between FPS and OUT, and FPS and APN are statistically significant, meaning that the OUT rule is significantly less efficient, and the APN rule is significantly more efficient than the first-price sealed-bid auction. The values of PAR measures show the same rank of efficiencies.

5. Conclusion

The laboratory experiments serve as a very useful tool, enabling the researchers to compare the properties of various market institutions. The results showed in this

paper demonstrate that two out of three auction rules under study do not seem to be an interesting alternative for a first-price sealed-bid auction. The OUT rule (an option for the second-best bidder to outbid the best price by one unit) leads to higher prices than FPS, additionally accompanied by a lower efficiency. The same is true about the REB rule (an option for the second-best bidder to make a new bid, without knowing what is the best one), even though in this case the differences between the REB and FPS mechanisms results are statistically less significant. The only modified mechanism that seems to be an interesting alternative to the first-price sealed-bid auction is the APN rule (additional price negotiations). Even though it ends up with a slightly higher prices than FPS, its efficiency is significantly higher.

The results presented in this paper are a fragment of more extensive research devoted to the analysis of the optimality and efficiency of a high number of auction and quasi-auction rules under various conditions. The experimental studies are an important tool used to compare the auctions' properties. But one must bear in mind that experiments, as always, serve only as a preliminary test – their role is to suggest some conclusions that should later be always confronted with the real life data.

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BADANIA EKSPERYMENTALNE POŚWIĘCONE OPTYMALNOŚCI I EFEKTYWNOŚCI INNOWACJI INSTYTUCJONALNYCH, DOTYCZĄCYCH REGUŁ AUKCYJNYCH STOSOWANYCH W PRZYPADKU PRZETARGÓW

Streszczenie: W pracy analizowane są trzy modyfikacje klasycznej reguły aukcyjnej zwanej przetargiem pisemnym, które obserwuje się niekiedy w czasie przetargów przeprowadzanych przez prywatne podmioty ekonomiczne. Wszystkie one polegają na wprowadzeniu dodatkowego etapu w aukcji, w którym podmiot, który zaproponował drugą najlepszą cenę, otrzymuje możliwość poprawienia swojej oferty. Praca opisuje wyniki eksperymentów poświęconych badaniu efektywności tak powstałych innowacji instytucjonalnych. Badania eksperymentalne pokazały, że dwie z analizowanych innowacji nie sprzyjają zwiększeniu efektywności reguły aukcyjnej, ale jedna, nazwana przetargiem pisemnym z dodatkowymi negocjacjami cenowymi, wygląda na potencjalnie ciekawą alternatywę dla przetargu pisemnego, charakteryzując się porównywalnym poziomem cen i istotnie wyższą efektywnością alokacyjną.

Słowa kluczowe: aukcja, przetarg jednokryterialny, efektywność, eksperymenty laboratoryjne.