THE VALUE OF PRIVACY IN CARTELS:
AN ANALYSIS OF THE INNER WORKINGS OF A BIDDING RING

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ABSTRACT

We study the inner workings of a bidding cartel focusing on the way in which bidders communicate with one another regarding how each bidder should bid. We show that the designated winner of the cartel can attain higher payoffs by randomizing its bid and keeping it secret from other bidders when defection is a concern. Intuitively, randomization makes defection less attractive as potential defectors face the risk of not winning the auction even if they deviate. We illustrate how our theoretical predictions are borne out in practice by studying a bidding cartel that operated in the town of Kumatori, Japan.

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1 Introduction

Consider the problem of a cartel member who has been pre-selected as the winner of an upcoming first-price sealed-bid procurement auction. The objective of the pre-selected winner is to be the lowest bidder and, at the same time, submit an inflated bid to secure high margins. The extent to which the bid can be inflated is limited by both the reserve price and the incentive compatibility (IC) constraints of the losing cartel bidders who may defect. This paper studies both theoretically and empirically the problem of how the cartel should bid in this scenario. We show that, when the IC constraints are binding, the pre-selected winner should randomize its bid and keep it secret from the designated losers. We then show that our theoretical predictions are borne out in practice through a case study of a detected bidding cartel in Japan. Our case study offers a concrete example in which privacy helps cartels achieve larger profits. Our findings also help understand when the "price-variance screen" (Abrantes-Metz et al., 2006) for collusion is likely to have power, and help rationalize collusive bidding patterns observed in other settings.

The analysis of the paper is based on the simple intuition that, by keeping its bid secret, the pre-determined winner can make it harder for other bidders to defect. If the pre-selected winner's bid is publicly known, a defector can undercut the announced bid to obtain maximal deviation profits. If instead the pre-selected winner's bid is unknown, a potential defector runs the risk of deviating (and be punished) without even winning the auction.

We formalize these ideas with a model in which a group of firms repeatedly plays a first-price procurement auction. The size of the project auctioned off is drawn i.i.d. each period, and firms share the same costs. Consistent with our empirical application, we assume that the cartel has access to a mediator and allocates contracts through a bid rotation scheme. We say that an equilibrium has *common-knowledge bids* if firms' bids depend deterministically on the public history.

Under the cartel's optimal bid rotation equilibrium with common-knowledge bids, winning bids are determined by either the losers' IC constraints or the reserve price. As in Rotemberg and Saloner (1986), winning bids are below the reserve price whenever the project

is sufficiently large.

Our main result shows that a cartel may strictly gain from bidding schemes without common-knowledge bids. Under the optimal bid rotation equilibrium, the mediator randomly draws the winner's bid from a distribution F, and privately communicates this bid to the predetermined winner. Non-winners are instructed to place a losing bid. Distribution F has the property that, under this equilibrium, non-winners are indifferent between placing a losing bid or deviating and placing any bid in the support of F. By keeping losing firms uninformed, such a bidding scheme relaxes incentive constraints and yields larger profits.

Our theory delivers two key predictions. First, since the incentive constraints of losing firms are more likely to bind for large projects, collusive schemes with randomized bids are most profitable (and hence most likely used) when the project auctioned off is large. Second, optimal randomized bidding schemes tend to have a sizable gap between the winning bid and the second lowest bid; i.e., there is significant money left on the table.

In order to illustrate how these theoretical forces are borne out in practice, we study the inner workings of a bidding ring consisting of mid and small contractors participating in procurement auctions let by the town of Kumatori, Japan. The cartel was active until October 2007, when members of the cartel were investigated and prosecuted for bid-rigging. The cartel case in Kumatori makes it ideal for studying the inner workings of a bidding ring because the criminal case and the subsequent liability claims case both went to trial. The court proceedings produced a wealth of information. The rulings of the case alone offer detailed and rich descriptions about the actions of the cartel members as well as the motivations behind their actions.

Another useful aspect of the collusion case is that there was significant variation in the size of projects let by the town. In particular, there was one occasion in which cartel members bid on a project (building a housing complex) that was about 20 times the size of the average project let by the town. The variation in project size induces variation in the IC constraints of losing cartel bidders as temptation to defect is typically bigger for larger projects. The variation in the IC constraint is useful for validating the theory. Consistent with the

predictions of our model, we find that the pre-determined winner took extra precautions to keep its bid secret when bidding on the housing complex. Court documents show that the designated losers were instructed how to bid but were kept in the dark as to how the designated winner would bid. Moreover, the winning bidder bid much lower than what the losing bidders were instructed to bid. The winner's bid was about 11.5% lower than the next lowest bid, while the average difference between the winning bid and the losing bids for other auctions was less than 1%. The court ruling describes the motive of the pre-determined winner for leaving money on the table in that auction as trying to make it difficult for other cartel members to guess its bid.

Our analysis has implications for screens of collusion, in particular, the price-variance screen proposed by Abrantes-Metz et al. (2006). The variance screen flags unusually low variance of the price sequence (or equivalently, high degrees of price stability) as a marker for collusion.[1] The price-variance screen was originally motivated by the observation that variance in prices increased substantially after the collapse of a bidding cartel consisting of seafood processors. Researchers have since found similar patterns in other settings such as Swiss procurement auctions (Imhof et al., 2016) and LIBOR (Abrantes-Metz et al., 2012), as well as in non-auction markets.[2] Our study provides a better understanding of when low price variance is likely to be associated with collusive bidding (when IC constraints don't bind, and all bids are clustered around the reserve price) and when it might not (when IC constraints bind).

Lastly, our analysis has implications for the role that transparency plays in sustaining a successful collusive scheme. It is well known from the theory of repeated games that transparency allows colluders to better coordinate and monitor each others' actions. However, motivated by the way communication was structured in several recently detected cartels, Sugaya and Wolitzky (2018) identify a potential drawback of transparency: they show that transparency may hinder collusion by enabling potential defectors to devise more profitable

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[1]Prior work that makes the connection between competition and stability of prices include Carlton (1986) and Levenstein (1997).

[2]Examples include retail gasoline and pasta products (Jiménez and Perdiguero, 2012, Crede, 2019)

deviations. Our analysis offers a concrete example of how privacy helps cartels.

Related literature. Our paper studies how cartels bid in a repeated-game setting. There is a large theoretical literature on this topic exploring issues such as monitoring (e.g., Green and Porter, 1984, Skrzypacz and Hopenhayn, 2004, Sugaya and Wolitzky, 2018), efficiency and private costs (e.g., Athey and Bagwell, 2001, Athey et al., 2004, Athey and Bagwell, 2008) and demand shocks (e.g., Rotemberg and Saloner, 1986, Haltiwanger and Harrington, 1991). Our work also relates to prior papers studying how communication may help sustain collusion (e.g., Compte, 1998, Kandori and Matsushima, 1998, Harrington and Skrzypacz, 2011, Rahman, 2014, Awaya and Krishna, 2016).

The empirical portion of our work is closely related to studies that test whether or not the price patterns implied by models of collusion are borne out in the data. Porter (1983) and Ellison (1994) study pricing by the Joint Executive Committee to test for the models of Green and Porter (1984) and Rotemberg and Saloner (1986). Levenstein (1997) studies the bromine cartel and finds evidence consistent with the model of Green and Porter (1984). Borenstein and Shepard (1996) study the retail gasoline market to test for the model of Haltiwanger and Harrington (1991). Wang (2009) also studies the retail gasoline market and finds evidence consistent with the equilibrium of Maskin and Tirole (1988).

Our paper is also related to the literature on detecting instances of collusion. Early seminal work includes Hendricks and Porter (1988), Baldwin et al. (1997) and Porter and Zona (1993, 1999). More recent work includes Bajari and Ye (2003), Abrantes-Metz et al. (2006), Athey et al. (2011), Conley and Decarolis (2016), Schurter (2017), Kawai and Nakabayashi (2018), and Chassang et al. (2020).[3]

Lastly, our results indirectly relate to the literature on information design (Kamenica and Gentzkow, 2011). In particular, the indifference condition characterizing the optimal bid distribution in our model has analogs in Condorelli and Szentes (2020), who study

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[3]Other related work includes Pesendorfer (2000), who studies bidding rings with and without side-payments, and Asker (2010), who studies knockout auctions among cartel members. Ohashi (2009) and Chassang and Ortner (2019) document how changes in auction design can affect the ability of bidders to sustain collusion. Clark et al. (2018) analyze the breakdown of a cartel and its implications on prices. For a survey of the literature, see Porter (2005) and Harrington (2008).

information acquisition by a buyer, Perez-Richet and Skreta (2018), who study test design, and Ortner and Chassang (2018), who study the design of anti-corruption schemes.

2 Bid-rigging in the Town of Kumatori

This section provides a brief description of the bidding ring that operated in the town of Kumatori until October 2007.

2.1 Background

Auctions for construction projects in Kumatori. The town of Kumatori uses auctions to allocate construction projects that are estimated to cost more than 1.3 million yen, or about 13 thousand dollars. The auction format is first-price sealed bid with a secret reserve price, although as we discuss below, some of the town officials were leaking the reserve price to the contractors. In fact, in all of the auctions that we study, the lowest bid was below the reserve price.

An important feature of the auctions is that participation is by invitation only. The town maintains a list of qualified contractors and invites a subset of firms from the list to bid. The town maintains separate lists for projects with different sizes. For example, for building construction, the city maintains four separate lists of contractors (Tier A through Tier D). The city typically invites Tier A firms to bid on the largest projects, Tier B firms to bid on the next largest projects, and so on, essentially segmenting the market by project size. All of Tier A firms are headquartered outside of Kumatori and are invited to bid only on exceptionally large projects. Tier B firms and below are local firms typically headquartered within the town. Most of the Tier B and C firms were members of the Kumatori Contractors Cooperative, a trade association that consisted of a little more than 20 mid and small size contractors in Kumatori. The members of this cooperative were found to be colluding.

Bidding ring in the town of Kumatori. Reports of police investigation of the members of the Kumatori Contractors Cooperative for bid-rigging first appeared in the news on

October 12, 2007. In addition to the contractors in Kumatori, more than 20 town officials, including the town mayor, were questioned by the police. The media reported that some of the town officials had helped the contractors collude by leaking the secret reserve price.[4] In November 2007, four individuals were indicted for bid-rigging. The criminal charges focused on the defendant's involvement in bid-rigging in a single auction that took place on August 22, 2006 that Imakatsu Construction won, an auction for rebuilding a public housing complex (Ohara Residences). The defendants included Mr. Kitagawa, the owner of Imakatsu Construction and director of the Kumatori Contractors Cooperative; his son, who was an employee of Imakatsu Construction; Mr. Nishio, the vice-director of the Cooperative; and Mr. Takano, an employee of the Cooperative. While Mr. Nishio and Mr. Takano were not participants of the auction, they mediated much of the communication between Mr. Kitagawa and the other participants of the auction. For example, Mr. Nishio gave out the instructions to other bidders on how they should bid. All four defendants were found guilty in trial in March 2008.

Although the criminal case focused on the defendants' involvement in bid-rigging in the Ohara Residences auction, the court ruling indicated that the Ohara Residences auction was not an isolated case and that the participants of the bid-rigging scheme were not confined to those that were criminally charged.[5] In the ruling, the court stated that the members of the Kumatori Contractors Cooperative allocated the projects according to a preset order to even out the work of each contractor. While none of the town officials were formally charged, the court ruling stated that the designated winner of the cartel would approach the town officials to seek out the engineering estimate.

In response to the ruling of the criminal case, the town of Kumatori withheld part of its payment to Imakatsu Construction for work that had been completed in order to off-set liability claims. However, the mayor and town officials showed little interest in pursuing claims for damages incurred on other auctions. This inaction led some of the residents of

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[4]See, e.g., Chunichi Shimbun, October 20, 2007

[5]Our description of the cartel in this paragraph is taken from page 2 and 3 of Ruling H19 (WA) No. 6418, Osaka District Court.

Kumatori to file suit against the mayor asking the court to order the mayor to pursue claims against 23 firms, all members of the Kumatori Contractors Cooperative, for damages incurred on other auctions. The District Court of Osaka ruled in favor of the plaintiffs, ordering the town to pursue claims against the bidders in the amount of about 375 million yen, or about 3.75 million dollars. The mayor appealed the ruling, but the verdict was upheld by the Osaka High Court with relatively minor modifications.

2.2 Ohara Residences Auction

Among the auctions that the cartel bid on, the Ohara residences auction was somewhat unique because of the large value of the project. This section discusses briefly how, despite the town's policy of segmenting the market by project size, the members of the Kumatori Contractors Cooperative were invited to bid in the auction. We also present preliminary evidence suggesting that the IC constraints of the losing bidders were binding in the auction.

The town of Kumatori started planning for the rebuilding of the Ohara Residence Complex, an ageing public housing project, around 2000 according to the minutes of the meeting of the town council.[6] The new residence complex would consist of three separate buildings. Construction of the first and smallest of the three buildings was put to an auction in April 2004 to Tier A firms. The winning bid was 363 million yen, or about 3.6 million dollars. The winner of the auction was Asanuma Corporation, a contractor headquartered in the city of Osaka with annual sales of about 2 billion dollars in FY 2005.

In the Fall of 2004, Mr. Kitagawa, the director of the Kumatori Contractors Cooperative and owner of Imakatsu Construction began lobbying the town's mayor and the head of the town's general affairs department to let Tier B firms bid on the second and third components of the Ohara Residences Complex.[7] Mr. Kitagawa was an important supporter of the mayor. Despite the lobbying by Mr. Kitagawa, the head of the department was reluctant to let Tier B firms bid on the Ohara residences project initially, according to court documents. However,

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[6]Minutes of the meeting of the town countil to discuss the budget, March 2001, page 49.

[7]Our description of the cartel in this paragraph are taken from page 17 of Ruling H21 (Gyo-U) No. 99, Osaka District Court.

the head of the department started to warm to the idea around April 2006. On August 3, 2006, the town office invited five contractors to bid on the housing complex project, including Imakatsu Construction. All of the five invited bidders were Tier B firms and also members of the Cooperative.

The left Panel of Figure 1 plots the reserve price for auctions let by the town of Kumatori in which cartel firms in Tier B were invited to bid. The horizontal axis corresponds to the calendar date and the vertical axis corresponds to the reserve price of the auction. The figure shows that, except for the Ohara Residence Auction that took place on August of 2006 (corresponding to the dark circle), Tier B firms were invited to bid on auctions with reserve prices below 200 million yen. The average reserve price during this period excluding the Ohara Residences auction is about 37.5 million yen. The Ohara Residences auction was about 17.5 times the average size of projects on which the bidders were invited to bid.

The right panel of Figure 1 plots the difference between the lowest and the second lowest bids as a fraction of the reserve price for these auctions. The figure shows that the difference is always less than 4%, except for the Ohara Residences auction (corresponding to the dark circle). The average difference for lettings excluding Ohara Residences is about 0.94%. The bid difference for Ohara Residences, on the other hand, is 11.4%. The bidding patterns suggest that the cartel members kept the winning margin small for small projects but not for the Ohara Residences project. The next two sections explore, first theoretically and then qualitatively – through close examination of court documents – how these bidding patterns can be explained as an optimal cartel response when IC constraints of designated losers bind.

3 Model

We consider a repeated game in which, in each period $t \in \mathbb{N}$, a buyer procures a project from firms $i = 1, 2$. To simplify the exposition, we assume that the buyer uses a first-price auction with a public reserve price. Our results generalize to the case of $n > 2$ bidders, and to auctions with secret reserve prices.
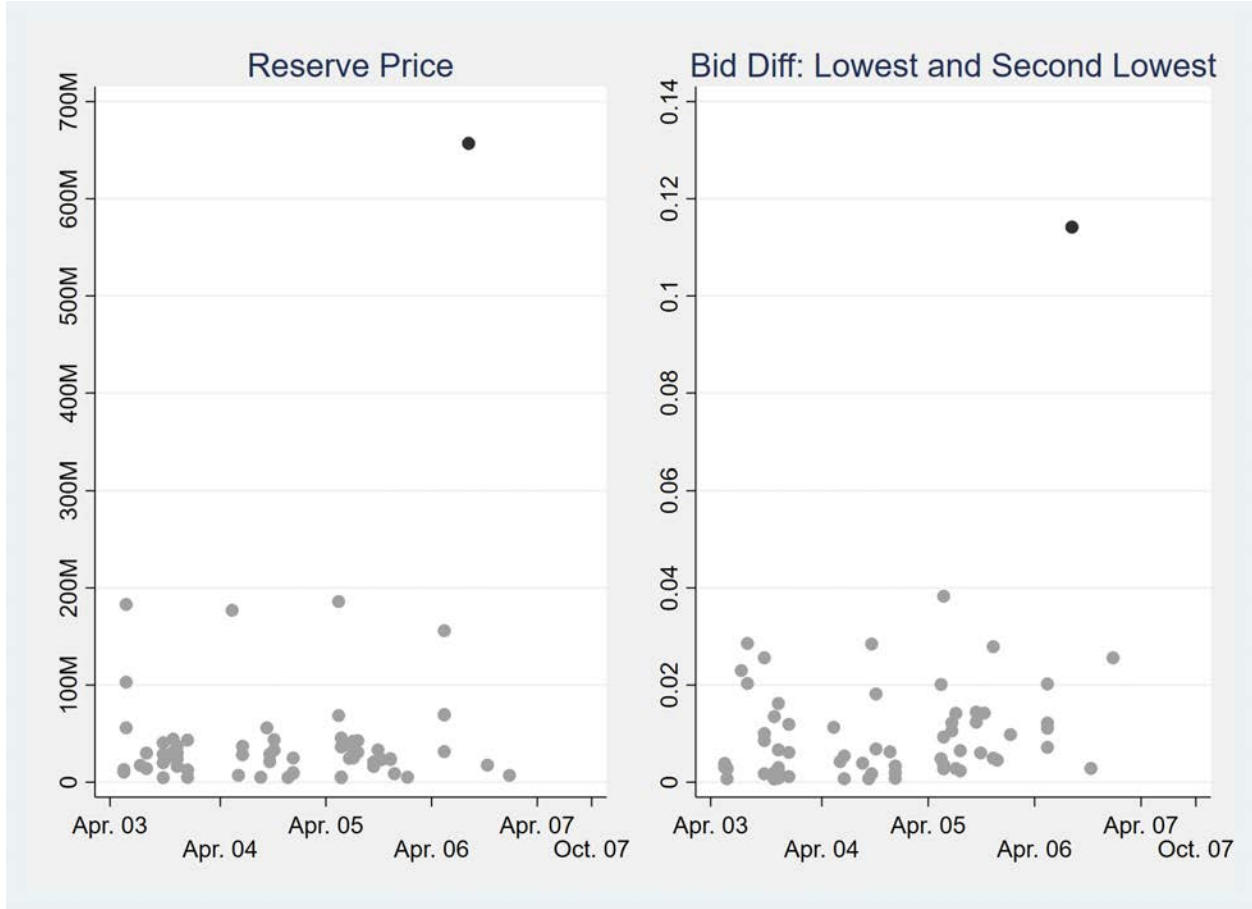
Figure 1: Reserve Price of Auctions (Left Panel) and Difference between Winning Bid and Second Lowest Bid (Right Panel). Left panel of the Figure plots the reserve price of auctions in which collusive firms in Tier B were invited to bid. The right panel plots the difference between the winning bid and the lowest losing bid, as a fraction of reserve prices.

In each period t, firms $i = 1, 2$ share the same procurement cost $c \geq 0$, which we normalize to $c = 0$. Public reserve price r_t is drawn i.i.d. over time from distribution F_r with support $[\underline{r}, \overline{r}]$, with $\overline{r} > \underline{r} \geq 0$. After observing r_t, firms submit public bids $\mathbf{b}_t = (b_{i,t})_{i=1,2}$. This yields allocation $\mathbf{x}_t = (x_{i,t})_{i=1,2} \in [0, 1]^2$ such that: if $b_{j,t} > b_{i,t}$ then $x_{i,t} = 1$; if $b_{j,t} < b_{i,t}$ then $x_{i,t} = 0$. In the case of ties, we follow Athey and Bagwell (2001) and Chassang and Ortner (2019) and let bidders jointly determine the allocation. Formally, we allow bidders $i = 1, 2$ to simultaneously and publicly pick numbers $\gamma_{i,t} \in [0, 1]$. When bids are tied, the allocation to bidder i is $x_{i,t} = \frac{\gamma_{i,t}}{\gamma_{i,t} + \gamma_{j,t}}$.[8] Firm i's profits in period t are $x_{i,t}(b_{i,t} - c) = x_{i,t}b_{i,t}$. Firms

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[8]If $\gamma_{i,t} = \gamma_{j,t} = 0$, then $x_{i,t} = x_{j,t} = 1/2$.

share a common discount factor $\delta < 1$.

Mediation. Firms have access to a mediator. In each period t, the mediator observes the history of past reserve prices and bids, as well as current reserve price r_t. Prior to bidding, the mediator privately sends recommended bids $(\widehat{b}_{i,t}, \widehat{\gamma}_{i,t})$ to firms $i = 1, 2$. Recommendations $(\widehat{b}_{i,t}, \widehat{\gamma}_{i,t})_{i=1,2}$ may depend on the history of past reserve prices and bids, current reserve price r_t, and the history of past recommendations.[9]

Solution concepts. A period-t history for bidder i,

$$h_{i,t} = (r_s, \widehat{b}_{i,s}, \widehat{\gamma}_{i,s}, \mathbf{b}_s, \boldsymbol{\gamma}_s)_{s<t} \sqcup (r_t, \widehat{b}_{i,t}, \widehat{\gamma}_{i,t}),$$

records past reserve prices $(r_s)_{s<t}$, mediator's recommendations $(\widehat{b}_{i,s}, \widehat{\gamma}_{i,s})_{s<t}$, and realized bids $(\mathbf{b}_s, \boldsymbol{\gamma}_s)_{s<t}$, as well as current reserve price r_t and mediator's recommendation $(\widehat{b}_{i,t}, \widehat{\gamma}_{i,t})$. A pure strategy $\sigma_i : h_{i,t} \mapsto (b_{i,t}, \gamma_{i,t})$ for bidder i maps bidder i histories to bids. Our solution concept is weak Perfect Bayesian Equilibrium, which we simply refer to as equilibrium. The period-t public history is $h_t^0 = (r_s, \mathbf{b}_s, \boldsymbol{\gamma}_s)_{s<t}$.

Definition 1. *We say that equilibrium $\sigma = (\sigma_i)_{i=1,2}$ is a* bid rotation equilibrium *if there exists $i, j = 1, 2$, $i \neq j$, such that for all on-path public histories h_t^0, $\mathbb{E}_\sigma[x_{i,t}|h_t^0] = 1$ if t is even and $\mathbb{E}_\sigma[x_{j,t}|h_t^0] = 1$ if t is odd.*

We focus on bid rotation equilibria, which corresponds to the bidding scheme the Kumatori cartel used.

Definition 2. *We say that equilibrium $\sigma = (\sigma_i)_{i=1,2}$ has* common-knowledge bids *if, for $i = 1, 2$ and for all histories $h_{i,t}$, $\sigma_i(h_{i,t})$ is a pure action and depends only on h_t^0 and r_t.*

We note that equilibria with common-knowledge bids correspond to pure strategy equilibria of the game without the mediator. Let Σ denote the set of bid rotation equilibria, and let $\Sigma^{\mathsf{CK}} \subset \Sigma$ denote the set of bid rotation equilibria with common-knowledge bids. For each

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[9]See Sugaya and Wolitzky (2017) for a detailed exposition of repeated games with a mediator.

equilibrium σ and $i = 1, 2$, let $V_i(\sigma)$ denote firm i's expected discounted payoff at the start of the game under σ. Define

$$\overline{V}^{\mathsf{CK}} \equiv \sup_{\sigma \in \Sigma^{\mathsf{CK}}} \sum_{i=1,2} V_i(\sigma), \text{ and}$$

$$\overline{V} \equiv \sup_{\sigma \in \Sigma} \sum_{i=1,2} V_i(\sigma),$$

to be, respectively, the cartel's largest payoffs under an equilibrium in Σ^{CK} and Σ. Since $\Sigma^{\mathsf{CK}} \subset \Sigma$, we have $\overline{V} \geq \overline{V}^{\mathsf{CK}}$.

Our first result characterizes optimal equilibria in Σ^{CK}. All proofs are in the Appendix.

Proposition 1. *On the equilibrium path, the bidding strategy in any $\sigma \in \Sigma^{\mathsf{CK}}$ that attains $\overline{V}^{\mathsf{CK}}$ is such that, in all periods t, the winning bid is given by the minimum between r_t and $\delta \overline{W}^{\mathsf{CK}}$, where $\delta \overline{W}^{\mathsf{CK}}$ is the expected continuation payoff of a designated loser under any equilibrium that attains $\overline{V}^{\mathsf{CK}}$.*

In an equilibrium that attains $\overline{V}^{\mathsf{CK}}$, along the equilibrium path the designated winner's bid is r_t or $\delta \overline{W}^{\mathsf{CK}}$, whichever is lowest, and the designated loser places a losing bid. Deviations are punished with Bertrand-Nash reversion. Intuitively, the winning bid must be below $\delta \overline{W}^{\mathsf{CK}}$ to deter the loser from deviating. Bid $\min\{r, \delta \overline{W}^{\mathsf{CK}}\}$ is the highest bid below r that satisfies the loser's incentive constraint. The appendix shows how value $\overline{W}^{\mathsf{CK}}$ is computed.

Our main result characterizes optimal equilibria in Σ, and establishes when $\overline{V} > \overline{V}^{\mathsf{CK}}$.

Proposition 2. *On the equilibrium path, the bidding strategy in any $\sigma \in \Sigma$ that attains $\overline{V}$ is such that, in all periods t, the winning bid is drawn from c.d.f. $F^*(\cdot; r_t)$. Distribution $F^*(\cdot; r_t)$ is degenerate at r_t if $r_t \leq \delta \overline{W}$ and is non-degenerate otherwise, where $\delta \overline{W}$ is the expected continuation payoff of a designated loser under any equilibrium that attains $\overline{V}$.*

Moreover, $\overline{V} > \overline{V}^{\mathsf{CK}}$ if and only if $\overline{r} > \delta \overline{W}^{\mathsf{CK}}$.

Proposition 2 shows that a cartel strictly benefits from strategies without common-knowledge bids when the largest point in the support of F_r is high enough; i.e., $\overline{r} > \delta \overline{W}^{\mathsf{CK}}$.

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Moreover, when the reserve price is high enough, the winning bid is drawn from a non-degenerate distribution in any equilibrium that attains $\overline{V}$. The appendix shows how $\overline{W}$ is computed.

We now describe the equilibrium that attains $\overline{V}$. Under this equilibrium, along the path of play the mediator recommends bid $(b, \gamma = 1)$ to the winner, with b drawn from c.d.f. $F^*(\cdot; r_t)$. The loser is recommended to bid $(\overline{b}, \gamma = 0)$, where $\overline{b}$ is the largest point in the support of $F^*(\cdot; r_t)$. If either bidder deviates, the mediator sends bidding recommendations $(b_i, \gamma_i) = (0, 1)$ to $i = 1, 2$ from the next period onwards, and players adhere to this recommendation; i.e., they play Bertrand-Nash. Note that, while deviations by the loser are publicly observed, deviations by the winner may only be detected by the mediator (since bidding recommendations are private). The mediator's messages following a deviation provide the winner with incentives to follow the recommended bid.

Next, we show how we derive the distribution $F^*(\cdot; r)$. Recall that the loser's discounted continuation payoff is $\delta \overline{W}$. Suppose that the winning bid at time t is drawn from c.d.f. F_t. Let $\overline{b}$ and $\underline{b}$ denote, respectively, the largest and smallest points in the support of F_t. For the loser not to have an incentive to deviate and place a bid $b < \overline{b}$, F_t must satisfy:

$$\forall b < \overline{b}, \quad (1 - F_t(b))b \le \delta \overline{W} \iff F_t(b) \ge 1 - \frac{\delta \overline{W}}{b}. \tag{1}$$

Equation (1) implies $\underline{b} \le \delta \overline{W}$.

Consider now the incentives of the predetermined winner. If the mediator recommends bid $b < \overline{b}$, the winner can increase its bid to $\overline{b} - \epsilon \approx \overline{b}$ and still win the auction. For the winner to have incentives to follow the mediator's recommendation, we must have

$$\underline{b} + \delta^2 \overline{W} \ge \overline{b}, \tag{2}$$

where the inequality follows since the winner's equilibrium continuation payoff is $\delta^2 \overline{W}$. Since $\underline{b} \le \delta \overline{W}$ (by equation (1)), inequality (2) gives us $\overline{b} \le \delta(1 + \delta)\overline{W}$. Distribution $F^*(\cdot; r)$ is the highest distribution (in terms of f.o.s.d.) with $\overline{b} \le r$ satisfying (1) and (2). When $\delta \overline{W} \ge r$,

$F^*(\cdot; r)$ puts all its mass at r. When $\delta\overline{W} < r$, $F^*(\cdot; r)$ is given by:

$$F^*(b; r) = \begin{cases} 0 \text{ if } b < \delta\overline{W}, \\ 1 - \frac{\delta\overline{W}}{b} \text{ if } b \in [\delta\overline{W}, \min\{r, \delta(1+\delta)\overline{W}\}), \\ 1 \text{ if } b \geq \min\{r, \delta(1+\delta)\overline{W}\}. \end{cases}$$

Note that distribution $F^*(b; r)$ has a mass point at $\min\{r, \delta(1+\delta)\overline{W}\}$.

4   Description of the Bidding-Ring in the Court Ruling

In this section, we illustrate how our theoretical predictions are borne out by drawing on the court rulings' descriptions of the events leading up to the Ohara Residences auction.[10]

According to the Osaka District Court ruling, Mr. Kitagawa of Imakatsu Construction started to believe, around April of 2006, that Tier B firms would be invited to bid on the second part of the Ohara residences project and started mentioning the project at the meetings of the Kumatori Contractors' Cooperative. In a meeting of the Cooperative in late June 2006, Mr. Kitagawa stated that he wanted others to let his firm, Imakatsu Construction, win the auction. He also told the members that he would be collecting the detailed project plan that the town distributes at the on-site briefing. This was understood by the members of the cooperative as a preventative measure to make defection more difficult by making cost estimates for other firms harder.

On August 3, 2006, the town office invited five contractors to bid on the housing complex project, including Imakatsu Construction. All invited bidders were Tier B firms and members of the Cooperative. On or around this day, Mr. Kitagawa asked Mr. Nishio to help him with the operation and to obtain confidential information about the project from the town. Mr. Nishio was the vice director of the Cooperative and a senior managing director of Nishinuki Construction at the time. Nishinuki Construction was not one of the invited bidders.

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[10]The descriptions are taken from the Osaka District Court ruling (Ruling H21 (Gyo-U) No. 99) and the Osaka High Court ruling (Ruling H24 (Gyo-Ko) No. 101).

On August 4, 2006, after the general meeting of the Cooperative, Mr. Kitagawa met with the four other bidders that were invited to bid on the Ohara Residences project and repeated his intention to collect the project plans.

The town of Kumatori held an on-site briefing for the Ohara residences project for the five invited firms on August 7. At the on-site briefing, the town distributed the detailed project plan as well as other documents required to estimate costs. These documents were collected immediately after the briefing by an employee of the Cooperative. The plans and the documents were not returned to the bidders until August 21, the day before the auction. During this time, Imakatsu Construction was the only firm that had access to the documents required to estimate costs. After the on-site briefing, Mr. Nishio obtained information regarding the reserve price from an official of the Buildings Division of the town.

On August 21, one day before the day of the auction, Mr. Kitagawa and Mr. Nishio met at the office of Imakatsu Construction and decided on a bid of 630 million yen for Imakatsu Construction and bids of above 700 million yen for all other bidders. According to the court ruling, they decided to set the losing bids to be above 700 million yen so as to make it hard for the other bidders to guess the lowest bid. Note that the bid difference between the winning bid and the losing bids is around 70 million yen, more than 10% of the winning bid. As we document in Section 2, the difference between the lowest bid and the losing bids were on average 0.9% before this auction, and never above 4%.

Also on the same day, Mr. Nishio contacted the four other invited bidders of the auction. He told them that he would hand them the document containing each firm's break-down of the estimated costs on the day of the auction. Mr. Nishio also told the bidders that he would give instructions on how much to bid on the day of the auction. According to the court ruling, Mr. Nishio's decision to hand the documents and give instructions on bids on the day of the auction (as opposed to two days prior to the day of the auction, as was customary for the bidding ring) was to prevent defection given the large size of the project.

The auction for the public housing complex was held at the town office on August 22 2006. Mr. Nishio went to the town office and stapled together the documents containing the

cost break-down of each bidder with the cover page brought by the representatives of the firms. Mr. Nishio also indicated the amount that each bidder should bid by showing a slip of paper with a number above 700 million yen. Importantly, the bid of Imakatsu Construction was kept secret to the other bidders. The representatives of the invited bidders bid the same or slightly above the amount shown on the slip of paper. As a result, Imakatsu Construction won the auction with a bid of 630 million yen. The other bids were 705 million yen, 707 million yen, 710 million yen and 723 million yen, respectively.

5 Discussion

This paper highlights the value of keeping winning bids secret from other cartel members in bidding rings. We think that the case study offers a first concrete documentation of the value of privacy over transparency in cartels.

We conclude the paper with discussions of (i) our model's implications for the price-variance screen for collusion, and (ii) how our model explains puzzling bidding patterns documented elsewhere.

Price-variance screen. Our model predicts that when the project is relatively small (i.e., r_t is small), the winning bid measured as a fraction of the reserve price $(\frac{\min_i b_{i,t}}{r_t})$ will be close to 1 and the money left on the table will be close to zero. This implies that the time series variance in the winning bids, $\frac{\min_i b_{i,t}}{r_t}$, will be close to zero and the within-auction variance of bids will also be close to zero. These results are consistent with the premise of the price-variance screen. However, when projects are relatively large, our model predicts that there will be considerable time-series variance in the winning bids that results from randomization. Moreover, the within-auction variance of bids will not be close to zero. Hence, increases in the variance of prices should not be taken as failure of collusion when those increases are associated with increases in project sizes.

Explaining other bidding patters. A distinct feature of the equilibrium in Proposition 2 is that the winner has a static incentive to raise its bid whenever the mediator recommends a bid below $\bar{b} = \sup_b \text{supp}\, F^*(\cdot; r)$. This feature is present in the bidding data analyzed in Chassang et al. (2020).[11] Chassang et al. (2020) study the sample distribution of normalized bid differences $\Delta_{i,t} \equiv (b_{i,t} - \wedge b_{-i,t})/r_t$ for procurement auctions let by the Ministry of Land, Infrastructure and Transportation of Japan, and by cities in Ibaraki prefecture and the Tohoku region (bid data from Kumatori are not included in the data analyzed by Chassang et al. (2020)). That paper documents a missing mass in the distribution of Δ around $\Delta = 0$: In other words, winning bids tend to be isolated. This implies that upward deviations by winners are profitable, consistent with the collusive scheme in Proposition 2.

Appendix

Proof of Proposition 1. Fix an equilibrium $\sigma \in \Sigma^{\mathsf{CK}}$. Let V^w and V^l denote, respectively, the expected discounted payoff that the designated winner and loser at $t = 0$ obtain under σ. Let $\overline{V}^w$ be the highest payoff that the designated winner at $t = 0$ can obtain under an equilibrium in Σ^{CK}. Since $V^w \leq \overline{V}^w$ and $V^l \leq \delta \overline{V}^w$ (since the loser at $t = 0$ is the winner at $t = 1$), $V^w + V^l \leq (1 + \delta)\overline{V}^w$. Since this inequality holds for all $\sigma \in \Sigma^{\mathsf{CK}}$, $\overline{V}^{\mathsf{CK}} \leq (1 + \delta)\overline{V}^w$.

Let $b(r_0)$ be the winning bid at time $t = 0$ under σ. Note that $b(r_0) \leq \delta \overline{V}^w$. Indeed, the continuation payoff of the loser at $t = 0$ can't be larger $\delta \overline{V}^w$ (since the loser at $t = 0$ is the winner at $t = 1$). If $b(r_0) > \delta \overline{V}^w$, the loser would have a strict incentive to undercut $b(r_0)$. Since $b(r_0)$ must be lower than r_0, $b(r_0) \leq \min\{r_0, \delta \overline{V}^w\}$. Hence, $V^w \leq \mathbb{E}_{F_r}[\min\{r_0, \delta \overline{V}^w\}] + \delta^2 \overline{V}^w$. Since the inequality holds for all $\sigma \in \Sigma^{\mathsf{CK}}$,

$$\overline{V}^w \leq \frac{1}{1 - \delta^2} \mathbb{E}_{F_r}[\min\{r_0, \delta \overline{V}^w\}].$$

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[11]Tóth et al. (2014), Imhof et al. (2016) and Clark et al. (2020) document similar patterns. Clark et al. (2020) offer an explanation based on the bidders' desire to leave some margin of error.

Let $\overline{W}^{\mathsf{CK}}$ be the largest $W \geq 0$ solving

$$W = \frac{1}{1-\delta^2}\mathbb{E}_{F_r}[\min\{r, \delta W\}]. \tag{3}$$

Note that $\overline{V}^w \leq \overline{W}^{\mathsf{CK}}$.[12] We now show that $\overline{V}^w = \overline{W}^{\mathsf{CK}}$. Consider the following strategy profile. Along the equilibrium path, in each period t the designated winner bids $\min\{r_0, \delta\overline{W}^{\mathsf{CK}}\}$ and $\gamma = 1$, and the designated loser bids $\min\{r_0, \delta\overline{W}^{\mathsf{CK}}\}$ and $\gamma = 0$. Deviations are punished with Nash reversion. This strategy profile is an equilibrium in Σ^{CK} giving the winner at $t = 0$ an expected discounted payoff of $\overline{W}^{\mathsf{CK}}$. Hence, $\overline{V}^w = \overline{W}^{\mathsf{CK}}$. Since $\overline{V}^{\mathsf{CK}} \leq (1+\delta)\overline{W}^{\mathsf{CK}}$, this equilibrium attains $\overline{V}^{\mathsf{CK}}$. ∎

For each reserve price r and each value $W \geq 0$, let $F(\cdot; r, W)$ be the c.d.f. given as follows. If $\delta W \geq r$, $F(\cdot; r, W)$ puts all its mass at r. If $\delta W < r$, $F(\cdot; r, W)$ is given by:

$$F(b; r, W) = \begin{cases} 0 \text{ if } b < \delta W, \\ 1 - \frac{\delta W}{b} \text{ if } b \in [\delta W, \min\{r, \delta(1+\delta)W\}), \\ 1 \text{ if } b \geq \min\{r, \delta(1+\delta)W\}. \end{cases} \tag{4}$$

Proof of Proposition 2. Fix an equilibrium $\sigma \in \Sigma$. Let V^w and V^l denote, respectively, the expected discounted payoff of the designated winner and loser at $t = 0$ under σ. Let $\hat{V}^w$ be the highest payoff that the winner at time $t = 0$ can obtain under an equilibrium in Σ. By the same arguments as in the proof of Proposition 1, $\overline{V} \leq (1+\delta)\hat{V}^w$.

Let $F(b; r_0)$ be the c.d.f. from which the winning bid at $t = 0$ is drawn under σ. Let $\overline{b} = \sup_b \mathsf{supp}\, F(\cdot; r_0)$ and $\underline{b} = \inf_b \mathsf{supp}\, F(\cdot; r_0)$. Note that the designated loser at $t = 0$ must place a bid weakly higher than $\overline{b}$ under σ; otherwise, it would win with positive probability.

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[12]Since the right-hand side of (3) is bounded by $\overline{r}/(1-\delta^2)$, $W > \frac{1}{1-\delta^2}\mathbb{E}_{F_r}[\min\{r, \delta W\}]$ for all $W > \overline{W}^{\mathsf{CK}}$.

Moreover, we must have

$$\forall b < \bar{b}, \qquad (1 - F(b; r_0))b \leq \delta \hat{V}^w, \tag{5}$$

$$\forall b \in \mathsf{supp}\, F(\cdot; r_0), \qquad \bar{b} \leq b + \delta^2 \hat{V}^w. \tag{6}$$

If inequality (5) didn't hold for some $b < \bar{b}$, the loser would have a strict incentive to bid b and win the auction with probability $1 - F(b; r_0)$. If inequality (6) didn't hold for $b \in \mathsf{supp}\, F(\cdot; r_0)$, the winner would have an incentive to bid $\bar{b} - \epsilon$ with $\epsilon \approx 0$ instead of $b < \bar{b}$. Condition (5) implies

$$\underline{b} \leq \delta \hat{V}^w \text{ and } \forall b < \bar{b}, F_b(b; r_0) \geq 1 - \delta \frac{\hat{V}^w}{b}. \tag{7}$$

Condition (6), together with $\bar{b} \leq r_0$, implies

$$\bar{b} \leq \min\{r_0, \underline{b} + \delta^2 \hat{V}^w\}. \tag{8}$$

Consider the problem of finding the c.d.f. F that maximizes expected winning bid $\int b\,dF$, subject to (7) and (8). When $\delta \hat{V}^w \geq r_0$, the c.d.f. F that solves this problem puts all its mass at r_0. When $\delta \hat{V}^w < r_0$, the c.d.f. F that solves this problem is given by (4), with $r = r_0$ and $W = \hat{V}^w$. Therefore, $V^w \leq \mathbb{E}_{F_r}\left[\int b\,dF(b; r, \hat{V}^w)\right] + \delta^2 \hat{V}^w$. Since the inequality holds for all $\sigma \in \Sigma$,

$$\hat{V}^w \leq \frac{1}{1 - \delta^2} \mathbb{E}_{F_r}\left[\int b\,dF(b; r, \hat{V}^w)\right].$$

Let $\overline{W} \geq 0$ be the largest solution to

$$W = \frac{1}{1 - \delta^2} \mathbb{E}_{F_r}\left[\int b\,dF(b; r, W)\right], \tag{9}$$

and note that $\hat{V}^w \leq \overline{W}$.[13] For each r, let $F^*(\cdot; r)$ be the c.d.f. given by $F^*(\cdot; r) = F(\cdot; r, \overline{W})$. We now show that $\hat{V}^w = \overline{W}$. Consider the following strategy profile. Along the equilib-

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[13]Since the right-hand side of (9) is bounded, $W > \frac{1}{1-\delta^2} \mathbb{E}_{F_r}\left[\int b\,dF(b; r, W)\right]$ for all $W > \overline{W}$.

rium path, in each period t, after observing r_t the mediator sends bidding recommendation $(\widehat{b}_i, \widehat{\gamma}_i) = (b, 1)$ to the designated winner, with b drawn from c.d.f. $F^*(\cdot; r_t) = F(\cdot; r_t, \overline{W})$; and sends bidding recommendation $(\widehat{b}_j, \widehat{\gamma}_j) = (\overline{b}_t, 0)$ to the designated loser, with $\overline{b}_t = \sup_b \mathsf{supp}\, F^*(\cdot; r_t)$. Deviations from the mediator's recommendations are punished with Nash reversion.[14] One can check that this strategy profile is an equilibrium in Σ, and gives the designated winner at $t = 0$ a payoff equal to $\overline{W}$. Hence, $\hat{V}^w = \overline{W}$. Since $\overline{V} \leq (1 + \delta)\hat{V}^w$, this equilibrium also attains $\overline{V}$.

Finally, note that $\int b \, dF(b; r, W) \geq \min\{r, \delta W\}$ for each r, W, with strict inequality whenever $\delta W < r$.[15] Hence, $\overline{W} \geq \overline{W}^{\mathsf{CK}}$, with strict inequality whenever $\delta \overline{W}^{\mathsf{CK}} < \overline{r}$. Hence, when $\overline{r} > \delta \overline{W}^{\mathsf{CK}}$, we have $(1 + \delta)\overline{W} = \overline{V} > \overline{V}^{\mathsf{CK}} = (1 + \delta)\overline{W}^{\mathsf{CK}}$. $\blacksquare$

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[14]Formally, following a deviation, the mediator sends bidding recommendations $(b_i, \gamma_i) = (0, 1)$, which both bidders follow.

[15]When $\delta W \geq r$, $r = \int b \, dF(b; r, W)$. When $\delta W < r$,

$$\delta W < \int b \, dF(b; r, W) = \begin{cases} \delta W[1 + \ln(1 + \delta)] & \text{if } \delta(1 + \delta)W < r, \\ \delta W\,[1 + \ln(r) - \ln(\delta W)] & \text{if } \delta(1 + \delta)W \geq r. \end{cases}$$

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