Collusion in Repeated Procurement Auction: a Study of Paving Market in Japan

Rieko Ishii*

November 22, 2006

Abstract

We present an econometric approach to the problem of detecting bid rigging in procurement auctions using bidding data in auctions 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.

*Osaka University. I am grateful to Masaki Aoyagi, Miki Kohara, and Shinichi Sakata for helpful suggestions and discussions. All errors are mine. e-mail: dg009ir@mail2.econ.osaka-u.ac.jp .

1 Introduction

Bid rigging is pervasive in Japanese procurement auctions. Lawyers estimate that bidder collusion is present in 95% in Japanese procurement auctions, whereas the corresponding figure is estimated to be 5% in the U.S. (Suzuki (2004)). In a typical collusion scheme, ring bidders communicate prior to each auction to decide which member win the auction. The designated winner then bids the reserve price, while the other bidders lose on purpose by submitting higher bids.

As bid rigging has recently become a major social problem and begun to attract more public attention, the working of bidding rings began to be documented by journalists, lawyers and industry experts who were formally involved in ring activities themselves. These reports make it possible to infer how ring bidders operate collusion in a real market.

This paper analyzes auctions for road-paving works in Ibaraki City, Osaka, Japan for the four-year period between 2002 and 2005. The objective of the paper is to find a statistical evidence of bid rigging in the market. Though there is no legal case of bid rigging filed against these bidders of these auctions, collusion is suspected because of consistently high winning prices with the exception of sporadic price wars.[1] We present two hypotheses on the workings of underlying bidding ring behaves. We analyze the data to see if the data support the hypotheses.

We first present a hypothesys on the cause of the price wars. The winning prices in auctions were mostly stable at a high level, but sometimes fell significantly. We suppose that the low prices were the outcome of price wars 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 analyze the firms' participation data to see if the price fell only when some specific firms were in the auction. The impact of each bidder's participation on the occurence of the price wars is examined. We find that the price wars during the data period mainly occurred when either of two specific firms were present.

The hypothesis on the price war is formed based on a bridge construction cartel exposed in 2005. It allocated public contracts to 47 firms for years. The cartel was nearly all-inclusive in the bridge construction market, except a firm from Fukushima Prefecture. It is reported that cartel members submitted extremely low bids when they faced an outsider in auctions, whereas they bid the reserve price in the absence of an outsider. The low bids were aimed at preventing the outsider from winning, even though they imply a negative profit from winning. The member who won the

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

contract in the price war was compensated with a profitable contract afterwards.[2]

We next hypothesize that the high prices were maintained by an all-inclusive ring, which allocates contracts to its members by some prespecified rule. We examine the difference in characteristics between the winner and the losers to see how the ring selected the winner among its members. We assume that the winner is selected by comparing priorities, and analyzed which factor determines a bidder's priority.

The result shows that the time elapsed from a firm's last win has a positive impact on the firm's probability of winning in the auction, whereas the firm's total amount of winning in the past has a negative impact. The result suggests that the ring tends to assign a win to a ring member whose waiting time is long and whose winning amount in the past is small relative to other ring members.

The analysis on the collusion scheme is based on the past bid rigging cases reported by journalists and lawyers. According to Suzuki (2004), who documents all bid rigging cases between 1947 and 2000, each ring had its own rule of facilitating pre-auction negotiations in selecting the winner.[3] In some cases, simple rotation was used, in which the winner was selected simply by turn. In other cases, the scheme was more involved with the use of a score assigned to each bidder: A member's score increases with his past contribution to the ring, and decreases with the benefit he received from the ring in the past. The ring allocates the win to the member with the highest score.

Our data enable us observe the history of each auction. The history of an auction is the dates, the identities of the winner and the losers, and the winning prices of all previous auctions. Among various collusion schemes documented by Suzuki, some, including the above two, only care about factors which can be calculated from the history. For example, simple rotation only uses the time elapsed from each bidder's last win. We try to determine whether the collusion scheme using such a rule is in operation in our case, using auction data over several years.

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 re-

[2]Asahi Shin bun May 19, 2005, Kahoku Shin pou, May 25, 2005.

[3]McMillan (1991) also documents the operation of Japanese bid rigging.

peated 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. Skrzypacz and Hopenhayn (2004) proposes a collusion scheme named a 'chips mechanism', in which the winner gives one chip to the loser, and when a bidder runs out of chips he is supposed to allow other bidders to win for a specific number of periods. A numerical analysis shows that this mechanism is asymptotically optimal when the distribution of bidders' values is assumed to be uniformly distributed.

Most empirical work on bid rigging aim at detecting collusion in procurement auctions, by comparing the behavior of known or suspected colluding bidders with that of competitive bidders. Porter and Zona (1993) study 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) analyzed the bidding behavior in school milk procurement auctions in Ohio State. They found that a competitive bidder's bid levels increase with the distance between the bidder and the school district, while those of collusive bidders often decrease with the distance. Bajari and Ye (2003) observe 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.

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 argues 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 empirical approach has mainly three advantages over the detection methods proposed by Porter and Zona (1993,1999) and Bajari and Ye (2003). 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. Our approach is useful since rings are often all-inclusive in Japan, where the regional business association is often the ring itself.

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. Bidder asymmetry is generally small in Japanese procurement auctions because of the discretionary prescreening of potential bidders by local governments: In many cases, only those firms in a close proximity to the work site are nominated in the name of promoting the regional economy, resulting in almost identical transportation costs. Asymmetry through capacity utilization is also absent since some local governments avoid nominating bidders who already have a local public project in order to equalize the opportunity.

Finally, our approach discriminates the effect of capacity utilization from bid rotation. The pattern in which a bidder with high capacity utilization loses and one with low capacity utilization wins can be observed under competition, as well as under collusive bid rotation. In competitive auctions, firms with idle capacity are more likely to win a contract than those with ongoing contracts, if bidder's cost functions exhibit decreasing returns to scale, as first pointed out by Zona (1986). Meanwhile, bid rotation allocates the winning in turn and hence, the bidder with idle capacity tends to be selected. As capacity utilization is one of main factors of the cost asymmetry in their methods, it does not work in discriminating competition and collusion.

Our method deals with this difficulty by constructing variables for firms' used capacity and for the factors that determine the turn in the rotation, separately. A competitive result may depend on history only through the capacity utilization, not through a collusion scheme. Therefore, we can discriminate competition and bid rotation by looking at the independence of the auction result from the factors of the rotation scheme.

The paper is organized as follows. Section 2 describes the market we analyze. Section 3 describes our hypotheses on the ring's behavior in the market. Section 4 describes the data. Section 5 analyzes the cause of the price war. The causality between the price wars and each firm's participation is examined. Section 6 analyzes the collusion scheme the ring uses. Section 7 concludes.

2 Auctions

Our data come from auctions for paving work contracts awarded by Ibaraki City in the four-year period from April 2002 to March 2006. The city awards 30-40 contracts through auction 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. Annual total of 2-3 hundred million yen is contracted out.

Thirteen firms participated in the auctions in the four-year 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.

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 bidders depends on the reserve price. When the reserve price is less than 5 million yen, the number of bidders is 5-8. The number of bidders is 6-9 for a contract whose reserve price is between 5 million and 10 million yen, 7-10 for a contract whose reserve price is between 10 million and 30 million yen, and 8-13 for a contract whose reserve price is higher than 30 million yen. Table 1 summarizes the distribution of the number of bids per contract.

3 Possible collusion scheme

In this section, we describe the observed bids, and present two hypotheses on the behavior of the ring. Figure 1 shows the distribution of bid, and Figure 2 shows the distribution of winning bids in the period we observe. The vertical axis in the figures represents the "Normalized bid" which is computed as the actual bid divided by the reserve price.[4]

Figure 1 shows that, in 123 out of 139 auctions, winning prices are in the neighborhood of 93% of the estimated price, and losing bids are distributed between the winning bid and the reserve price. Remaining 16 contracts were won at the minimum price. In the 16 auctions, most bids were submitted at the minimum price, and the winner was determined by a public lottery. The minimum price was set at about 80-85% of the reserve price. 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 2.

3.1 An agreement to bid at the minimum price

The first hypothesis is 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 bidder 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 are instructed to bid at the minimum price in the auction.

Bajari and Ye (2003) model 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 cartel members are supposed to submit the lowest possible bid when they face an outsider in the market we analyze.

It is not conclusive evidence of collusion that many bidders simultaneously bid the minimum price. It can result from competition if the contract is profitable even when it is won at the minimum price. It would be the case, for example, when the material price suddenly dropped, or when the minimum price is set high by mistake. However, it is more natural to think that a collusive agreement is in place if it happens only when a specific bidder participates.

In Section 5, we examine the data to see if the price wars took place only in auctions where a specific firm submitted a bid, and to find out the possible outsiders.

[4]Sometimes collusiveness of auctions is measured by the normalized bid. It is claimed by lawyers that a market is suspicious of bid rigging if the normalized bid is higher than 95% on average. Actually, in bid rigging cases in the past, the winning price was extremely close to the reserve price. From that point of view, the market we analyze seems to be non-collusive. However, the reason of a high normalized bid is not necessarily bid rigging, and a low normalized bid does not always mean competition. We don't conclude if the market is competitive or not based only on the level of the normalized bid.

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

The second hypothesis is that the winner was selected according to a collusion scheme when the ring was all-inclusive in the auction.

According to Suzuki (2004), every Japanese bidding ring had its own rule to select the winner.[5] Some of those rules are based on comparing its members' *priority* to win the contract.

In this study, we supposed that a bidder's priority is evaluated based on the history of auctions. We can categorize those schemes as follows.

1) Simple rotation scheme

   A simple rotation scheme equalizes the chance of winning by assigning contracts to ring members in turn. Because of the exogenous choice of bidders by the city before each auction, the ring cannot use mechanical rotation. Instead, a bidder is chosen as the winner if he has not won for the longest time among ring members. The ring compares the number of days from the last winning, 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 rewarding scheme gives more priority to bidders who made more contribution in the past auctions. A member's contribution is to submit a phony bid allowing the other bidder to win. Once his contribution is rewarded with a winning, the amount of his contribution is decreased. Therefore, the winner may be selected by comparing a measure of contribution, which is increasing in the number of losing, and decreasing in the number of winning in the past.

4) Combination

   There can be a scheme in which some of above schemes are combined.[6] There can be various combinations of above schemes. In the following analysis, we focus on

[5] According to the reports written by former industry experts, there seems to be a lot of bid rigging groups in which the winner is just selected through discussions, consuming a plenty of time. Hironaka (1994), Kato (2005).

[6] According to Suzuki (2004), such a scheme is often called a "scoring scheme", since the scheme systematically assigns each member a score in order to take various factors into evaluation of the priority. The ring compares the members' scores, and then, the bidder with the highest score is selected as the winner.

a combination of the revenue equalizing scheme and the simple rotation scheme, in which both the time elapsed from the last win and the amount of win in the past are considered in the selection of the winner.

These schemes assure each member of winning regularly in order to maintain collusion. They can be operated when the value of contracts for members is common or private.

When either of above schemes are in operation, it is possible to detect the collusion. There must be a link between the outcome of each auction and history (the date, the participants, the winner, and bids of every previous auction) when bidders collude using the scheme, whereas, there must be no such link between each auction result and the historical factors that are considered in the scheme under competition. Therefore, we can see whether they collude or not by testing if the historical factors have an impact on the auction result. In Section 6, we examine the data to see if these schemes were in operation.

4 The data

This study looks at auctions for paving contract awarded by Ibaraki City during four years between April 2002 and March 2005. 139 contracts were awarded and 13 firms submitted bids in the auctions during the period.

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 3.

5 Analysis of price wars

In this section, we observe the data to find a support for the first hypothesis that all the ring bidders submitted bids at the minimum price only when outsiders were in the auction.

In our data, we can clearly discriminate normal prices and unusually low prices: In 16 auctions out of 139, the winning price is equal to the minimum price, and further, most bids were submitted at the minimum price in these auctions.

First we run a simple binary response mode to see whether the price wars took place only when a specific firm participated in auctions. We analyze if a specific firm's participation in an auction raised the probability that the auction was the price war.

y_t indicates whether auction t was a price war or not. Define $y_t = 1$ if the winning price was equal to the minimum price in auction t, and $y_t = 0$ otherwise.

The explanatory variables are index variables that represent the participation of firms. Suppose that F_{it} is an index variable which represents whether firm i participated in auction t. $\mathrm{F}_{it} = 1$ if $i \in M_t$, and $\mathrm{F}_{it} = 0$ otherwise, where M_t indicates the set of bidders in auction t. Suppose that y_t^* is an index which consists of F_{it}s and an error term u_t,

$$y_t^* = a + b_1\mathrm{F}_{1t} + ... + b_{13}\mathrm{F}_{13t} + u_t.$$

We analyze if there is the participation of each firm has a positive impact on the probability of price wars. That is, assuming that $y_t = 1$ if $y_t^* > 0$, we examine if $b_i > 0$ for some i. u_t is assumed to follow the standard logistic distribution. The probability of the price war for auction t is then written as

$$\Pr(y_t = 1 \mid \mathrm{F}_{1t}, ..., \mathrm{F}_{13t}) = \Pr(y_t^* > 0 \mid \mathrm{F}_{1t}, ..., \mathrm{F}_{13t}) = \frac{\exp(a + \sum_{i=1}^{13} b_i\mathrm{F}_{it})}{1 + \exp(a + \sum_{i=1}^{13} b_i\mathrm{F}_{it})}.$$

We then maximize the likelihood $L(a, b_1, ..., b_{13}|\mathrm{F}_{1t}, ..., \mathrm{F}_{13t}) = \prod_{t=1}^{139} \Pr(y_t = 1 \mid \mathrm{F}_{1t}, ..., \mathrm{F}_{13t})$.

We test the null hypothesis $b_i = 0$, against the alternative hypothesis that $b_i > 0$. If $b_i > 0$ for some i, then firm i's participation has a positive impact on the probability of price wars. That is, it is likely that price wars were caused by firm i's participation, and that firm i was possibly an outsider of the ring.

Table 5 reports the result. The parameter of firm 13's participation dummy was not estimated and 4 observations were lost because of perfect prediction. That is, price wars took place in all of 4 auctions that firm 13 participated in. The only significant parameter is that of firm 8's participation dummy, which is positive and significant at 1% significance level.

It is found that firm 8 and firm 13 are possible outsiders. Having this result, we further observe the data. Figure 3 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. For example, the black dot at coordinate $(15, 2)$ implies that firm 2 submitted a bid in Auction 15, and that the auction was not a price war.

In Figure 3, we can find a sequence of 4 white dots from coordinate $(2, 13)$ to coordinate $(10, 13)$, which is framed by a square. 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. In addition, firm 13 did not submit 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.

We find another sequence of 8 white dots from coordinate $(68, 8)$ to coordinate $(81, 8)$ framed by another square. 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. The ring must have been all-inclusive after firm 13 was excluded from the market and firm 8 was included into the ring.

We are not sure that winning a contract at the minimum price is profitable for firms. It can be unprofitable for some firms, since the ratio of profit to sales is 0.27% on average (Table 4).

If it is unprofitable, the above observations fit to the context of the "deep pocket predation". In general, it is the behavior of a large firm deriving a small competitor out of the market by causing a price war that gives losses to both. The small competitor has limited resources and will therefore be unable to survive such losses for a long time. Sooner or later, it will have to give up and leave the industry, allowing the large firm to increase prices and recoup losses (Motta (2004)).

The ring plays the role of the large firm in that story. Bidding at the minimum price can be a predatory behavior of the ring to exclude an outsider from the market. 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.

The analysis in this section reveals that the price wars took place in all auctions where firm 13 submitted bids and in a series of auctions where firm 8 submitted bids during 5 months. This suggests that there may have been an agreement that the ring bidders bids at the minimum price when one of these two firms participated in the auction. 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.

Note that the observed price wars cannot be an evidence of collusion by itself. There still remains a possibility that there is no agreement among bidders. Suppose a situation where winning a contract at the minimum price is profitable for firms, and firm 8 and firm 13 are so aggressive bidders that they always bid at the minimum price. If it is recognized by the others, a price war can be a natural outcome without any agreement, since it is best for other bidders to respond by bidding at the minimum price.

6 Analysis of collusion scheme

In the following, we analyze the data to detect the collusion by identifying the ring's collusion scheme. 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 which were not the price war.

An important assumption here is that the ring was all-inclusive in the 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.

We run both collusive models and a competitive model which is an arrangement of a model first proposed Porter and Zona (1993). In the competitive model, only the cost factors have impacts on the winning. In the collusive models, the ring chooses the designated winner according to either of the collusion schemes described in Section 3.2. We then compare the goodness of fit of the models, and discuss which model is most likely.

6.1 Conditional logit model of the ring's choice on the winner

We model the ring's choice of the winner as a conditional logit model. Let M_t denote the set of bidders in auction t. We suppose that the ring chooses the bidder whose priority is the highest among M_t, and that for $i \in M_t$, bidder i's priority can be written as $a_i + \mathrm{BRANCH}_i + \beta' \mathbf{x}_{it}$, where $\mathbf{x}_{it}$ denotes the vector of factors that determine bidder i's priority in the collusion scheme, and BRANCH_i is a dummy variable which indicates if bidder i is a branch office of an outside firm. Bidders are suppoed to have different intercepts a_i since we consider that bidders may not be treated equally in the scheme even though their $\mathbf{x}_{it}$ are the same. 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 model the ring's choice on the winner as a comparison of the following index w^*_{it}.

$$w^*_{it} = \sum_{k=1,2,\ldots,12} a_k d_k + \beta' \mathbf{x}_{it} + \gamma\, \text{BRANCH}_i + \delta\, \text{CAP}_{it} + u_{it},\ i \in M_t. \tag{1}$$

u_{it} is the disturbance that arises in bidder's priority. a_k is the firm specific constant term for each firm k. d_k is a dummy variables, which is $d_k = 1$ if $i = k$ and $d_k = 0$ otherwise. CAP_{it} is the measure of bidder i's used capacity on project t. Since used capacity can be correlated with some $\mathbf{x}_{it}$, we add it to the model to separate its effect. For example, the number of days from one's last winning may be negatively correlated with his used capacity, since a bidder who won a contract recently has high capacity utilization and small number of days from the last winning.

We suppose that bidder i wins when his w^*_{it} is higher than that of any other bidder in the auction. Therefore, the probability that bidder i wins in auction t conditional on M_t and $\mathbf{x}_t$ is written as:

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

where w_t indicates the identity of the winner in auction t and $\mathbf{x}_t$ is a vector that consists of $\mathbf{x}_{it}$ for all $i \in M_t$. McFadden (19733) 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:

$$\Pr(w_t = i| \ M_t, \mathbf{x}_t) = \frac{\exp(a_i + \beta' \mathbf{x}_{it} + \gamma\, \text{BRANCH}_i + \delta\, \text{CAP}_{it})}{\sum_{j \in M_t} \exp(a_j + \beta' \mathbf{x}_{jt} + \gamma\, \text{BRANCH}_j + \delta\, \text{CAP}_{jt})}. \tag{2}$$

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

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

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.

The key factors $\mathbf{x}_{it}$ under each possible scheme is modeled as follows. The definition of variables are in Table 3.

1) Model for the simple rotation scheme

$$\mathbf{x}_{it} = \text{WAITING}_{it} \tag{3}$$

2) Model for the revenue equalizing scheme

$$\mathbf{x}_{it} = \text{WINVALUE}_{it} \tag{4}$$

3) Model for the contribution rewarding scheme

$$\mathbf{x}_{it} = (\text{WINNUM}_{it}, \text{LOSENUM}_{it}) \tag{5}$$

4) Model for the combination

$$\mathbf{x}_{it} = (\text{WAITING}_{it}, \text{WINVALUE}_{it}) \tag{6}$$

6.2 The competitive model

For comparison, we estimate an arrangement of the conditional logit model proposed by Porter and Zona (1993). They derive bidder's probability of winning in competition, imposing an assumption that the firms respond similarly to changes in the observable cost factors. They model firm i's bidding behavior in auction t as:

$$b_{it} = a_i + \beta \mathbf{x}^c_{it} + u_{it}, \tag{7}$$

where $\mathbf{x}^c_{it}$ is a vector of observable variables affecting bidder i's cost on project t. a_i is the firm specific constant term and u_{it} is the disturbance. Assuming that u_{it} is distributed as a Type I extreme random variable, the probability of winning of firm $i \in M_t$ is written as:

$$\Pr(w_t = i \mid M_t, \mathbf{x}^c_t) = \Pr(b_{it} \geq b_{jt} \ \forall j \in M_t, j \neq i \mid M_t, \mathbf{x}^c_t) = \frac{\exp(a_i + \beta \mathbf{x}^c_{it})}{\sum_{j \in M_t} \exp(a_j + \beta \mathbf{x}^c_{jt})}.$$

In our analysis, $\mathbf{x}^c_{it}$ = (CAP$_{it}$, CAPSQ$_{it}$, YEARS$_i$, WORKER$_i$, PROFITRATE$_i$).[7]

6.3 Result

Figure 4 shows the empirical results of models for competition and collusion under various schems including the simple rotation scheme, the revenue equalizing scheme, the contribution rewarding scheme, and the combination.

[7]In Porter and Zona (1993), $\mathbf{x}^c_{it}$ includes the capacity utilization rate (CAP$_{it}$), squared utilization rate (CAPSQ$_{it}$), a firm's maximum capacity, squared maximum capacity, and a dummy which indicates if the firm is in a close proximity of the work site. CAP$_{it}$ and CAPSQ$_{it}$ are the only statistically significant variables in their model.

The first column shows the estimates of the competitive model described in 6.2. The parameter of used capacity is significant in the model. However, the null hypothesis that all parameters except the constant term are zero is accepted, with LM test statistics of 16.7 and degree of freedom 12.

The remaining columns show the estimates of the models of collusion described in 6.1. The second column shows the estimates of the simple rotation scheme model. It can be seen that a bidder's probability of winning tends to be high if his time elapsed from his last win is long.

The third column shows the estimates of the revenue equalizing scheme model. We can see that a bidder's winning probability tends to be low if his capacity utilization is high, and if the accumulated value of winning is high relative to the other firms.

The fourth column shows the estimates of the contribution rewarding scheme. The number of losing does not raise the winning probability significantly. That is, a bidder's contribution is not rewarded.

The final column shows the estimates of the combination model, which is the combination of the simple rotation scheme and the revenue equalizing scheme.[8] In this scheme, both the length of waiting and the total revenue are considered into the choice on the winner. The result shows that both the parameters of the length of waiting and the accumulated value of winning are significant. It can be seen that a bidder tends to win if he has been waiting long or his accumulated value of winning until the auction is low relative to other bidders.

Throughout the specifications, the branch dummy is negative. That is, being a branch decreases the probability of winning. An outside firm might have been handicapped in the actual scheme. As we can see in Table 4, 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.

We note that some of the models violate Independence from Irrelevant Alternatives (IIA) assumption.[9] By applying the Hausman test, it is confirmed that IIA assumption is violated in models of the revenue equalizing scheme and the contribution rewarding scheme. Hence these should be excluded from possible collusion schemes.

In comparison of the log likelihood and adjusted pseudo R^2 of the models, the combination model is outperforming among them, and therefore, we consider that the combination model is most likely to be true. It can be suggested that the ring

[8] We run several forms of combination, and this works best among them.

[9] IIA assumption is that the logit probability ratio between any two alternatives does not depend on any alternatives other than the two.

selected a bidder as the winner, if its waiting time was long and its winning value until the auction was small relative to the other bidders.

The above finding can be the evidence of collusion. The historical factors such as each bidder's waiting time don't affect the cost. Therefore, if an auction is competitive, there must be no link between the auction result and those factors. We can say that the detected impact of the factors on the auction results is due to collusion.

Table 6 shows the estimated marginal effects in the combination model. Being an outside firm decreases the probability of winning by 43%. Waiting for a day longer increases the probability by 0.1%. An increase in the amount of past winning by one million yen decreases the probability by 0.5%.

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, or because the scheme is flexibly used in actual collusion.

7 Conclusion

We analyze auction data to find an empirical evidence of collusion in procurement auctions for paving works. We propose two hypotheses on the behavior of the ring. The first is that all the ring bidders submitted bids at the minimum price only when outsiders were in the auction. We analyzed the impact of each firm's participation on happening of the price war using a binary response model. It is found that price wars tended to occur when either of specific two firms submitted bids. The two firms were probably outsiders of the ring. It can be inferred that one of them exited from the market due to the predatory price wars, and the other may have joined the ring, ending a series of price wars.

The second hypothesis is that the winner was selected according to some systematic scheme when the ring was all-inclusive in an auction. We suppose that the scheme took the form of a comparison of each member's priority to win, and the ring selects the member whose priority is the greatest among other bidders. We also suppose that a bidder's priority is measured by historical factors such as the time elapsed from one's last win.

We run several models including a competitive model and collusion models in which the winner is selected according to possible collusion schemes. We then compare the goodness of fit of the models. It is found that, in the outperforming model, a bidder tends to win if his time elapsed from his last win is long, and his amount of win in the past was low relative to other bidders. If an auction is competitive, there must be no link between the auction outcome and those two factors. Therefore, it can be said that the detected impact of the factors on the winning probability is due to collusion.

Our findings figure out the behavior of the ring. The ring allocated contracts to the ring bidders, equalizing the frequency of winning and the revenue among ring members when the ring was all-inclusive in the auction. When an outsider submitted a bid in an auction, all of the ring bidders bid at the minimum price.

A Appendix: Similarity of collusion schemes: an analysis on artificially generated data

In Appendix A, we examine artificially generated data sets to show that the alternative collusion schemes are similar and can be misidentified in our method. Several data sets are generated artificially. In each data set, the winner is selected according to a rigid collusion scheme. We then apply the models used in Section 6.1 to the data sets and show the possibility that an untrue model is identified.

A.1 Data generating procedure

We assume a market where there are symmetric 10 firms. A procurement auction is held every period $t = 1, 2, ..., 2000$. 5 bidders are randomly chosen among the firms for every auction. The reserve price of each auction is realized from a uniform distribution over $[0, 1]$. In every auction, the contract is won at the reserve price. We generate the following four data sets and then, create the following variables for each data set: WAITING_{it}, WINVALUE_{it}, WINNUM_{it} and LOSENUM_{it}.

a) Random selection data: The winner is randomly selected among the bidders.

b) Simple rotation scheme data: A bidder whose length of waiting is longer than any other bidders is selected as the winner. In case of a tie, the winner is selected randomly among the tie bidders.

c) Revenue equalizing scheme data: A bidder whose amount of winning in the past is less than any other bidders is selected as the winner. In case of a tie, the winner is selected randomly.

d) Contribution rewarding scheme data: A bidder whose *contribution* is greater than that of any other bidder is selected as the winner. Bidder i's contribution at period t is calculated as follows.

$$\text{contribution}_{it} = -5 * (\text{the number of winning until } t) + (\text{the number of losing until } t)$$

In case of a tie, the winner is selected randomly.

Each data set is further arranged into two types of data sets: the small data set and the large data set. The small data set includes the data of auctions $t = 1, 2, ..., 500$ with 2500 observations, whereas, the large data set includes all 2000 auctions with 10000 observations.

A.2 Discussion

The estimation results are shown in Table 7. Table 7-a) shows the estimation results using the data sets in which the winner is randomly selected. The estimated parameters of the variables in the collusion schemes are not significant except WINVALUE and WINNUM. WINVALUE and WINNUM are significant but do not have the expected signs. The significance of these parameters remains unexplained. However, it is confirmed that the variables which are used in the collusion schemes do not have the expected impact on the auction results if the winner is selected randomly.

Table 7-b), c) and d) show the estimation results using the data sets in which the winner is selected according to the simple rotation scheme, the revenue equalizing scheme, and the contribution rewarding scheme, respectively.

As shown in b), WINVALUE is negative and significant in the estimations using the simple rotation scheme data. That is, the simple rotation scheme looks like the revenue equalizing scheme. As shown in c), WAITING is positive and significant in the estimations using the revenue equalizing scheme data. We can say that the simple rotation scheme and the revenue equalizing scheme are similar to each other.

In b), WINNUM is also significant, but LOSENUM is not. In c), both WINNUM and LOSENUM are significant, but LOSENUM does not have the expected sign. We can say that neither the simple rotation scheme nor the revenue equalizing scheme looks like the contribution rewarding scheme. However, as shown in d), both WAITING and WINVALUE are significant and have expected sign, and hence, the contribution rewarding scheme looks like the simple rotation scheme and the revenue equalizing scheme. By the comparison of R^2 and the log likelihood, it can be said that the contribution rewarding scheme is more similar to the simple rotation scheme.

References

[1] Aoyagi, M. (2003), “Bid Rotation and Collusion in Repeated Auctions,” Journal of Economic Theory, 112, pages 79-105.

[2] Bajari, P. and Ye, L. (2003), “Deciding Between Competition and Collusion,” Review of Economics and Statistics, 85.4, pages 971-989.

[3] Hironaka, K. (1994), "*Dango* survives after all (*Soredemo dango ha naku-naranai*)," Tokei Publishing (in Japanese).

[4] Kato, M. (2005), "We did *Dango* (*Dango shimashita*)", Saizusha (in Japanese).

[5] McAfee, R. P. and McMillan, J. (1992), "Bidding Rings," American Economic Review, 82.3, pages 579-599.

[6] McFadden, D. (1973) "Conditional Logit Analysis of Qualitative Choice Behavior," in *Frontier in Econometrics*, edited by Paul Zarembka. Academic Press.

[7] McMillan, J. (1991) "Dango: Japans Price Fixing Conspiracies", Economics and Politics, 3, pages 201-218.

[8] Motta, M. (2004), "Competition Policy," Cambridge University Press.

[9] Pesendorfer, M. (2000), "A Study of Collusion in First-Price Auctions," Review of Economic Studies, 67, pages 381-411.

[10] Porter, R. H. and Zona, J. D. (1993), "Detecting of Bid Rigging in Procurement Auctions," Journal of Political Economy, 101.3, pages 518-538.

[11] Porter, R. H. and Zona, J. D. (1999), "Ohio school milk markets: an analysis of bidding," RAND Journal of Economics, 30.2, pages 263-288.

[12] Skrzypacz, A. and Hopenhayn, H. (2004), "Tacit collusion in repeated auctions," Journal of Economic Theory.

[13] Suzuki, M. (2004), "A study of bid rigging (*Nyusatsu dango no kenkyu*)," Shinzansha (in Japanese).

[14] Zona, J. D. (1986), "Bid-rigging and the Competitive Bidding Process: Theory and Evidence." Ph.D. dissertation, State University of New York at Stony Brook.

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: Definition of variables

Variables	Definition
CAP_{it}	The measure of capacity utilization rate. This is defined as the value of backlog contracts devided by the firm's average annual sales. 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.
$PROFITRATE_{i}$	The rate of profit on sales, observed in 2004.
$BRANCH_{i}$	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.
$WAITING_{it}$	The number of days between Firm i's last winning and the date of Auction t.
$WINVALUE_{it}$	The total value of contract that Firm i won from the start of the data period until the date 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: Distribution of bids

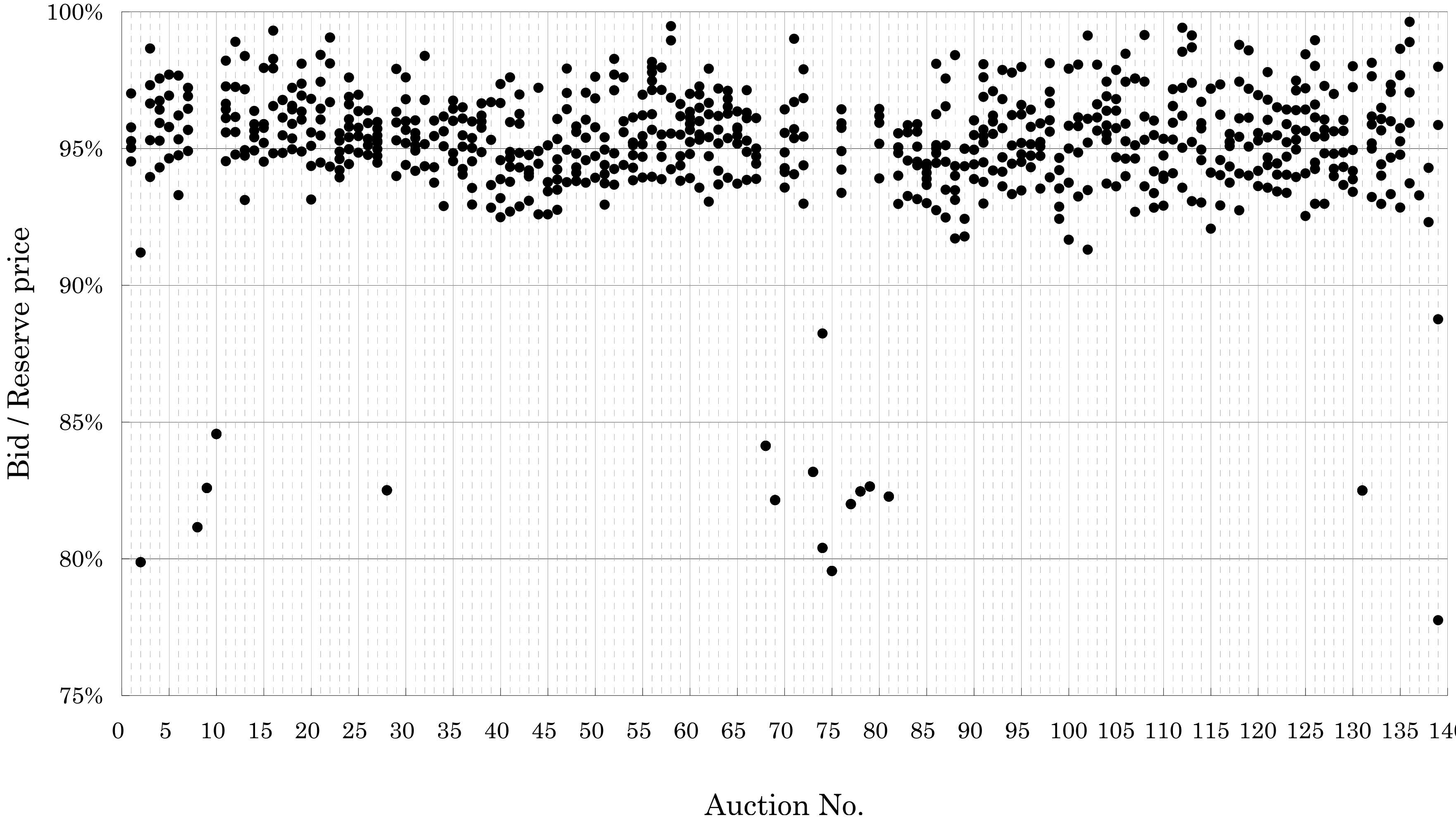

Figure 2: Distribution of winning price

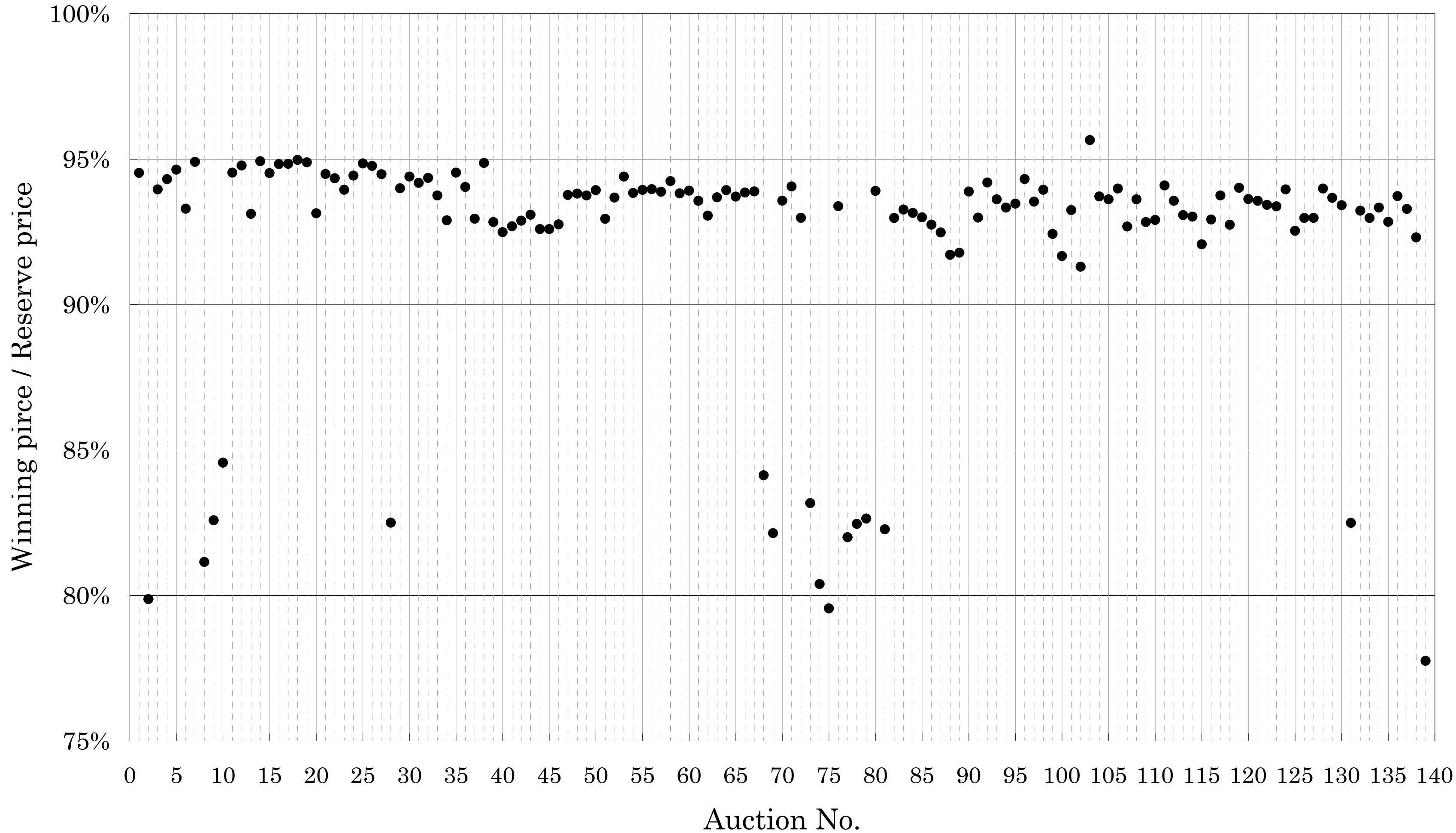

Table 4: Information of firms

Firm ID	Headquarter / Blanch	Number of technical workers	Years of operating	Ratio of operating profit to sales	Number of bids submitted	Number 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 5: Estimates of logit analysis

Variables	Estimates
Firm 1	0.509
	(1.107)
Firm 2	-0.357
	(1.094)
Firm 3	1.587
	(0.965)
Firm 4	-0.066
	(0.893)
Firm 5	0.689
	(0.948)
Firm 6	-1.523
	(1.375)
Firm 7	-0.407
	(1.081)
Firm 8	2.667**
	(1.021)
Firm 9	-0.009
	(0.836)
Firm 10	-0.34
	(0.94)
Firm 11	-1.716
	(1.364)
Firm 12	0.134
	(0.9)
Firm 13	-
	(-)
Constant	-4.738
	(3.11)
Num of Obs.	135
Log Likelihood	-28.771
Pseudo R2	0.245

Note: Standard errors in parentheses

Figure 3: Participation and price wars

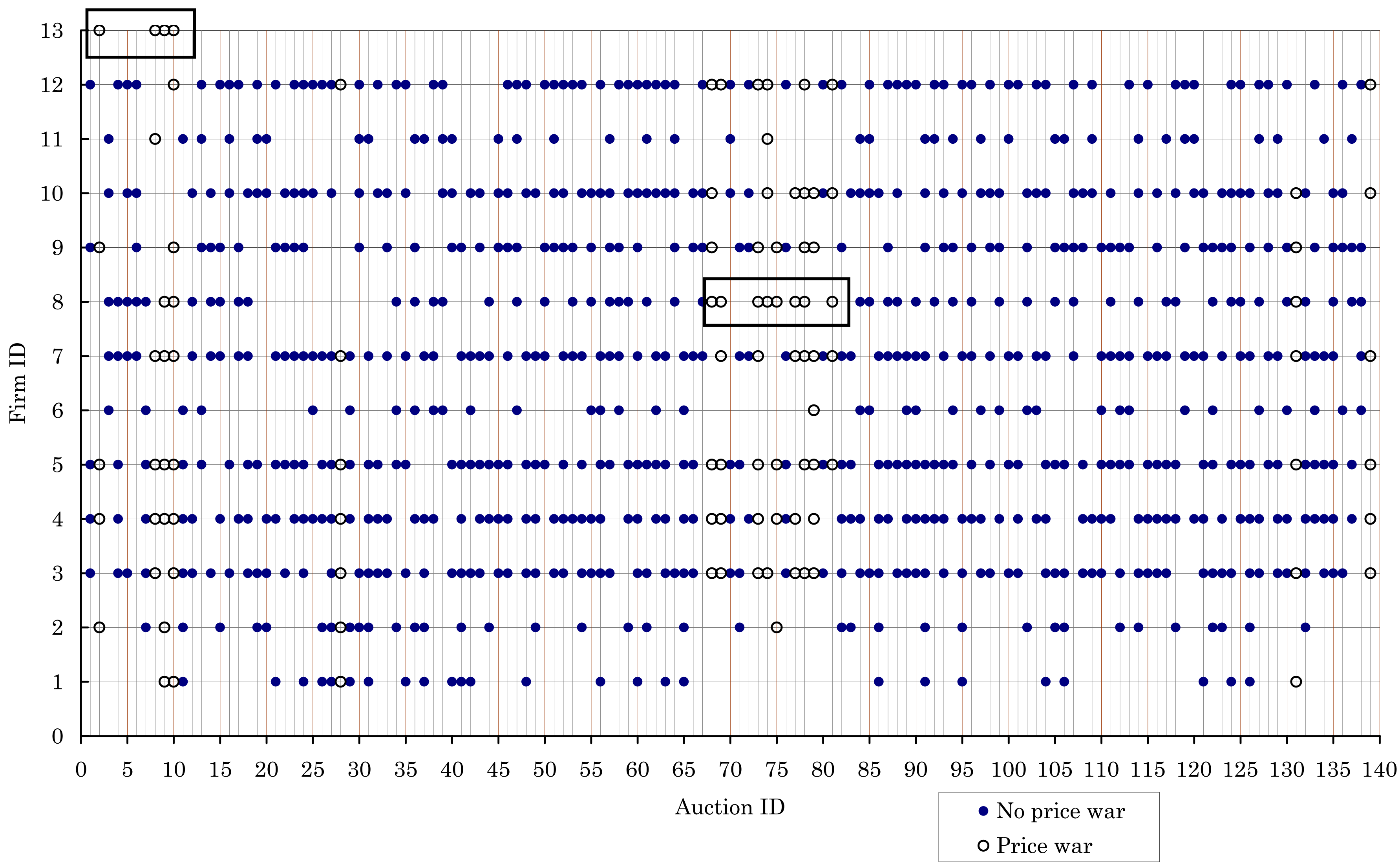

Figure 4: Estimation result for conditional logit models

Variables	Competitive	Simple rotation	Revenue equalizing	Contribution rewarding	Combination
CAP	-0.0101**	-0.0037	-0.0059*	-0.0054*	-0.0036
	(0.004)	(0.0024)	(0.0024)	(0.0024)	(0.0025)
CAPSQ	1.36E-05	-	-	-	-
	(9.72E-06)				
YEARS	-0.0253	-	-	-	-
	(0.0230)				
WORKER	0.0301	-	-	-	-
	(0.0535)				
PROFITRATE	-0.0008	-	-	-	-
	(0.0470)				
WAITING	-	0.0072**	-	-	0.0068**
		(0.0014)			(0.0014)
WINVALUE	-	-	-0.0236**	-	-0.0209*
			(0.0076)		(0.0082)
WINNUM	-	-	-	-0.2282**	-
				(0.0717)	
LOSENUM	-	-	-	0.0148	-
				(0.0195)	
BRANCH	-	-3.9163**	-2.018*	-3.0163**	-4.0883**
		(1.0234)	(0.8518)	(0.9856)	(1.0288)
Number of obs.	731	731	731	731	731
Log Likelihood	-209.65	-195.40	-205.08	-204.95	-191.97
Violation of IIA	No	No	Yes	Yes	No
Pseudo R2	0.041	0.107	0.062	0.063	0.122
Adjusted Pseudo R2	-0.018	0.047	0.003	-0.001	0.058

Note: Standard errors are displayed in parentheses.
The models also include a dummy for each firm in the market.
**: 1% significance, *: 5% significance.

Table 6: Estimated marginal effects in the combination model

Variables	Marginal effects
CAP	-0.0008
	(0.0005)
BRANCH	-0.4254**
	(0.1535)
WAITING	0.0014*
	(0.0006)
WINVALUE	-0.0053*
	(0.0022)

Table 7: Estimation results with artificially generated data

a) Data in which the winner is randomly selected

Model	A	A	B	B	C	C
WAITING	-0.0021	0.0017				
	(0.0025)	(0.0053)				
WINVALUE			0.0069*	0.0165		
			(0.0034)	(0.0166)		
WINNUM					0.0051*	0.0055
					(0.0025)	(0.0128)
LOSENUM					0.0005	-0.004545
					(0.0017)	(0.0095)
Num of Obs.	10000	2500	10000	2500	10000	2500
Log Likelihood	-3216.91	-803.06	3215.24	-802.61	-3214.25	-802.48
Pseudo R2	0.0001	0.0001	0.0006	0.0006	0.0009	0.0006

b) Data generated by the Simple rotation scheme

Model	A	A	B	B	C	C
WAITING	36.3146	36.3921				
	(2913440)	(5829895)				
WINVALUE			-0.0335**	-0.2646**		
			(0.0088)	(0.0484)		
WINNUM					-0.1805**	-0.7453**
					(0.0155)	(0.0716)
LOSENUM					-0.0026	0.0119
					(0.0016)	(0.0093)
Num of Obs.	10000	2500	10000	2500	10000	2500
Log Likelihood	-9.35	-9.35	-3211.56	-789.19	-3144.56	-735.49
Pseudo R2	0.997	0.988	0.019	0.019	0.023	0.086

c) Data generated by the Revenue equalizing scheme

Model	A	A	B	B	C	C
WAITING	0.1134**	0.1069**				
	(0.0048)	(0.0094)				
WINVALUE			-519337.6	-529070.9		
			(-)	(-)		
WINNUM					-0.0111**	-0.0837**
					(0.0043)	(0.0238)
LOSENUM					-0.0036*	-0.0233*
					(0.0017)	(0.0098)
Num of Obs.	10000	2500	10000	2500	10000	2500
Log Likelihood	-2921.22	-736.85	-9.57	-9.57	-3214.84	-798.52
Pseudo R2	0.093	0.084	0.997	0.988	0.001	0.008

d) Data generated by the Contribution rewarding scheme

Model	A	A	B	B	C	C
WAITING	0.5309**	0.5157**				
	(0.014)	(0.0274)				
WINVALUE			-0.0331**	-0.0874**		
			(0.009)	(0.0293)		
WINNUM					-185.3124	-200.9755
					(-)	(-)
LOSENUM					18.5898**	20.0815**
					(0.0075)	(0.0492)
Num of Obs.	10000	2500	10000	2500	10000	2500
Log Likelihood	-1603.09	-412.55	-3211.96	-800.3	-197.29	-63.02
Pseudo R2	0.502	0.487	0.002	0.006	0.939	0.922

Note:
Model A: Simple rotation scheme model
Model B: Revenue equalizing scheme model
Model C: Contribution rewarding scheme model
**: 1% significance, *: 5% significance