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Abstract

We present an econometric approach to the problem of detecting bid rigging in procurement auctions using bidding data for paving works in Ibaraki City, Osaka, Japan. We first show that sporadic price wars are caused by the participation of potential "outsiders." Assuming that the ring is all-inclusive in the absence of these outsiders, we estimate the rule by which the ring selects the winner. It is found that the ring tends to select a bidder whose time elapsed from the last winning is long and whose winning amount in the past is small relative to other bidders.

JEL Classification D44, H57, L44
Keywords: Bid rigging, repeated auction.

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1 Introduction

Bid rigging is pervasive in public procurement auctions. As bid rigging in public auctions has recently become a major social problem and attracted more public attention, the inner working of bidding rings has begun to be revealed by journalists, lawyers and industry experts who were formally involved in ring activities themselves.[1] Their reports uncover the rules under which contracts are allocated among ring bidders. For example, Suzuki (2004) documents the allocation rules of 252 bid rigging cases between 1947 and 2000. It is nortworthy that a number of rings use a class of schemes which allocates contracts mainly based on the history of auctions.

This paper proposes an approach to detect bid rigging, which is effective when the ring is all-inclusive in the market and its allocation rule belongs to a class, in which allocation is based on public history of auctions.

We look at auctions for road-paving works in Ibaraki City, Osaka, Japan for the four-year period between 2002 and 2005. Though there is no legal case of bid rigging filed against bidders in the market, collusion is suspected due to consistently high winning prices with the exception of sporadic price wars.[2]

We first analyze the cause of the price wars and find that the price wars during the data period mainly occurred when either of two specific firms were present. It is supposed that the price wars were between the ring and a small number of competitive bidders in the market, and that all the ring bidders submitted low bids in order to prevent the outsiders from winning.

We then assume that the high prices were maintained by an all-inclusive ring which allocates contracts to its members by some prespecified rule, and examine the data to see how the ring selects the winner among its members. We find that the ring tends to assign a win to its member whose time elapsed from his last win is long and whose winning amount in the past is small relative to other ring bidders.

It has been pointed out that the pattern of bid rotation is not of itself evidence of collusion. When bidders' cost functions exhibit decreasing returns to scale, bid rotation can be an outcome of a competitive equilibrium. In competitive auctions, firms with idle capacity are more likely to win a contract than those with ongoing contracts, and hence bid rotation can be a natural outcome (Zona (1986), Porter and Zona (1993), Porter (2005)). Our approach descriminates between collusive and non-collusive bid rotation by separating the effect of capacity utilization from the rotating bid aggreement. We construct variables for firms' used capacity and for the priority measure that determine the turn in the rotation scheme, separately, and analyze their effect on the events of winning or losing. We can

[1] Hironaka (1994), Kato (2005).

[2] In this paper, we use the term, a "price war" to indicate an auction whose winning price is significantly below the usual prices.

discriminate competition and collusion by testing the independence of the events from the priority measure of the rotation scheme.

There are many empirical work on bid rigging aiming at detecting collusion in procurement auctions. Most of them compare the behavior of known or suspected colluding bidders with that of competitive bidders. Porter and Zona (1993) studies auctions for paving works on Long Island, New York. They find that a colluding winner's response in bidding to a change of the cost factor is different from that of colluding losers even when there should be no statistical difference between them in the absence of collusion. Porter and Zona (1999) analyzes the ring members' bidding behavior in school milk procurement auctions in Ohio State. They focus on the relationship between the bids and the distance between schools and bidders. Their results suggest that the bidders form territories. Bajari and Ye (2003) observes the violation of exchangeability and conditional independence, the two conditions that a competitive bidding strategy must satisfy, using the auction data for highway construction works in Midwest. These approaches make full use of observable cost asymmetry among bidders by measuring firms' used capacity or the distance between their offices and the work site.

The previous works and ours are complementary in detecting collusion. The advantages of our empirical approach over previous methods are, first, it works even when the existing methods require a large number of competitive bidders for specification and comparison purposes, and hence are not applicable because the ring is nearly all inclusive. Second, unlike the previous methods, we do not require a large degree of asymmetry across bidders in observable features such as distance from the work site and capacity utilization.

Theories of collusion in auctions highlights the role of pre-auction meeting of bidders. The seminal paper by McAfee and McMillan (1992) shows that the most efficient bidder collusion in a first price auctions is that the ring member with the minimum cost bids at the reserve price while the other members bid 0 along with the monetary transfers from the winner to the losers. They also characterize an efficient collusion when no side transfer is possible. It is a static scheme in which the choice of the designed winner is independent of the history.

The analysis is extended to a repeated framework by Aoyagi (2003) and Skrzypacz and Hopenhayn (2004), who analyze collusion without a side transfer in repeated auctions. In contrast to McAfee and McMillan's static bid rotation, Aoyagi constructs a dynamic bid rotation scheme in which bidders coordination is based on past history. In the scheme, play rotates among different phases that treat the bidders differently and collusion is sustained because these phases enable intertemporal transfer of bidders' payoff.

Among the existing works, Skrzypacz and Hopenhayn (2004) and Pesendorfer (2000) are most closely related to ours. Skrzypacz and Hopenhayn (2004) proposes a collusion scheme named a "chips mechanism", in which the winner gives one chip to each loser, and when a bidder runs out of chips he is supposed to allow other bidders to win for a specific number of periods. An important factor in the scheme is the number of winning and losing in the past. Surprisingly, it is known that an alike mechanism has been used by Japanese bidding rings (we name it the "contribution rewarding scheme"), and our method is aimed at detecting this type of scheme.

Pesendorfer (2000) illustrates the difference of two forms of cartel, in which one cartel in Florida uses side payments and the other in Texas does not. He finds that the cartel without side payments maintains relatively constant market shares, despite some efficiency losses from not allocating a contract to the low cost firm, in order to maintain internal discipline. Our method is also aimed at detecting the scheme which keeps the balance of the members' total revenues in the past, which is the very scheme used by the cartel in Texas.

The paper is organized as follows. Section 2 describes the market, the auction procedure, and the data we analyze. Section 3 documents the observation on the price wars, and describes the possible ring's behavior in the market. Section 4 shows the empirical result of the analyses on collusion scheme. Section 5 concludes.

2 The Market Description

This study looks at auctions for paving contract awarded by Ibaraki City, Osaka, Japan, during four years between April 2002 and March 2005. During the data period, Ibaraki City awards 139 contracts through auction (30-40 contracts every year). Typically, the contracted work involves the resurfacing of local roads for hundreds of meters. The winning price varies from 1 to 40 million yen, with an average of about 7 million yen. Figure 1 shows the distribution of the contract value. Annual total of 2-3 hundred million yen is contracted out.

Thirteen firms participated in the auctions during the data period with one firm exiting early. Most firms do paving work as their primary business, and other civil engineering works as secondary. Nine firms are local in the sense that their headquarters are located within Ibaraki City, and the rest only have a branch in the city.

2.1 Auction procedure

The auction is the first price sealed bid format with a maximum acceptable (reserve) price and a minimum acceptable price (henceforth a minimum price). The minimum price is set aiming at preventing firms from doing works with a low quality. A bidder with the lowest bid wins the contract, if and only if the bid is between the minimum price and the reserve price. Auction proceeds as follows: Prior to each auction, the city officials estimate how much the work will cost an average firm to complete the work, taking into account material prices and the budget of the city. The estimated price is then used as the reserve price in the auction. The minimum price is set at about 80% of the reserve price. The city announces the reserve price and the minimum price one week before the auction.

Actual participants of the auction are chosen by the city. A limited number of firms are nominated from a list of candidates a week before each auction. Technical documents, which are needed to estimate the cost, are distributed to eligible bidders at the city office at the announced date and time prior to the auction. It gives the bidders a chance to see each other in advance and to know whether there is an outsider. On the date of the auction, bidders gather and submit sealed bids. If there are more than two bidders who submit the lowest bid, then the winner is determined by a public lottery.

The cost of each contract is private information of each bidder, and hence, each auction is a private value auction. When a bidder wins an auction, he would earn profit equal to the winning price minus his private cost.

The number of nominated bidders depends on the reserve price of the auction. When the reserve price is high, the number of bidders tends to be large. Table 1 summarizes the distribution of the number of bids per auction.

2.2 The Data Source

We have two data sources, bid data and corporate data. The bid data were provided by Ibaraki City Office. The bid data contain the following information on every project awarded: date of auctions, submitted bids, names of bidders, the reserve price and the minimum price, the starting and ending dates of projects, and location of projects.

The corporate data of each firm were provided by Construction Industry Information Center's database. The corporate data contain the number of years of running, number of technical workers, annual sales, and profit per sales.

In the analyses, we used a variable which represents bidder's used capacity. It is not sufficient in capturing the firm's used capacity as long as we see only the contracts bought by Ibaraki City, since the firms do the works bought by private firms and other local governments neighboring Ibaraki City. In calculating each bidder's used capacity, we used the data of contracts which were awarded by Osaka Prefectural Government, as well as by Ibaraki City. Osaka Prefectural Government is one of the major clients of firms, and provides contract data through its website. The definition of variables are shown in Table 4.

3 Possible collusion scheme

3.1 Agreement to fight against outsiders

We describe distinctive price wars observed during the data period and argue the reason. The observation in this section shows that most bidders bid at the minimum price in the price wars, and that such a price war take place mainly when either of two firms participates in the auction. It is natural to think that an agreement in bidding at the minimum price is in place when a specific bidder participates.

Figure 2 shows the variance of "normalized bids" of each auction, and Figure 3 shows the "normalized winning bids" of each auction. "Normalized" means that the bids are divided by the reserve price. As Figure 3 shows, in 123 out of 139 auctions, winning prices are in the neighborhood of 93% of the reserve price. On the other hand, remaining 16 contracts were won at the minimum price which was set at 80-85% of the reserve price, that is, the auctions were price wars. There is no contract won between 85% and 90% of the reserve price, and therefore, the distribution of winning bids has a gap as shown in Figure 3. Furthermore, in 13 price wars, the variance of the normalized bids is zero as shown in Figure 2, indicating that all of the bidds were submitted at the minimum price and hence, the winner was determined by the public lottery.

It is likely that the ring bidders have an agreement on submitting a bid at the minimum price when they face an outsider in an auction. As described, the bidders have an official chance to meet each other prior to the auction. Once the existence of an outsider is confirmed, all of the ring bidders must be instructed to bid at the minimum price in the auction.[3]

We further show that price wars are mainly caused by the pariticipation of either of two specific firms. Figure 4 shows the participation of every firm in every auction. The X axis shows auction ID, $t = 1, 2, ..., 139$, and the Y axis shows firm ID, $i = 1, 2, ..., 13$. A white dot in the figure indicates that the auction was a price war, and a black dot indicates that it was not. When a dot at coodinate (x, y) is framed, it indicates bidder y wins in auction x. For example, the black dot without a frame at coordinate $(15, 2)$ implies that firm 2 submitted a bid and lost in auction 15, and that the auction was not a price war.

In Figure 4, there exists a sequence of 4 white dots from coordinate $(2, 13)$ to coordinate $(10, 13)$, which are in square A. The dots indicate the price wars which may have been caused by the participation of firm 13. These auctions took place during 3 months from May 2002 to July 2002. No auction is price war if firm 13 was absent during this period. It can be inferred that firm 13 is a possible outsiders. In addition, firm 13 did not submit

[3] Bajari and Ye (2003) models a cartel behavior when it faces outsiders in auctions. In their model, the member with the minimum cost in the cartel submits a serious bid, and the other member submit phony high bids. In contrast to their model, all the ring members must be supposed to submit the lowest possible bid when they face an outsider in the market we analyze.

a bid in any auctions after auction 11. It suggests that firm 13 went out of the market after the auction, perhaps due to the price war against the ring continued from before the data period.

There exists another sequence of 8 white dots from coordinate $(68, 8)$ to coordinate $(81, 8)$ in square B. The dots indicate the price wars which were probably caused by the participation of firm 8. These 8 auctions were held during 5 months from May 2004 to October 2004. The other 53 auctions that firm 8 submitted a bid were not price wars. This may suggest that firm 8 stayed out of the ring only during the 5 months, and reconciled with the ring after that.

It is confirmed that the price wars took place in all auctions where firm 13 submitted bids and in a series of auctions during 5 months where firm 8 submitted bids. This suggests that there may have been an agreement that the ring bidders bid at the minimum price when one of the two firms participated in the auction. We further infer that the ring must have been all-inclusive after firm 13's exit, except the five months in which firm 8 stayed out of the ring. The causes of 12 price wars out of 16 are explained: 4 of them were caused by firm 13 and 8 were caused by firm 8. However, 4 price wars in Auction 28, 78, 131 and 139 are left unexplained.

The exit of firm 13 and the possible reconciliation of firm 8 suggest that the price wars worked as a predation. It is likely that winning a contract at the minimum price is unprofitable for most of the firms, since the ratio of profit to sales is 0.27% on average in this market (Table 3). If it is unprofitable in fact, the above observations fit to the context of the "deep pocket predation" in which the ring aims at deriving the outsiders out of the market by causing price wars that give losses to both. While the ring's losses can be shared among the members, the outsiders will therefore be unable to survive such losses for a long time. Sooner or later, they have to give up and leave the market or join the ring, allowing the ring to be all inclusive and recoup losses. The ring might have been doing this at the sacrifice of short term profit, aiming at the all inclusive environment which enables the ring to enjoy the benefit of collusion fully in the long run.

Note that the price wars we find cannot be an evidence of collusion by itself. There still remains a possibility that there is no agreement among bidders.[4] However, the finding gives a significant support for the assumption we use in the main analysis that all the bidders belong to the ring if the auction is not a price war.

[4]Suppose a situation where winning a contract is profitable for all firms even when the price is equal to the minimum price, and firm 8 and firm 13 are so aggressive bidders that they always bid at the minimum price. If it is common knowledge, a series of price wars we observe can be a natural outcome without any agreement, since it is best for other bidders to respond by bidding at the minimum price.

3.2 Operation of a collusion scheme as a comparison of bidders' priority

We next hypothesize the rules under which the winner is selected when the ring is all-inclusive in the auction. Many of those schemes are based on comparing its members' *priority* to win the contract. We pick following four classes of hisotry dependent schemes typically used in the past cases.

1) Simple rotation scheme

   In a simple rotation scheme, the ring members rotate the chance of winning. Note that the ring cannot use a mechanical rotation, due to the exogenous choice of bidders by the city before each auction. Instead, a bidder is chosen as the winner if his time of losing streak is longer than that of any other members. The ring compares the number of days from the last win, and the bidder with the greatest number wins the contract.

2) Revenue equalizing scheme

   A revenue equalizing scheme maintains equity of the revenue of its members by assigning a contract to the bidder whose total revenue in the past is the smallest among the members.

3) Contribution rewarding scheme

   A contribution of the ring member is to submit a phony bid allowing the other bidder to win. A contribution rewarding scheme gives more priority to bidders who made more contribution in the past auctions. Once his contribution is rewarded with a winning, the amount of his contribution is decreased. The ring compares each member's contribution to the ring, which is measured by the number of losing and the number of winning in the past.

4) Combination

   There can be a scheme in which some of above schemes are combined. There can be various combinations of above schemes in which more than two factors of the above schemes are considered in the selection of the winner. For example, a bidding ring in Okayama prefecture used a combination of the symple rotation scheme and the revenue equalization scheme, that is, the ring basically uses revenue equalizing scheme, and in case of a tie, they compared the number of days elapsed from one's last win.

Each scheme depends only on the public history (the date, the participants, the winner, and bids of every previous auction), and not on the private information. A merit of these schemes is the simplicity of the operation. They do not require any report from bidders even when the cost of doing the work is private information. They maintains collusion by giving each member an expectation to win in a near future. The schemes are efficient in the sense that a bidder who recently won a contract tends to lose in the next auction.

When either of above schemes is in operation, it is possible for us to detect the collusion. There must be a link between the outcome of each auction and history when bidders collude using the scheme, whereas, there must be no such link between each auction result and the history under competition. Therefore, we can see if they are collusive by testing if the history has a supposed impacts on the auction result. In Section 4, we examine the data to see if these schemes were in operation.

4 Detection of collusion scheme

In the following, we analyze the data to detect the collusion by testing if there is a collusion scheme that explains the data. We examine if there is a factor that has nothing to do with the cost, but has an impact on the auction result. The existence of bid rigging is supported by the existence of such a factor. In the analysis, we use the data of 123 auctions that were not the price war.

An important assumption here is that the ring was all-inclusive in these auctions. When the ring is all-inclusive in an auction, the designated winner wins the contract for sure. Therefore, the winner's characteristic in all-inclusive ring must reflect characteristics of the collusion scheme.

Porter and Zona (1993) models bidder's probability of winning in competition, imposing an assumption that the firms respond similarly to changes in the observable cost factors. Each bidder's probability of winning in an auction is represented as a function of cost factors, since bidder i's bidding function in auction t is approximated as a linear function of cost factors. We extend their model allowing the ring to choose the designated winner according to the collusion schemes described in Section 3.2.

4.1 The model of the ring's choice on the winner

Porter and Zona (1993) models a bidder's bidding function in an auction as a linear function of cost factors, and then, analyzes winning probability of the bidder given the cost factors as a conditional logit model.

The model is modified into the ring's choice model. We suppose that the ring chooses a bidder i as the winner if his measure of priority w_{it}^* is the highest among the set of bidders M_t in auction t, where

$$w_{it}^* = \beta' \mathbf{x}_{it} + \gamma' \mathbf{z}_{it} + u_{it}, \ i \in M_t. \tag{1}$$

$\mathbf{x}_{it}$ denotes the vector of factors that determine bidder i's priority in the collusion schemes. $\mathbf{z}_{it}$ is a vector of observable variables affecting bidder i's cost on project t. u_{it} is the disturbance that arises in bidder's priority.

The probability that bidder i is chosen as the winner in auction t conditional on M_t and $\mathbf{x}_t$ is written as:

$$\Pr(w_t = i \mid M_t, \mathbf{x}_t, \mathbf{z}_t) = \Pr(w^*_{it} \geq w^*_{jt} \ \forall j \in M_t, j \neq i \mid M_t, \mathbf{x}_t, \mathbf{z}_t),$$

where w_t indicates the identity of the winner in auction t, and $\mathbf{x}_t$ and $\mathbf{z}_t$ are vectors that consist of $\mathbf{x}_{it}$ and $\mathbf{z}_{it}$ for all $i \in M_t$, respectively. McFadden (1973) showed that when we assume that the u_{it}'s are independent and identically distributed with Type I extreme distribution, the probability can be written as:

$$\Pr(w_t = i | \ M_t, \mathbf{x}_t, \mathbf{z}_t) = \frac{\exp(\beta' \mathbf{x}_{it} + \gamma' \mathbf{z}_{it})}{\sum_{j \in M_t} \exp(\beta' \mathbf{x}_{jt} + \gamma' \mathbf{z}_{jt})}. \tag{2}$$

We obtain the estimator of parameters by maximizing the following log likelihood function:

$$\ln L(\beta, \gamma | w_t, M_t, \mathbf{x}_t, \mathbf{z}_t) = \sum_{t \in S} \sum_{i \in M_t} e_{it} \ln \Pr(w_t = i | \ M_t, \mathbf{x}_t, \mathbf{z}_t),$$

where e_{it} is an index variable which is 1 if i won in auction t and 0 otherwise and S is the set of auctions that were not the price wars.

Recall that the factors that determine bidder i's priority in each collusion scheme is 1) the number of days elapsed from one's last winning in the simple rotation scheme, 2) the total revenue in the past in the revenue equalizing scheme, 3) the number of winning and the number of losing in the past in contribution rewarding scheme. Therefore, $\mathbf{x}_{it}$ = (NUMDAYS$_{it}$, WINVALUE$_{it}$, WINNUM$_{it}$, LOSENUM$_{it}$). We construct two variables which capture the revenue in the past, WINVALUE1$_{it}$ and WINVALUE2$_{it}$. Since WINVALUE$_{it}$ and WINNUM$_{it}$ are highly correlated, we estimate some specifications dropping either of them.

The variables which represent observable cost factors in our model are $\mathbf{z}_{it}$ = (CAP$_{it}$, CAPSQ$_{it}$, YEARS$_i$, WORKER$_i$, PROFRATE$_i$, DIST$_{it}$, BRANCH$_i$).[5] We allow bidders to have different intercepts in w^*_{it}.

Since we are interested in whether $\mathbf{x}_{it}$ has an impact on the winning probability in auctions, we test the null hypothesis $H_0 : \beta = \mathbf{0}$ against $H_1 : \beta \neq \mathbf{0}$.

We also try the following extension in which the impact of $\mathbf{x}_{it}$ on the priority is different across bidders:

$$w^*_{it} = e^{\delta_i} \beta' \mathbf{x}_{it} + \gamma' \mathbf{z}_{it} + u_{it}. \tag{3}$$

The extension allows us to estimate the schemes which treat the ring members differently: bidders may not be treated equally in the schemes even though their $\mathbf{x}_{it}$ are the same.

[5] In Porter and Zona (1993), $\mathbf{z}_{it}$ includes the capacity utilization rate (CAP$_{it}$), squared utilization rate (CAPSQ$_{it}$), a firm's maximum capacity, squared maximum capacity, and CAP$_{it}$ and CAPSQ$_{it}$ are the only statistically significant variables in their model.

Some firms may be treated better than the others, for example, because they are the founding members of the ring, or outside firms may be handicapped due to local firms' territorial imperative. We set $\delta_1 = 0$ for bidder 1 as a standard. The greater value of δ_i implies the better treatment for bidder i.

4.2 Result

Table 5 shows the empirical results.

Columns (1) and (2) of Table 5 show the results using WINVALUE1 as the proxy of the total revenue in the past, and (3) and (4) correspond to the results using WINVALUE2. (5) and (6) show the result using the number of winning in the past, instead of the total revenue. Column (7) shows the result of the extended model which allows the heterogeneity of bargaining power.

Throughout the specifications, it can be seen that a bidder's probability of winning tends to be high if the number of days elapsed from his last win is large, and in some specifications, it can be seen that the total revenue in the past decreases the winning probability.

The estimate for branch dummy is negative. This may suggest that an outside firm is less powerful in the bargaining for the allocation. As shown in Table 3, the number of winning tends to be small if a firm's headquarter is not located within Ibaraki City. Firm 1,2,6 and 11 are outside firms, and their frequencies of winning are less than half of those of the local firms.

It can be said that either the simple rotation scheme or the combination of the simple rotation scheme and the revenue equalizing scheme is most likely to be used. That is, the ring selected a bidder as the winner if he is on a losing streak for a long time and its winning value until the auction was small relative to the other bidders.

The above finding can be the evidence of collusion if we can say competitive bidding behavior is never affected by the number of days elapsed from one's last win. However, there remains a possibility that the number of days from the last win may be related to the financial pressure which makes a competitive bidder aggressive, and therefore may induce the bidder to decrease his bids. If so, it is natural if the winner has the larger number of days elapsed from the last win.

In order to see if the number of days from the last win increases competitive bids, we analyze the normalized "losing" bids. Table 5 shows the results of linear regression models which explains the normalized losing bids by the independent variables of the conditional logit model. The number of days from the last win increases the losing bids in some specifications, however, there is no evidence that the number of days from the last win reduces the bids.

In total, there is little support that the positive impact of the length of one's loosing streak found in the conditional logit analyses is due to the financial pressures. It can be concluded that the impact is the evidence of collusion.

We should note that the models do not fit the data well. This may be because there remain some other factors which are not considered in our model. Figure 5 shows who won in each auction. A small dot, a middle-size dot, and a big dot show that the contract value is small (less than 5 million yen), middle (5-10 million yen) and big (greater than 10 million yen), respectively. The figure shows that firm 3 tends to win big contracts with long intervals, while firm 9 and 10 tend to win small or middle-size contracts with short intervals. This may suggests that some factors such as bargaining power or preference of firms may also affect the decision significantly.

5 Conclusion

We analyze auction data to find an empirical evidence of collusion in procurement auctions for paving works. We first observe the happening of the price wars and find that most price wars occured when either of specific two firms submitted bids. It is inferred that the two firms are possible outsiders and that all the ring bidders submit bids at the minimum price only when outsiders were in the auction.

We next analyze if some possible collusion schemes are used when the winner was selected assuming that the ring is all-inclusive if the auction is not a price war. We model some possible schemes as a comparison of each member's priority to win, and the ring selects the member whose priority is the greatest among other bidders. We focus on schemes in which a bidder's priority is measured based on events in the past.

It is found that, a bidder tends to win when the time elapsed from his last win is long, and his amount of win in the past was low relative to other bidders.

Since the number of days from the last win may be related to the financial pressure which makes a competitive bidder aggressive, it may induce a competitive bidder to decrease his bids. We find that there is no relation between the number of days from the last win and the losing bids, and confirm that the impact of the number of days from the last win on the winning probability is the evidence of collusion.

Our finding figures out the behavior of the ring. The ring allocates contracts to the ring bidders, balancing the frequency of winning and the revenue among its members, and when an outsider is in an auction, all the ring bidders bid at the minimum price.

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Table 1: Bid concentration

Number of bidders	5	6	7	8	9	Total
Number of auctions	52	52	28	5	2	139

Table 2: Winning price

Winning price (in million yen)	1-3	3-5	5-10	10-20	20-30	30-	total
Num of auctions	24	36	58	16	4	1	139

Table 3: Information of firms

Firm ID	Headquarter/ Blanch	Num. of workers	Years of operating	Ratio of operating profit to sales	Num. of bids	Num. of winning
1	B	158	55	5.79%	29	4
2	B	22	15	-0.33%	40	5
3	H	16	15	1.21%	93	14
4	H	12	31	1.27%	95	17
5	H	19	36	1.14%	97	13
6	B	9	34	-0.86%	37	3
7	H	3	30	2.58%	95	14
8	H	9	24	0.41%	61	13
9	H	6	22	0.60%	72	20
10	H	4	6	1.04%	83	13
11	B	16	26	-9.50%	39	6
12	H	7	21	-0.17%	81	17
13	H	-	-	-	4	0
Average		23.4	26.3	0.27%	63.5	10.7

Table 4: Definition of variables 2

Variables	Definition
CAP_{it}	The measure of capacity utilization rate. This is defined as the value of backlog contracts devided by the firm's annual sales, which is observed in 2004. A backlog contract is a contract which Firm i already won in public auctions in Ibaraki City and Osaka Prefecture, and whose time overlaps the contract of Auction t.
CAPSQ_{it}	Square of CAP.
YEARS_{i}	The number of years of Firm i's operation, observed in 2004.
WORKER_{i}	The number of technical workers, observed in 2004.
PROFRATE_{i}	The rate of profit on sales, observed in 2004.
DIST_{it}	Distance between the work site and Firm i's office.
BRANCH_{i}	A dummy variable that takes 0 if bidder i is the headquarter of a firm located within Ibaraki City, and 1 if bidder i is a branch office of an outside firm.
NUMDAYS_{it}	The number of days between Firm i's last winning and the date of Auction t.
WINVALUE1_{it}	The total value of contract that Firm i has won since the start of the data period until the date of Auction t.
WINVALUE2_{it}	The total value of contract that Firm i has won within half a year of Auction t.
WINVALUE3_{it}	The total value of contract that Firm i has won within a year of Auction t.
WINNUM_{it}	The number of times that Firm i won in auctions from the start of the data period until the date of Auction t.
LOSENUM_{it}	The number of times that Firm i lost in auctions from the start of the data period until the date of Auction t.

Figure 1: Winning price

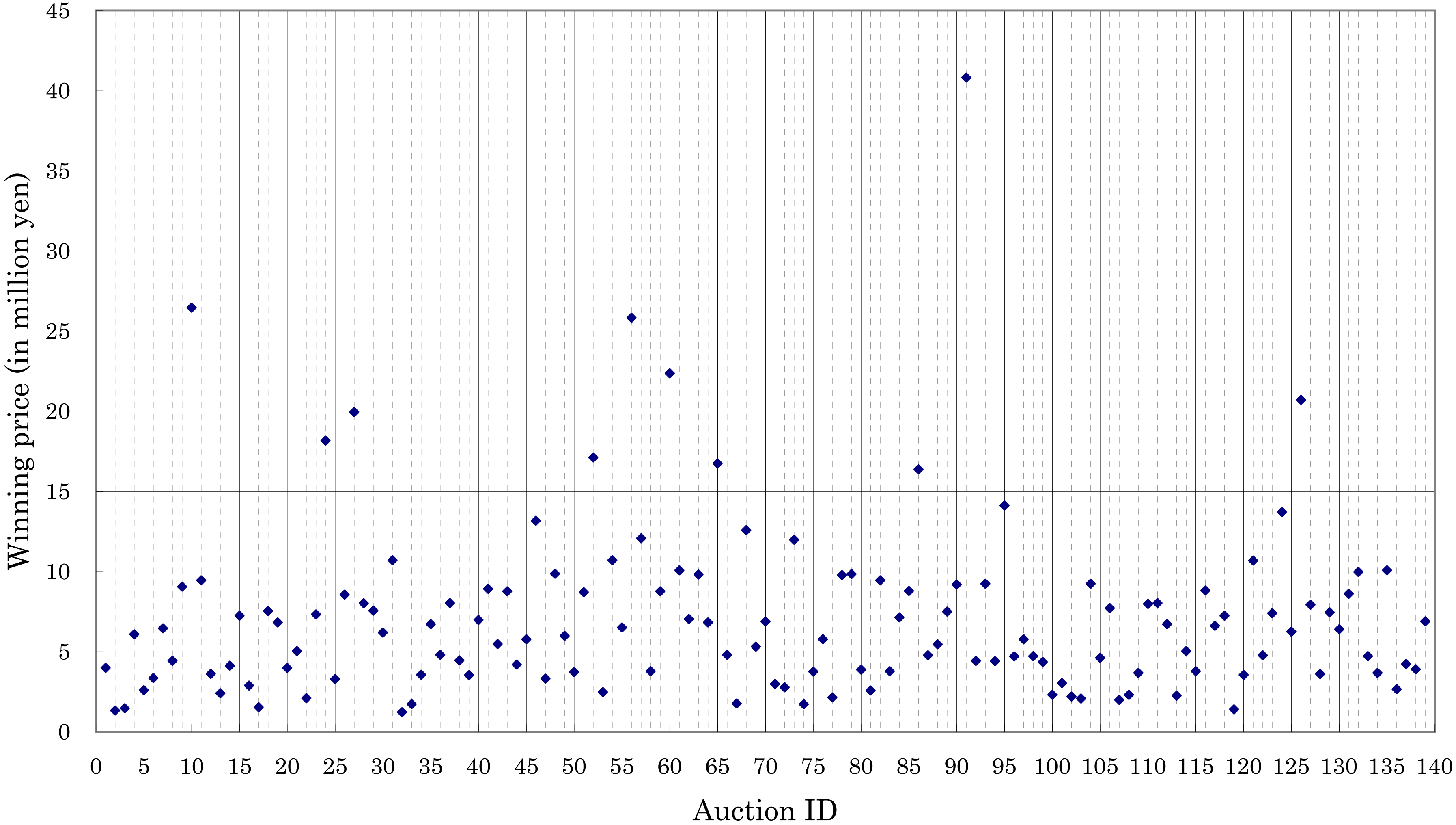
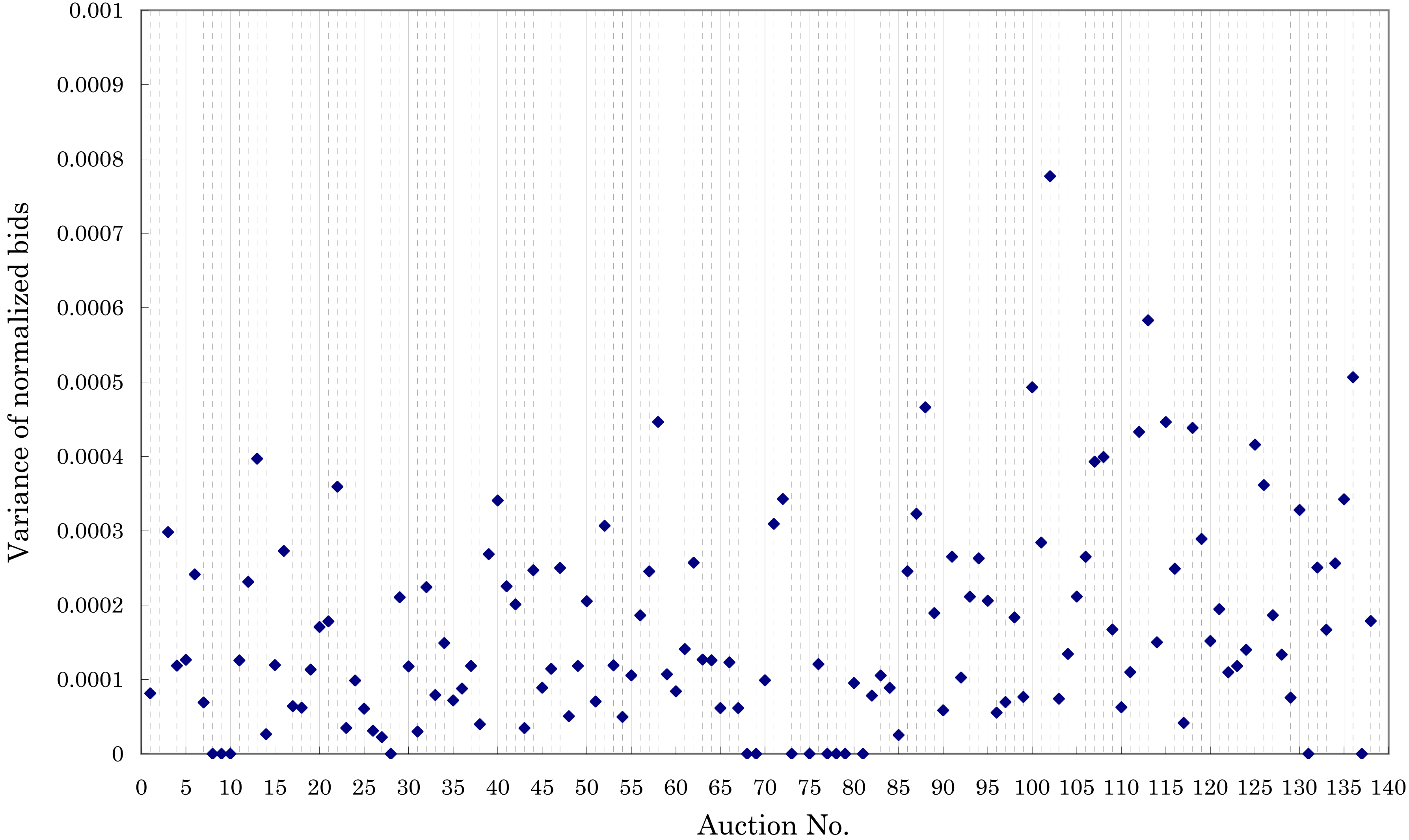


Figure 2: Variance of normalized bids



Note: The figure does not include three exceptionally large values 0.0023, 0.0011, and 0.0076 for Auction No. 2, 74, and 139, respectively.

Figure 3: Normalized winning bids

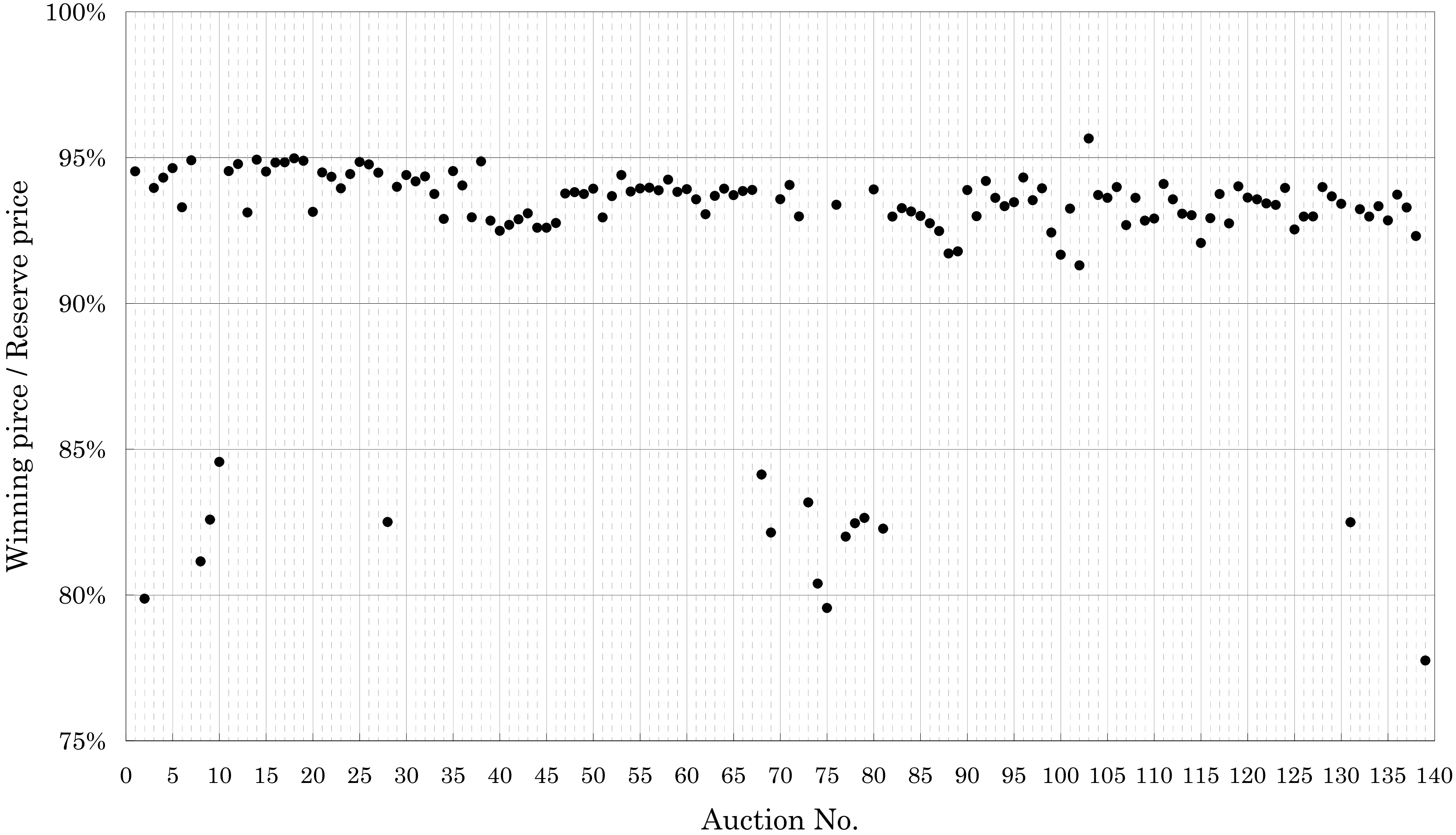


Figure 4: Participation and price wars

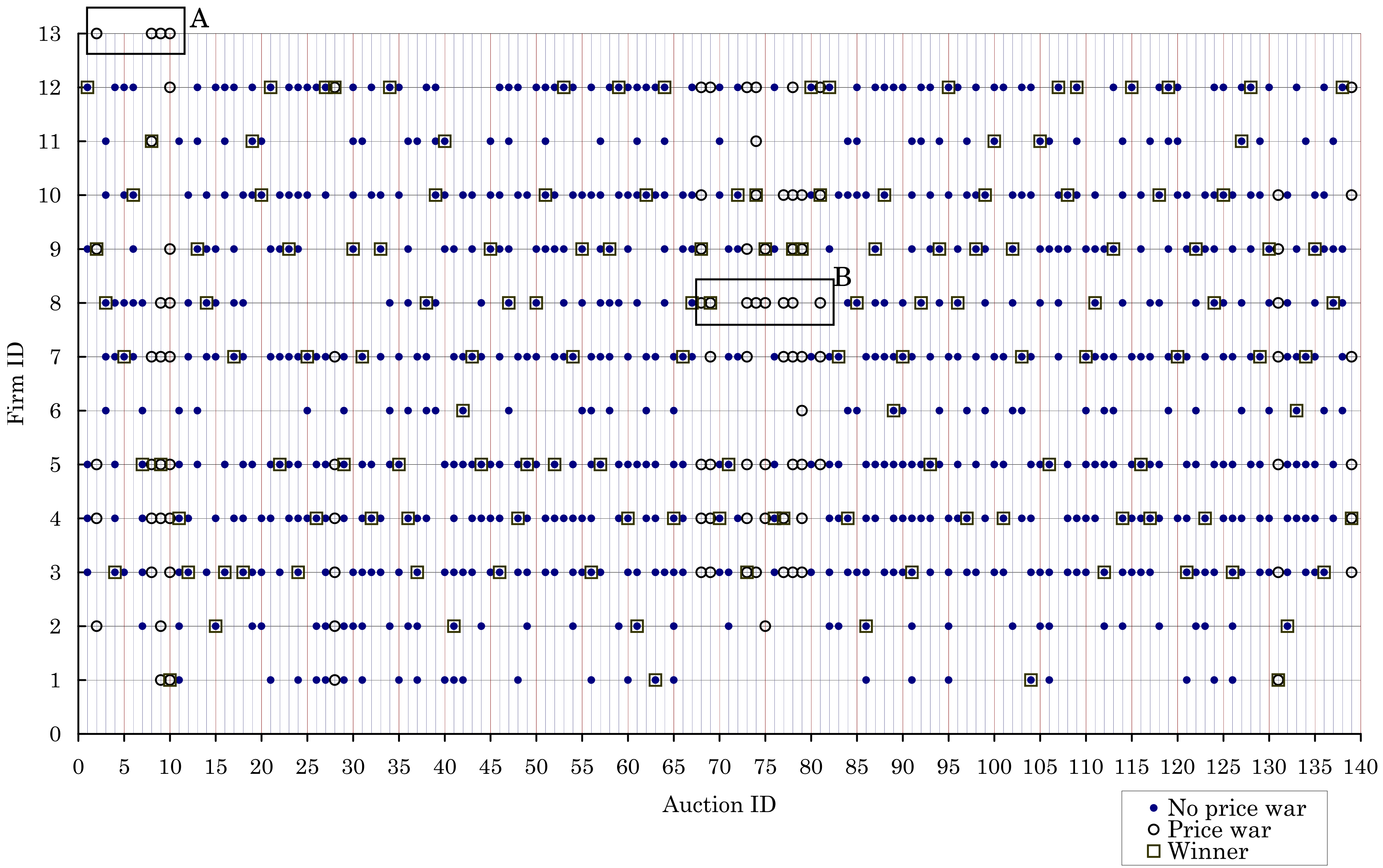


Table 5: Estimation results for conditional logit model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
WINVALUE1	-0.010	-0.027**					-0.007
	(0.006)	(0.009)					(0.010)
WINVALUE2			-0.033*	-0.038*			
			(0.016)	(0.018)			
WINNUM					-0.065	-0.139	
					(0.060)	(0.077)	
LOSENUM	0.006	0.031	-0.005	-0.006	-0.004	0.008	0.021
	(0.015)	(0.023)	(0.014)	(0.021)	(0.014)	(0.021)	(0.020)
NUMDAYS	0.006**	0.006**	0.006**	0.006**	0.006**	0.006**	0.012**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)
CAP	-3.810	-5.978	-2.126	-3.401	-3.793	-5.100	-3.587
	(3.985)	(4.116)	(4.186)	(4.291)	(4.022)	(4.106)	(4.809)
CAPSQ	5.024	7.278	2.500	3.310	4.587	5.119	3.603
	(10.120)	(10.690)	(11.235)	(11.785)	(10.032)	(10.560)	(12.354)
YEARS	-0.004	-0.042	-0.002	-0.047	0.002	-0.042	-0.018
	(0.012)	(0.027)	(0.012)	(0.027)	(0.012)	(0.027)	(0.027)
WORKER	-0.013	0.011	-0.021	-0.069	-0.034	-0.079	0.089
	(0.026)	(0.057)	(0.024)	(0.046)	(0.022)	(0.045)	(0.053)
PROFRATE	-0.052	0.032	-0.053	0.033	-0.065	0.029	-0.367*
	(0.056)	(0.071)	(0.055)	(0.070)	(0.056)	(0.071)	(0.149)
DIST	-0.146**	-0.114	-0.152*	-0.125	-0.139*	-0.116	-0.107
	(0.062)	(0.064)	(0.062)	(0.064)	(0.062)	(0.064)	(0.065)
BRANCH	-2.287**	-1.722*	-2.300**	-1.728*	-2.561**	-1.750*	-3.349*
	(0.560)	(0.732)	(0.552)	(0.734)	(0.659)	(0.790)	(1.477)
δ_2							0.108
							(0.263)
δ_3							-1.179
							(0.797)
δ_4							-0.005
							(0.384)
δ_5							-1.191
							(1.017)
δ_6							-0.092
							(0.244)
δ_7							0.620
							(0.384)
δ_8							-0.240
							(0.502)
δ_9							0.201
							(0.456)
δ_{10}							-0.034
							(0.552)
δ_{11}							-1.791
							(1.256)
δ_{12}							0.273
							(0.461)
Bidder fixed effect	No	Yes	No	Yes	No	Yes	No
Log likelihood	-194.23	-187.70	-193.39	-189.65	-195.15	-190.52	-181.30
Pseudo R2	0.105	0.135	0.108	0.126	0.100	0.122	0.164

Notes:
(i) **: 1% significance level, *: 5% significance level.
(ii) The number of observations of each column is 725.

Table 6: Estimation results for normalized bids 1

	(1)	(2)	(3)	(4)	(5)
util	2.485**	-0.018	0.380	0.000**	2.485**
	(0.277)	(0.013)	(0.363)	(0.000)	(0.537)
utilsq	-4.795**	0.033	-0.791	0.000**	-4.795**
	(0.768)	(0.026)	(0.773)	(0.000)	(1.315)
years	0.013**	0.000**	0.002	0.000**	0.013**
	(0.001)	(0.000)	(0.002)	(0.000)	(0.004)
staff	0.015**	0.051**	0.001	0.050**	0.015
	(0.002)	(0.000)	(0.001)	(0.000)	(0.008)
profit	-0.015**	-0.017**	-0.002	-0.017**	-0.015
	(0.004)	(0.000)	(0.002)	(0.000)	(0.019)
distdir	0.053**	0.000	0.014	0.000**	0.053**
	(0.007)	(0.000)	(0.013)	(0.000)	(0.014)
blanch	-0.078*	0.378**	0.009	0.371**	-0.078
	(0.038)	(0.002)	(0.010)	(0.000)	(0.149)
totalwin1	0.007**	0.000	0.002	0.000**	0.007*
	(0.001)	(0.000)	(0.002)	(0.000)	(0.002)
dayfroml n	0.001**	-7.81E-06	2.88E-05	1.06E-17**	0.001*
	(0.000)	(4.52E-06)	(3.41E-05)	(2.60E-18)	(0.000)
R-squared	0.940	1.000	0.995	1.000	0.940
Fixed effect	No	B	A	A & B	No
Clustering	A	A	A	A	B

Notes:
(i) **: 1% significance level, *: 5% significance level.
(ii) The number of observations of each column is 602.
(iii) "A" in the "Fixed effect" row indicates that auction specific fixed effects are included in the model, and "B" indicates bidder specific fixed effects.
(iv) "A" in the "Clustering" row indicates that the standard errors are clustered by auctions, and "B" indicates clustering by bidders.

Figure 5: Winner of auctions