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Detecting Collusions in Japanese Municipalities*

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Abstract

This paper presents evidence on the pervasiveness of bid rigging in procurement auctions by Japanese municipalities. Using bid data on public works projects from 56 municipalities in the Tohoku region, we examine persistence of rank order of bidders in the initial auction and reauction that occurs when all bids fail to meet the secret reserve price in the initial auction. We find that there is much unknown bid rigging. We also develop a formal test for bid rigging that can be applied to sets of firms. Our test results suggest that a lower bound of the share of ring firms is 23.5% of all contracts.

Key words: Collusion, Procurement Auctions, Antitrust
JEL classification: D44, H57, K21, L12

1 Introduction

This paper presents descriptive evidence on the pervasiveness of bid rigging in public procurement auctions by Japanese municipalities. Although bid rigging is illegal and violators

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face severe penalties including payment of fines, temporary exclusion from government procurement auctions, and even criminal charges in some cases, many bidding rings may exist without being detected by competition authorities. In this paper, we document evidence of widespread collusion among municipal public works auctions held in recent years (2010-2017) in the Tohoku region of Japan. Given that public works projects typically account for a substantial part of the economy (in Japan, it is about $\$200$ billion per year, or about 4% of its GDP (12 % in OECD countries[1]), successful detection and prosecution of collusive activity can have economy-wide significance.

The detection method that we apply in this paper is based on Kawai and Nakabayashi (2018), who study procurement auctions let by the Ministry of Land, Infrastructure and Transport in Japan between 2003 and 2006. Kawai and Nakabayashi (2018) exploit bidding data from reauctions to detect collusive behavior. Reauction is an auction that takes place after an unsuccessful initial auction in which none of the bids meets the secret reserve price. In this paper, we apply the method to a novel dataset that includes approximately 50,000 procurement auctions held by more than fifty municipalities in Japan.

In our dataset, we observe that reauctions occur in approximately 13% of lettings. Given that bidding rings often predesignate a member to be the winner, bidding data from reauctions offer an opportunity to detect collusion by examining whether or not there is persistence in the identity of the lowest bidder across the initial auction and the reauction. In particular, by focusing on auctions in which the lowest- and the second-lowest bidders bid almost identically in the initial auction, it is possible to differentiate between persistence attributable to simple cost differences and persistence attributable to the winner being prearranged. Persistence in the identity of the lowest bidder, beyond what can be explained by simple cost differences, suggests that the allocation of the project is predetermined through a collusive agreement.

Using data collected from municipal public works auctions in Japan, we first document high levels of persistence, of more than 90 percent, in the identity of the lowest bidder among the municipal procurement auctions that we study. We also find that the percentage remains high even as we take the difference in the bids between the lowest and the second-lowest bidders from the initial auction to zero. This is in contrast to the fact that the persistence in trailing bidders is quite low between the initial auction and the reauction, e.g., the probability that the first-round second lowest bidder outbids the initial-round third lowest bidder in the reauction is about 50 percent of the time.

[1]OECD (2017), "Size of public procurement", in *Government at a Glance 2017*, OECD Publishing, Paris.

We then examine more closely how the lowest and the second-lowest bidders from the initial auction bid in the reauction. We document anomalous bidding patterns in the reauction, in which the lowest bidder from the initial auction is seemingly able to consistently outbid the second-lowest bidder by a small margin, while being able to avoid being outbid by the second-lowest bidder by a small margin. In particular, the distribution of the bid difference in the reauction between the two lowest bidders from the initial auction has a sharp kink at zero. We find no such kink for the distribution of the bid difference in the reauction between any two trailing bidders from the initial auction. Our findings imply that the bidders know how each other will bid in the reauction, and moreover, the second-lowest bidder from the initial auction (as well as all of the other bidders) purposely bid higher than the lowest bidder to let the designated firm win the auction. These findings are suggestive of communication among auction participants.

We finally construct a formal test for pervasiveness of collusion in the data. We focus on three municipalities that do not reveal the lowest bid in each round. The null of competition is that the rank order of the first round does not affect the second-round bidding. In particular, the second-round bidding of bidder i should not depend on whether bidder j's ($j \neq i$) first-round bid is marginally above or below its first-round bid if the auctioneer does not reveal the lowest bid in each round. Based on the observation, we test for collusion in the second round by a regression discontinuity estimation, measuring the marginal effect of the rank order in the first round on the second-round bidding.

In practice, we apply the test to sets of bidders and compute the share of the bidders by taking the number of contract awards divided by the lettings. Then, we estimate a lower bound of the share of bidders whose second-round bidding rejects the null of competition. In the baseline estimation, we find that a lower bound is 23.5%.[2]

The remainder of the paper is as follows. Section 2 reviews related literature. Section 3 explains the institutional detail of procurement auctions in our data. Section 4 describes the data. Section 5 provides the main analysis. Section 6 discusses the validity of our main analysis. Section 7 tests for pervasiveness of collusion. Section 8 concludes.

[2]The number of auctions whose winner is inconsistent with the null of competition is 630, and the total number of lettings in our sub-sample is 2,679. Note that the number of firms that won in the 630 collusive auctions is 68.

2 Literature Review

Our paper is related to empirical studies on cartels. There are two strands of empirical studies on collusion, depending on whether the test for collusion is based on known episodes of cartels or not.

The first group includes Porter and Zona (1993; 1999), Asker (2010), and Ishii (2014). Porter and Zona (1993; 1999) test for collusion by using data on DOT in New York state and school milk procurement auctions in Ohio. They test whether firms bid according to their costs by focusing on bid ranking (1993) and bid amounts (1999). Asker (2010) analyzes bid rigging in collective stamp auctions. He studies a novel dataset on "knockout" auctions, operated by the stamp dealers, as well as the data on stamp auctions that were targeted by the knockout auctions. By establishing a collusion equilibrium, he estimates damages, inefficiency, and ring members' benefits from collusion. Ishii (2014) tests for collusion, focusing on the "roundness level" of bids. Using data on auctions for construction works in Okinawa Prefectural Government, she finds that more zeros appear at the end of both winning and trailing bids when the auction is collusive than when the auction is competitive. The second group includes Bajari and Ye (2003), Ishii (2009), Conley and Decarolis (2016), and Kawai and Nakabayashi (2018). Bajari and Ye (2003) test for collusion by first deriving two conditions competitive bids must satisfy, i) conditional independence of bids and ii) exchangeability. They then test the conditions by using bid data on seal coat contracts. Ishii (2009) tests for bid rotation among land compensation consultants in Okinawa prefecture in Japan. By using a conditional logit model, she finds that observed bid patterns are not from competition but from "the exchange of favor" among ring members, a typical scheme of rotation cartels.

Conley and Decarolis (2016) study the average bid auctions (ABAs). In this auction, the winner is the bidder whose bid is closest to an average bid. By using bid data for road construction works procured by municipalities in Italy, they document evidence of collusion.

Kawai and Nakabayashi (2018) detect large-scale collusion in procurement auctions by the national government of Japan. Their analysis focuses on reauctions and documents evidence of collusion by using an idea similar to the regression discontinuity design. While our paper follows Kawai and Nakabayashi (2018), the following two features are new. First, we document evidence of widespread collusion, using a novel dataset of municipal public-works auctions held in recent years. Second, we propose a formal test for collusion with which we identify a lower bound of the contract share of collusive firms. In this test, we focus on a set of municipalities that do not reveal the lowest bid of the initial auction when a reauction occurs. Given that bidders are *ex ante* symmetric in both initial auction and reauction in terms of information, the rank order of the initial auction should not affect rebidding unless bidders communicate with each other.

Our paper is also related to theoretical analyses on cartels. Awaya and Krishna (2017) model a repeated price-competition game in which players not only set prices but also play a cheap-talk game in each stage in terms of sales. Their results suggest that collusion can achieve higher payoffs if communication is possible and that communication among collusion members may be detrimental to social welfare. By constructing a model of an infinitely-repeated first-price auction, Chassang and Ortner (2015) investigate cartel stability. They show that a price constraint in the auction imposed by procurement buyers weakens cartel enforcement. Moreover, they test the theoretical prediction on procurement data from municipalities in Japan and obtain empirical results consistent with the prediction.

3 Institution

The format of the procurement auctions in the sample is first-price sealed bidding: the lowest bidder wins the project, subject to meeting the reserve price set by the auctioneer. Some municipalities use public reserve prices while others use secret reserve prices. For auctions with secret reserve prices, there is typically rebidding for the same project if all bids fail to meet the secret reserve price. In most cases, rebidding takes place within the same day, with the same set of bidders. If no bid meets the reserve price after several rounds of rebidding, the municipality may enter into a bilateral negotiation with one of the bidders.

For auctions with secret reserve prices, it is quite common for the auctioneer to announce the lowest bid to all of the bidders, as well as whether or not that bid meets the reserve price. None of the other bids is announced at this point, however. Because the distribution of the secret reserve price remains the same between the initial bidding and all subsequent rounds of rebidding, the bidders can update their beliefs about the reserve price based on the lowest bid from the previous round. All of the bids, the secret reserve price, and the identity of the bidders are made public after the auction concludes.

4 Data

We use bidding data for public construction projects let by municipalities in the Tohoku region of Japan. The data include all the bids in the initial auction as well as in subsequent rebidding. We also have information on the reserve price, the auction date, and bidder identities.

Our sample includes a total of 74,458 procurement auctions held by 56 municipalities between the years 2010 and 2017.[3] For some municipalities, the sample starts as early as 2010, while for others, the sample includes only the last few years. The construction projects that are part of our data comprise an important part of the economy of this region. For example, for the 2013 fiscal year, the data include about 12,000 auctions worth about 430 billion yen (or about 4.3 billion USD).Given that the total GDP of the 56 municipalities combined is 11.0 trillion yen, the public works projects in our data account for about 3.9 percent of the region's GDP.

Table 1 reports the summary statistics of our sample. The average reserve price is about 27 million yen, or about 270,000 dollars. The average winning bid is about 25 million yen. The average of the winning bid divided by the reserve price is 0.918. A large fraction of the auctions concludes in the first round. Approximately 13% of auctions proceed to the second round, and 4% of auctions proceed to the third round. The data includes all the bids in the initial auction as well as in subsequent rounds of rebidding. The data also includes reserve prices, dates, auction formats, and firm identities.

5 Analysis

Persistence in the Identity of the Lowest Bidder We begin by investigating whether persistence in the identity of the lowest bidder between the initial and subsequent rounds of bidding is beyond what competitive bidding would imply. When bidders form a bidding ring, the ring typically designates one of the bidders as the winner in advance. The non-designated members of the bidding ring bid less competitively than the designated bidder to make sure that the project is allocated as planned. Given that the secret reserve price is uncertain for ring members, the designated bidder can be expected to submit the lowest bid in each round of bidding. Hence, collusion may generate high persistence in the identity of

[3]We obtained data from a total of 122 municipalities. However, given that our detection method exploits rebidding, we use only data from the subset of municipalities that use rebidding.

Concluding Round	(R)eserve Yen M.	(W)inbid Yen M.	(W)/(R)	Lowest bid/Reserve Round 1	Round 2	Round 3	# Bidders	N
1	27.570	25.291	0.908	0.908	-	-	8.725	42,333
	(115.929)	(107.825)	(0.093)	(0.093)			(5.083)	86.75%
2	22.529	22.272	0.979	1.036	0.979	-	8.555	4,408
	(101.293)	(100.191)	(0.026)	(0.055)	(0.026)		(5.746)	9.03%
3	22.412	22.155	0.978	1.089	1.049	0.978	8.584	2,060
	(79.770)	(79.380)	(0.028)	(0.090)	(0.212)	(0.028)	(5.861)	4.22%
All	26.897	24.886	0.918	0.927	1.002	0.978	8.704	48,801
	(113.386)	(106.107)	(0.090)	(0.103)	(0.126)	(0.028)	(5.182)	100%

Table 1: Sample Statistics. The first row presents the sample in which the auction ends in the first round. The second or third row corresponds to the sample in which the auction proceeds to the second or third round. The first and second columns present the averages of the reserve price and the winning bid. The third column shows the fraction of the winning bid over the reserve price. The fourth through the sixth columns present the average fractions of the lowest bid over the reserve price in the initial auction, the first round of rebidding, and the second-round of rebidding. The number of bidders is shown in the seventh column. The last column presents the sample size.

the lowest bidder across multiple rounds of bidding.

The panels in Figure 1 illustrate the probability that the rank order of a pair of bidders is preserved across rounds as a function of the difference of their first-round bids. More precisely, let $i(k)$ denote the identity of the k-th lowest bidder in the initial auction. Let Δ_{kk+1} denote the difference between the first-round bids of $i(k)$ and $i(k+1)$ normalized by the secret reserve price:[4]

$$\Delta_{kk+1} \equiv \frac{\text{[First round bid of } i(k+1)] - \text{[First round bid of } i(k)]}{\text{Reserve price}}.$$

The vertical axis corresponds to the fraction of lettings in which the rank order of the two bidders is the same between the first and the second rounds. The horizontal axis describes $\Delta_{k,k+1}$ for $k = \{1, 2, 3, 4\}$. The top left panel illustrates that the probability of i(1)'s bid being lower than i(2)'s bid in the second round is close to 100% for most values of Δ_{12}, implying that reversals in ranking rarely occur across rounds. The figure also shows that even as Δ_{12} approaches 0, the probability that $i(1)$ outbids $i(2)$ in the second round remains very high. Note that if two bidders bid the same amount in the first round, the bidders are considered to be symmetric, i.e., their costs (and risk attitudes etc.) should be the same on average. Therefore, which bidder bids lower in the subsequent round should be as good as random if the lowest bid is not revealed. As we discuss later, we should expect that $i(2)$ outbids $i(1)$ more than 50% of the time, but not less if the lowest bid is revealed at the end of the first round.[5] Hence, the high frequency that $i(1)$ outbids $i(2)$ in the top-left panel is unlikely to be driven by simple cost differences.

The top right panel of the figure plots the probability that $i(2)$ outbids $i(3)$ in the reauction, as a function of Δ_{23}. For $i(2)$ and $i(3)$, the figure shows that the probability that $i(2)$ outbids $i(3)$ in the second round becomes close to 51% when Δ_{23} approaches zero. The bottom two panels illustrate analogous probabilities for $i(3)$ and $i(4)$, and for $i(5)$ and $i(6)$.

The bidding pattern illustrated in Figure 1 suggests that the persistence in the identity of the lowest bidder is beyond what competitive bidding would generate. These bidding patterns are consistent with a collusive bidding scheme in which the designated winner bids lowest in each round, and all the other bidders submit phantom bids that are not necessarily correlated with underlying costs.

[5] We also find that the probability that $i(1)$ outbids $i(2)$ is close to 100% for auctions in which the lowest bid is not announced. See Section 5 for details.

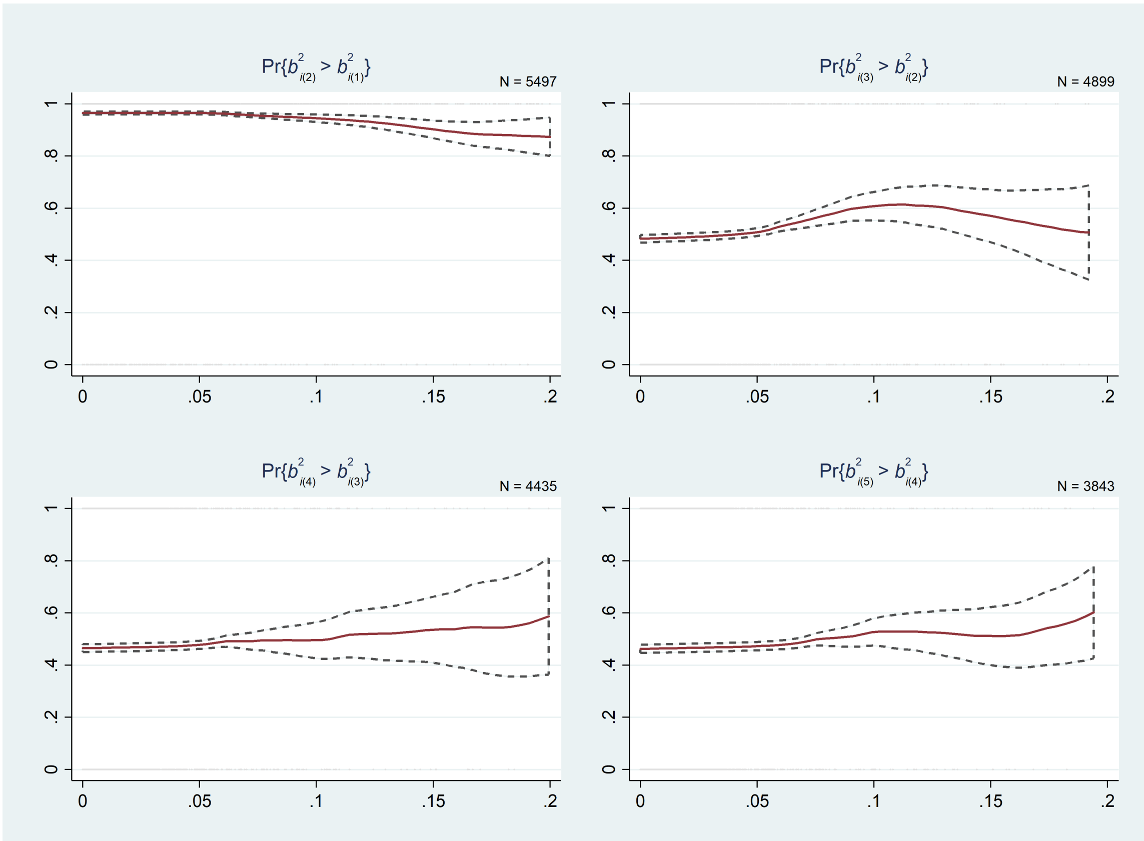

Figure 1: Persistence Rank Order across Rounds. The top left panel plots the probability that the rank order between $i(1)$ and $i(2)$ is preserved from the initial auction (Round 1 auction) to the next round of rebidding (Round 2 auction) as a function of the difference of their first-round bids denoted by Δ_{12}. The vertical axis corresponds to the fraction of lettings in which the rank order of the two bidders is the same between the Round 1 auction and the Round 2 auction as a function of the difference in $i(2)$ and $i(3)$'s first-round bids. The top right panel plots the probability that the rank order between $i(2)$ and $i(3)$ is preserved from the Round 1 auction to the Round 2 auction. The bottom two panels plot the probabilities that the rank orders between $i(3)$ and $i(4)$ (left) and between $i(4)$ and $i(5)$ (right) are preserved from the Round 1 auction to the Round 2 as function of their first-round bid differences, respectively.

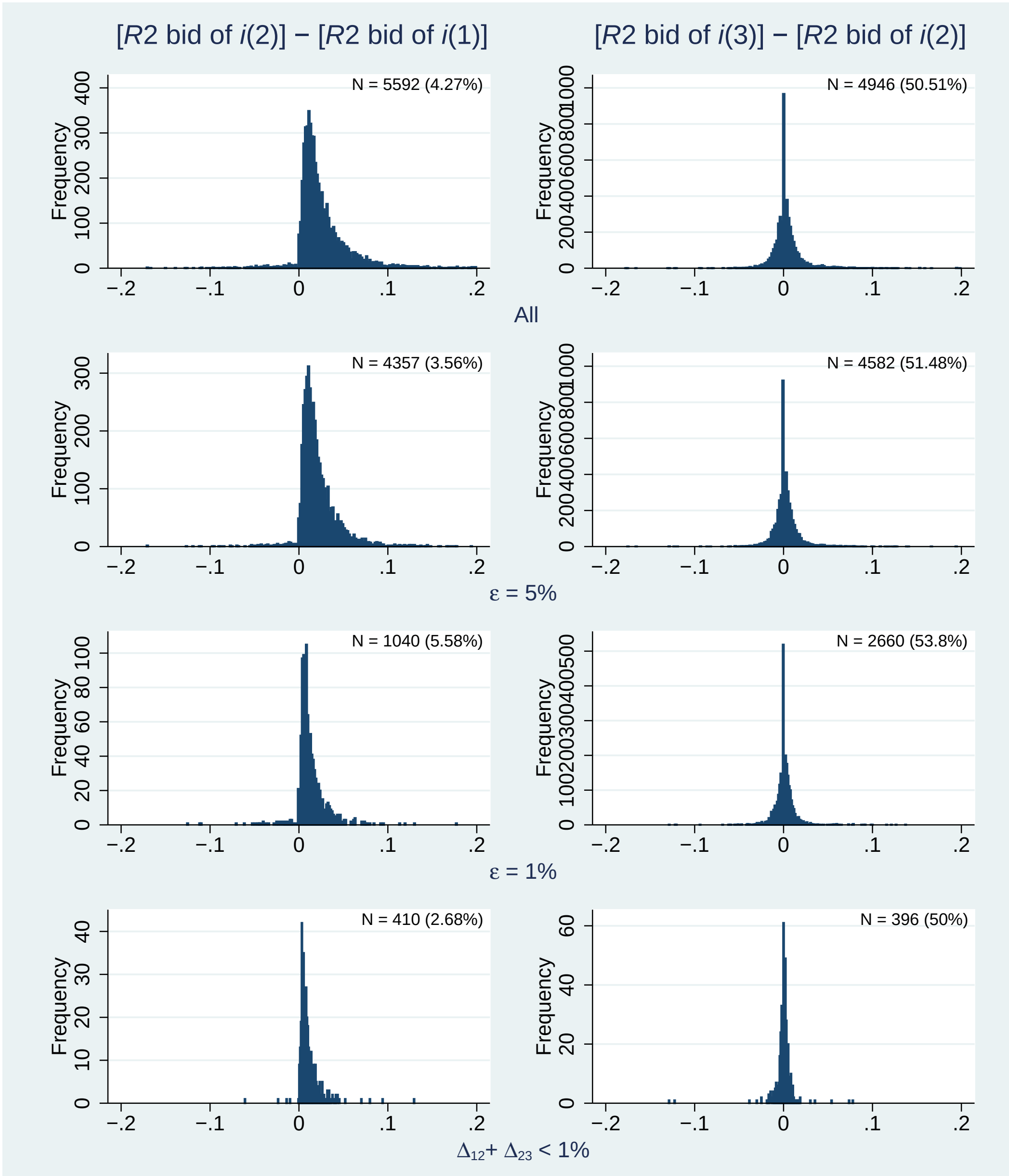

Figure 2: Difference in the Second-Round Bids of $i(1)$ and $i(2)$ (Left Panels) and the Difference in the Second-Round Bids of $i(2)$ and $i(3)$ (Right Panels). The first row is the histogram for the set of auctions that reach the second round; and $i(1)$ and $i(2)$ (or $i(2)$ and $i(3)$) submit valid bids in that round. The second to fourth rows plot the same histogram but only for auctions in which the differences in the first-round bids are relatively small. Note that the sample sizes are different between the top left and the top right panels because in some auctions, $i(1)$ or $i(3)$ does not bid in the second round. With the same reason, the sameple sizes are different between the bottom left and right panels.

In order to illustrate how bidders maintain persistence in the identity of the lowest bidder across rounds, Figure 2 plots Δ_{12}^2 and Δ_{23}^2, where Δ_{kk+1}^2 denotes the (normalized) difference between the *second*-round bids of $i(k)$ and $i(k+1)$:

$$\Delta_{kk+1}^2 = \frac{[\text{Second round bid of } i(k+1)] - [\text{Second round bid of } i(k)]}{\text{Reserve price}}.$$

The top two panels of Figure 2 plot the histograms of Δ_{12}^2 and Δ_{23}^2 for all auctions that reach the second round. While the panels confirm what we have already documented in Figure 1 – on the left panels, much of the mass lies to the right of zero, reflecting the fact that $i(1)$ outbids $i(2)$ in the reauction with very high probability, while the densities are almost symmetric around zero on the right panels – these highlight a notable aspect of bidding patterns in reauctions. That is, focusing on the density of Δ_{12}^2 in the top left panel around zero on the horizontal axis, there are many auctions in which Δ_{12}^2 lies slightly to the right of zero, but there are almost no auctions in which Δ_{12}^2 lies slightly to the left of zero. This implies that $i(2)$ is consistently outbid by $i(1)$ by a narrow margin but that $i(2)$ rarely outbids $i(1)$ by a narrow margin.

The left panels of the second and third rows of Figure 2 plot Δ_{12}^2 conditional on auctions in which the difference in the first-round bids of $i(1)$ and $i(2)$ is less than 5% and 1% of the reserve price, respectively. Similarly, the right panels of the second and third rows plot Δ_{23}^2 conditional on auctions in which the difference in the first-round bids of $i(2)$ and $i(3)$ is less than 5% and 1%, respectively. The fourth panel plots Δ_{12}^2 and Δ_{23}^2 conditional on Δ_{13} being less than 1%, i.e., auctions in which all three lowest bids in the initial auction fall within 1% of the reserve price. We find that the shapes of the distributions of Δ_{12}^2 and Δ_{23}^2 remain relatively similar across all four rows.

The bidding pattern illustrated in the left panels of Figure 2 suggests that persistence in the identity of the lowest bidder is maintained with some form of communication between the bidders. When we look at the panels in the right column of Figure 2, we see that Δ_{23}^2 has some amount of variance for all rows. This suggests that there are some idiosyncrasies even among bidders who bid approximately the same amount in the initial auction, such as beliefs over the secret reserve price, inducing variance in the second-round bidding. Hence, from the perspective of $i(2)$, consistently losing to $i(1)$ by a narrow margin without winning by a narrow margin seems difficult to achieve without knowing how $i(1)$ is going to bid. The particular shape of the distribution of Δ_{12}^2 around zero suggests that $i(2)$ is deliberately losing to the designated winner.

6 Validation of the Main Analysis

In this section, we provide further evidence that the bidding patterns documented in the previous section are indicative of collusion. We first study $i(2)$ who outbids $i(1)$ in the reauction. When $i(1)$ loses to $i(2)$ in the reauction, it is likely that there is no predetermined winner for the auction. Hence, the bidders who participate in these auctions are likely to be competitive. We provide evidence of this.

We then study auctions in municipalities that do not announce the lowest bid from the initial auction before rebidding takes place. We find very similar bidding patterns for these auctions. This analysis rules out the possibility that the patterns we documented in the previous section are explained by the asymmetry created between $i(1)$ and all other bidders by the announcement of the lowest bid.

Firms that outbid $i(1)$ in the reauction There are only about 240 auctions in which $i(2)$ outbids $i(1)$ in the second round. We now explore whether there are any differences between an $i(2)$ firm that outbids $i(1)$ in the reauction and an $i(2)$ firm that is outbid by $i(1)$ in the reauction. We have argued above that the distribution of Δ_{12}^2 has much of the mass to the right of zero under collusion, but that this is not necessarily the case under competition. Hence, $i(2)$ firms who outbid $i(1)$ in the reauction are likely to be bidding more competitively than $i(2)$ who are outbid by $i(1)$.

To test this idea, we plot the average winning bid of auctions in which $i(2)$ firms participate as a function of Δ_{12}^2 in Figure 3. More specifically, for each auction that reaches the second round, we identify an $i(2)$ firm in the auction and compute the average winning bid of the auctions in which the firm participates and that include one that ends in the initial round.

For robustness, we consider two ways of computing the average winning bid: first by taking the average over the winning bid of the five auctions preceding (but not including) the auction in question; and second, by taking the average over the five subsequent auctions, excluding the relevant auction. Specifically, let $b_{i(2),t}^{\text{before}}$ and $b_{i(2),t}^{\text{after}}$ denote the average winning bid of five auctions preceding and succeeding auction t and in which the $i(2)$ firm in auction t bids. Let b_{τ}^{win} denote the winning bid in auction τ. Then, for each auction t, we have

$$b_{i(2),t}^{\text{before}} = \frac{1}{5} \sum_{\tau=t-5}^{\tau=t-1} b_{\tau}^{win}, \qquad b_{i(2),t}^{\text{after}} = \frac{1}{5} \sum_{\tau=t+1}^{\tau=t+5} b_{\tau}^{win}.$$

The left and right panels of Figure 3 are bin plots of $b^{\text{before}}_{i(2),t}$ and $b^{\text{after}}_{i(2),t}$. The horizontal axis is Δ^2_{12} and the vertical axis is the winning bid normalized by the reserve price. Therefore, plots to the left of zero correspond to the average winning bid of $i(2)$ firms that outbid $i(1)$ in some auctions, and plots to the right of zero correspond to the average winning bid of $i(2)$ firms that are outbid by $i(1)$.

Both panels of Figure 3 show that the average winning bid of $i(2)$ that marginally outbid $i(1)$ is lower than the average winning bid of $i(2)$ that is marginally outbid by $i(1)$, by about 5%.[6] These results suggest that bidders that outbid $i(1)$ in the second round are quite different from those that are outbid by $i(2)$. There seems to be more competition among the former set of bidders than the latter.

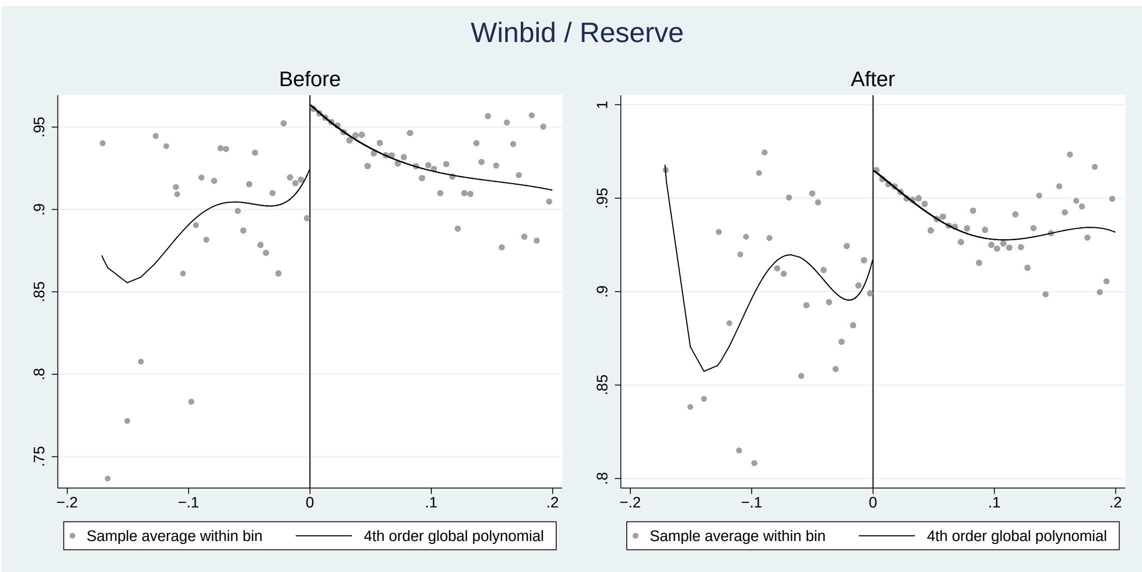

Figure 3: Bin Plots of Average Winning Bid in Auctions for which $i(2)$ Firms Bid. For each auction that reaches the second round, we identify $i(2)$ and compute the winning bid of auctions in which the firm participates. We first compute the winning bid by taking the average over the five auctions preceding (but not including) the auction in question. Second, we compute the average over the five subsequent auctions. The left panel plots the average winning bid of the five preceding auctions against Δ^2_{12}. The right panel plots the average of the five subsequent auctions against Δ^2_{12}. The size of the bin is 0.5%.

[6] We find that the differences at zero are 4.97% for the left panel and 5.35% for the right panel, respectively, and that both are statistically significant at the 5% significance level.

Differences in Information Between $i(1)$ and $i(2)$ For most auctions in our sample, the auctioneer announces the lowest bid among the bidders to all participants at the end of each round of bidding. This creates a possible asymmetry between $i(1)$ and $i(2)$ even if $i(1)$ and $i(2)$ are similar in terms of costs. To see this, suppose that $i(1)$ bids Z and $i(2)$ bids $Z + \varepsilon$, where $\varepsilon > 0$ is a small number. If the lowest bid is announced to everyone, $i(1)$ learns that Z is the lowest bid, but $i(1)$ does not gain any knowledge about how any of the other bidders bid. On the other hand, $i(2)$ learns that Z is the lowest bid, and that one bidder besides itself bids Z. This asymmetry in information exists between $i(1)$ and $i(2)$ but not between $i(2)$ and $i(3)$. We now discuss whether or not this asymmetry can account for the persistence in the identity of the lowest bidder even in the absence of collusion.

First, note that when the differences in i(1) and i(2)'s bids in the initial round are small, the announcement of the lowest bid creates information asymmetry between $i(1)$ and $i(2)$. That is, while $i(1)$ does not know how close the second lowest bid is, $i(2)$ knows that the bids are almost exactly tied. Hence, $i(2)$ should be able to outbid $i(1)$ by bidding *slightly more aggressively* than the bidding strategy employed by $i(1)$. As long as we condition on auctions in which the first-round bids of $i(1)$ and $i(2)$ are sufficiently close, we should expect $i(2)$ to outbid $i(1)$ more than 50% of the time, not less, under competition. This is certainly not the case in the data, suggesting that information asymmetry is unlikely to explain the persistence in the identity of the lowest bidder.

In order to further explore the importance of information asymmetry, we next study the persistence in the identity of the lowest bidder and the distributions of Δ_{12}^2 and Δ_{23}^2 for the set of municipalities that do not announce the lowest bid after each round.[7] When none of the bids are announced, there are no differences in the information available to $i(1)$, $i(2)$, and $i(3)$ for auctions in which the first-round bids are close. Figure 4 and Figure 5 replicate Figure 1 and Figure 2 for these municipalities. We find that the probability of ranking reversals and the shapes of the distributions of Δ_{12}^2 and Δ_{23}^2 for the restricted sample look very similar to those in Figure 1 and 2. These findings imply that the bidding patterns documented in the previous section are unlikely to be explained by the announcement of the lowest bid.

[7]Municipalities that do not disclose the lowest bid in each round of bidding are cities of Kitakami (all years), Tamura (Fiscal Years 2010-2013), and Hanamaki (until Fiscal Year 2010, and 2011).

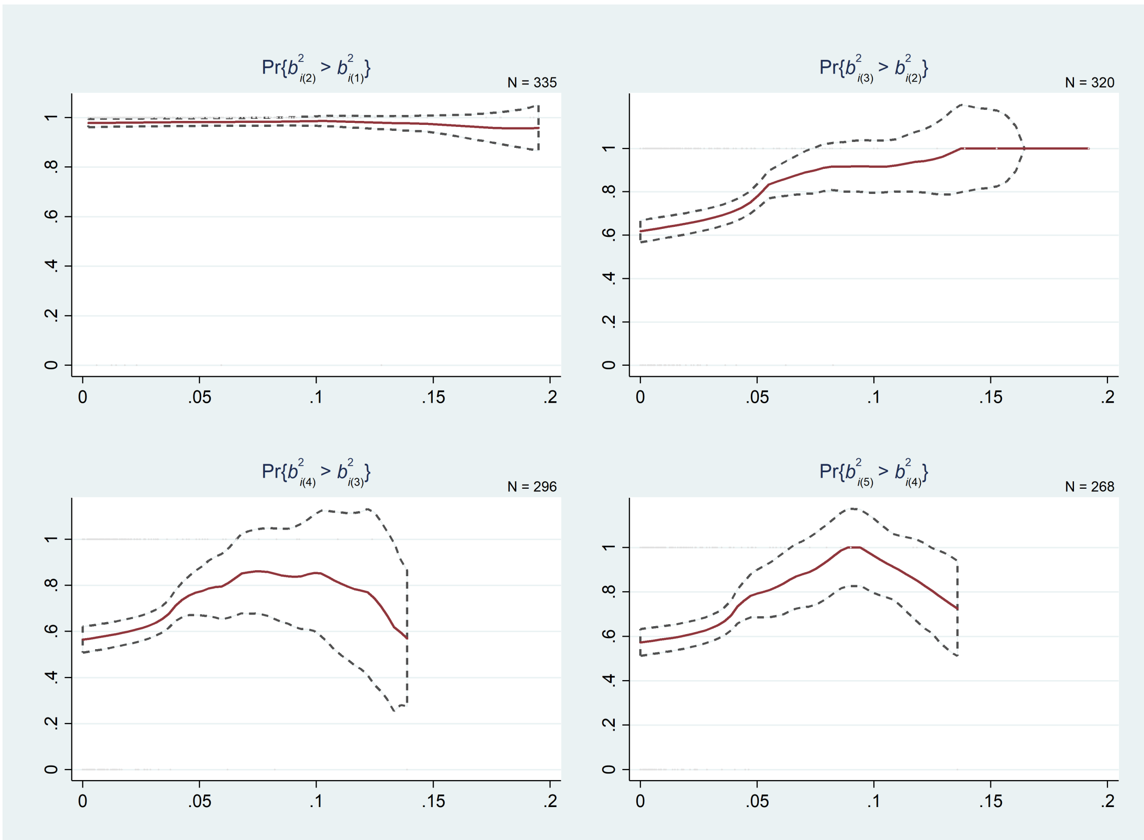

Figure 4: Persistence of Rank Order across Rounds for the Three Municipalities. The figure replicates Figure 1 for the three municipalities in which none of the bids are announced. The top left panel plots the probability that the rank order between $i(1)$ and $i(2)$ is preserved from the first to the second round as a function of the difference of their first-round bids. The vertical axis corresponds to the fraction of lettings in which the rank order of the two bidders is the same between the first and second rounds. The horizontal axis describes Δ_{kk+1} for $k = \{1, 2, 3, 4\}$. The top right panel plots the probability that the rank order between $i(2)$ and $i(3)$ is preserved from the first to the second round. The bottom two panels plot the probabilities that the rank orders between $i(3)$ and $i(4)$ (left) and between $i(4)$ and $i(5)$ (right) are preserved from the first to the second round, respectively.

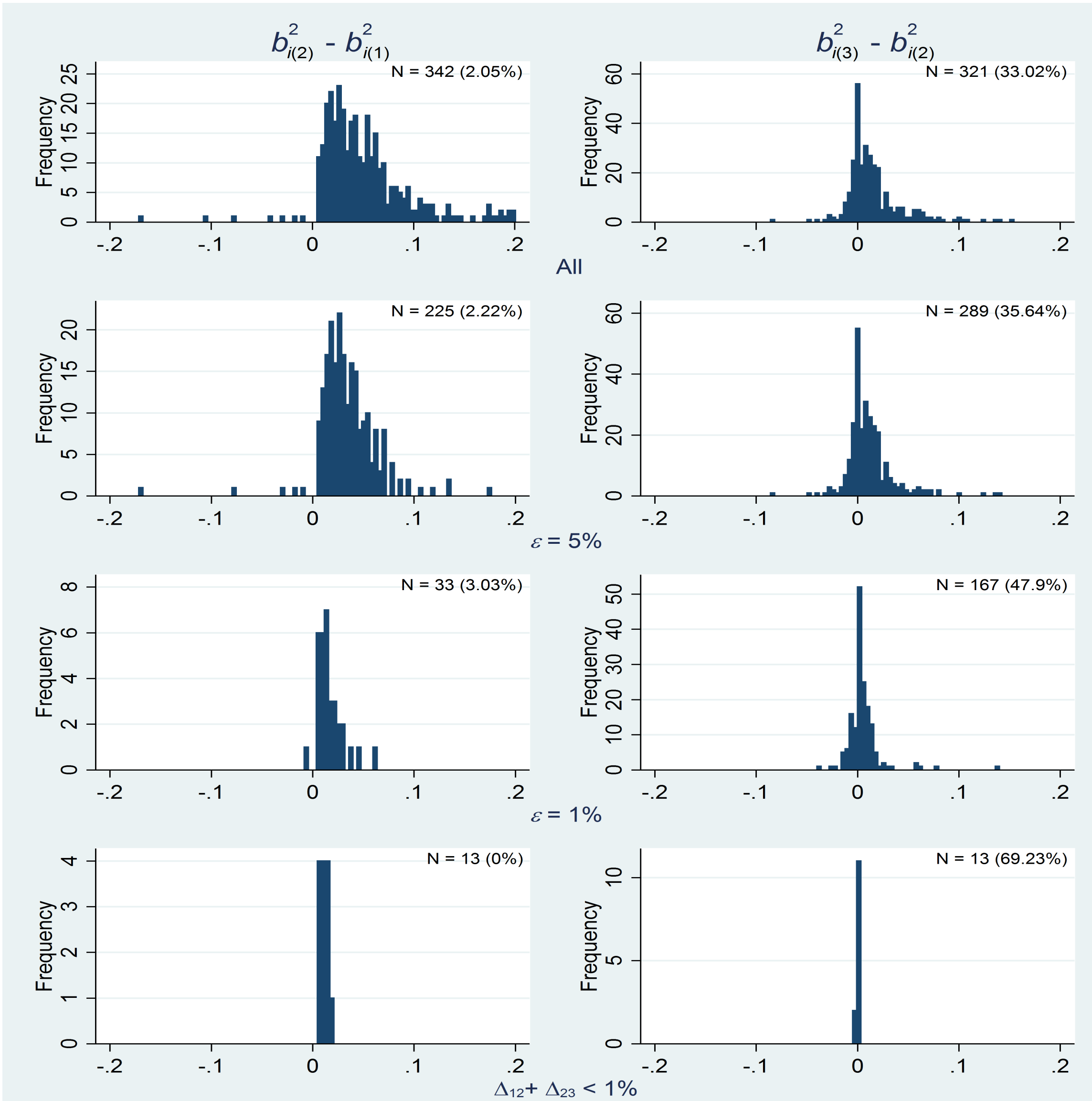

Figure 5: Difference in the Second-Round Bids for the Three Municipalities. The figure plots Δ^2_{12} (left column) and Δ^2_{23} (right column) for the three municipalities in which none of the bids are announced. The first row is the histogram for the set of auctions that reach the second stage. The second to fourth rows plot the same histogram but only for auctions in which the differences in the first-round bids are relatively small. Note that the sample sizes are different between the top left and top right panels, because in some auctions $i(1)$ or $i(3)$ does not bid in the second round. This is similar for the bottom left and right panels.

7 How Pervasive is Collusion?

We now discuss how to draw inferences on the extent to which auction participants engage in bid rigging in our data. One informal approach is to draw the distribution of Δ_{12}^2 and Δ_{23}^2 conditional on auction characteristics such as municipality and year in which the auction takes place, project type, etc. One can obtain a sense of how widespread collusion is by exploring whether or not the distributions of Δ_{12}^2 and Δ_{23}^2 is different for a large set of auction characteristics or only for a specific set of auction characteristics. In this section, we consider a slightly more formal approach.

In this section, we focus on municipalities that do not reveal the lowest bid after each round of bidding. For these auctions, whether other bids are below or above its own bid is not in the information set of the firm when it rebids. Hence, the second round bidding strategy of bidder i should not depend on whether bidder j's ($i \neq j$) first-round bid is above or below its first round bid under the null of competition, i.e.,

$$\mathbf{E}[b_i^2 | \mathcal{J}_i, \{b_i^1 < b_j^1\}] = \mathbf{E}[b_i^2 | \mathcal{J}_i, \{b_i^1 > b_j^1\}], \tag{1}$$

where b_i^r is bidder i's bid in round r and $\mathcal{J}_i$ is the information set of bidder i when it bids in the second round. In what follows, we construct a test for collusive bidding based on this observation.

To define our test statistic, we introduce some notation. Let $\mathcal{I}_0$ denote the set of all firms observed in our data, $\mathcal{I}_{cp}$ denote the set of competitive firms that never engage in bid rigging, and $\mathcal{I}_{cl} = \mathcal{I}_0 \backslash \mathcal{I}_{cp}$ denote the set of collusive firms. Let $W(\mathcal{I})$ ($\mathcal{I} \subseteq \mathcal{I}_0$) denote the set of auctions in which the winner is a firm in $\mathcal{I}$. Moreover, let $|W(\mathcal{I})|$ denote the share of the auctions whose winner is a firm in $\mathcal{I}$, i.e.,

$$|W(\mathcal{I})| = \frac{\text{Number of auctions in}\, W(\mathcal{I})}{\text{Number of all auctions}}.$$

Then, the null hypothesis that we would like to test is as follows.

$$H_0 : |W(\mathcal{I}_{cp})| \geq \alpha \in [0, 1]$$

Consider the set of bidders with the share of auctions greater than α. If we set $\alpha = 1$, then the set of bidders with $|W(\mathcal{I})| \geq \alpha$ is $\mathcal{I}_0$ only. Under H_0, there exists $\mathcal{I} \subseteq \mathcal{I}_0$ such that $|W(\mathcal{I})| \geq \alpha$ and (1) holds for all $i \in \mathcal{I}$. Let $\mathcal{I}_1 \cdots \mathcal{I}_{S(\alpha)}$ be the enumeration of all the subsets of bidders such that $|W(\mathcal{I}_s)| \geq \alpha$ for all $s \in \{1, \ldots, S(\alpha)\}$, and let H_s denote the hypothesis that (1) holds for all $i \in \mathcal{I}_s$. The null hypothesis H_0 is equivalent to the null hypothesis that at least one among $\{H_1, \cdots, H_{S(\alpha)}\}$ is true.

To test for H_s, consider a regression of b_i^2 on a dummy of whether or not b_i^2 is higher or lower than its most competitive rival. Let t denote the index of lettings for which at least one bidder in $\mathcal{I}_s$ bids. Let $c(i)$ ($i \in \mathcal{I}_s$) denote i's most competitive rival bidder from the first round, i.e., $c(i)$ is $i(2)$ or $i(1)$, depending on whether or not i is $i(1)$. Consider the following regression of $\{b_{it}^2\}_{i \in \mathcal{I}_s}$:

$$b_{it}^2 = g(b_{it}^1) + \beta^+ \mathbf{1}_{\{b_{it}^1 - b_{c(i)t}^1 \in (0, \delta)\}} + \beta^- \mathbf{1}_{\{b_{it}^1 - b_{c(i)t}^1 \in (-\delta, 0)\}} + D_t + \varepsilon_{it}. \tag{2}$$

The left-hand side of the regression is bidder i's second-round bid in auction t. $g(b_{it}^1)$ is a fourth order polynomial of bidder i's first-round bid and D_t is a month-year fixed effect. The second and third terms capture the effect of bidder $c(i)$'s first-round bid on b_{it}^2. $\mathbf{1}_{\{\}}$ is an indicator function, and δ is a positive scalar. Because more than one bidder in $\mathcal{I}_s$ may participate in auction t, we allow for the errors to be correlated within an auction. The object of interest is $\beta^+ - \beta^-$; it measures the effect of whether the rank of bidder i is marginally the lowest or not in the first round. If $\mathcal{J}_i$ does not include whether other bids are below or above its own bid, i's second-round bidding strategy should not depend on the rank order in the first round. Hence, $\beta^+ - \beta^- = 0$ under the null.

Let p_s denote the p-value for $\beta^+ - \beta^- = 0$ from regression (2), conditioning on firms in $\mathcal{I}_s$. Let $\bar{p}(\alpha) = \max\{p_1, \ldots, p_{S(\alpha)}\}$. We reject H_0 if $\bar{p}(\alpha)$ is less than 0.05. This formulation is a standard multiple hypothesis test by enumerating all the set of bidders whose combined share exceeds α.[8]

Before we present our results, we discuss the limitations of the test. Because we do not have much information on auction characteristics, it is difficult to condition fully on the information set of the bidders, $\mathcal{J}_i$. To the extent that there are omitted auction characteristics that are correlated with b_{it}^1 or $b_{c(i)t}^1$, our estimates of β^+ and β^- may be biased.

To address this issue, we use a fairly small δ in the estimation. By choosing a small δ, the coefficients β^+ and β^- are identified from a relatively homogeneous sample of auctions. As $\delta \to 0$, the estimate of $\beta^+ - \beta^-$ becomes a regression discontinuity estimate. In

[8] The test statistic is conservative, because we do not reject H_0 until we reject $\beta^+ - \beta^- = 0$ for all $s \in \{1, \ldots, S(\alpha)\}$.

particular, we have

$$\lim_{\delta\to 0} \mathbf{E}[b_i^2|b_i^1 - b_{c(i)}^1 \in (0,\delta)] - \mathbf{E}[b_i^2|b_i^1 - b_{c(i)}^1 \in (-\delta, 0)] = 0$$

under the null hypothesis.

We obtain an upper bound on the share of competitive firms by considering the constraint optimization

$$\text{Maximize } \alpha \text{ s.t. } \bar{p}(\alpha) \geq 0.05.$$

Let α^* denote the solution to this problem. Then, $1-\alpha^*$ can be interpreted as a lower bound on the share of auctions in which the winner is a firm whose rebidding behavior rejects the competitive null. Hence, the solution to this problem gives us a conservative bound on the set of auctions that are rigged by colluding bidders.

To solve for the constraint optimization problem, we first find a set of 10 firms whose share of lettings is very high and whose rebid patterns do not reject the competitive null. We then apply the greedy algorithm to find α^*, taking these 10 firms as the initial condition. We obtain $p_s(\cdot)$ for each $s \in \{1, \ldots, S(\alpha)\}$ by implementing an F test for $\hat{\beta}^+ = \hat{\beta}^-$, where $\hat{\beta}^+$ and $\hat{\beta}^-$ are regression coefficients obtained from (2). For robustness, we use a set of δ, i.e., $\delta \in \{0.03, 0.04, 0.05\}$.

We find that $1 - \alpha^*$ is around 20%. For instance, $1 - \alpha^*$ is 23.5% at $\delta = 0.04$, i.e., a lower bound on the number of collusive auctions is 630 and the number of lettings in our sample is 2679. We also find that the number of firms that won in the 630 collusive auctions is 68. If $\delta = 0.03$, $1 - \alpha^*$ is 18.6%. Also, if $\delta = 0.05$, $1 - \alpha^*$ is 28.2%.

Recall that the winning bid in the auction in which a collusive firm bids is higher by approximately 5% than the winning bid in the auction in which a competitive firm bids, c.f. see footnote 6. If the share of the collusive firms is 23.5% for all of the 56 municipalities in our sample, the award amount of collusive firms is at least 2.85 billion dollars during the sample period. Hence, taxpayers lose at least 143 million dollars through higher contract prices.

8 Concluding Remark

In this paper, we explore the extent to which collusion is widespread in the public procurement auctions of Japanese municipalities. We find that the persistence in the identity of the lowest bidder is very high across rounds, which is inconsistent with competitive bidding.

We also find that the initial-round lowest bidder quite often outbids the initial-round second lowest bidder in the reauction by a small margin, even for lettings in which their bids in the initial round are very close. This finding suggests that the ring members communicate how they will bid in the subsequent round. We then construct a statistical test for pervasiveness of collusion. Our test results indicate that at least about 20% of government contracts are awarded to firms whose bidding behavior is inconsistent with competition.

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