Collusion by Exclusion in Public Procurement*

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Abstract

This paper studies bid-rigging in auctions with bidder preselection. We develop a theoretical model to analyze the optimal behavior of a partial bid-rigging cartel and show how commonly used two-stage auction formats, in which the first stage is used to preselect bidders, may be exploited. Bidder preselection based on opening bids allows cartels to exclude competitive rivals and thereby increase procurement costs above what would be possible without preselection. To test our predictions, we use administrative data on public procurement auctions in Slovakia. We develop a collusion marker reflecting the optimal cartel strategy and identify bidders suspected of collusion. In auctions where collusive bidders participate, savings, defined as the difference between reserve price and winning bid, are lower by 3.7 percentage points. After a selective auction procedure was abandoned, collusive bidders adjusted their strategy, and the difference in savings between collusive and competitive auctions decreases to 1.5 percentage points, closing almost 60% of the gap.

Keywords: auctions, collusion, public procurement, preselection, bid-rigging.

JEL: D43, D44, H57, L12, L13

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1 Introduction

Spending on public procurement amounts to around 29% of government expenditures and 12% of GDP in OECD countries (OECD, 2019). Thus, failing to ensure that the procurement process is competitive and efficient can strain government budgets, impair public goods provision and undermine the credibility of public institutions. At the same time, bid-rigging in public procurement auctions is pervasive, and thus, it is not surprising that the fight against bid-rigging has become a top enforcement priority for competition authorities across the globe (OECD, 2016). A prominent example of this development is the formation of a new Procurement Collusion Strike Force by the United States Department of Justice in 2019.[1]

An effective fight against bid-rigging consists of both ex-ante prevention of collusion by appropriate auction design choice and ex-post detection and prosecution of cartels. Previous literature has contributed to the understanding of these two elements with respect to single-stage auctions, corresponding to open auction procedures where all interested bidders can participate in the auction.[2] However, a substantial share of public contracts are not tendered in open procedures. From 2008 to 2012, more than 50% of contracts in the UK and more than 20% in Denmark and the Netherlands were awarded using restricted procedures (Chong, Klien and Saussier, 2016). In a restrictive procedure, only a certain number of firms is preselected for participation in the main tender. Preselection criteria usually refer to technical specifications and product quality but may also include an initial price offer.[3] When such an "invitation to quote" precedes the actual procurement auction, this effectively constitutes the first stage of a two-stage procurement process. Two-stage auctions may reduce the cost of the procurement process if many firms are qualified to procure the good or service but participation in the procurement process is costly such that firms are willing to participate only if their chance of winning the contract is sufficiently high.[4] However, this reasoning ignores the possibility that some firms may coordinate their bidding decisions.

In this paper, we detect collusion and analyze its consequences in two-stage auctions.[5] First, we develop a theoretical model to derive the optimal behavior of a bid-

[1] See https://www.justice.gov/opa/pr/justice-department-announces-procurement-collusion-strike-force-coordinated-national-response.

[2] See, for instance, Athey, Levin and Seira (2011) or Chassang and Ortner (2019). Moreover, a number of papers cover cartel detection in such auctions; see Harrington (2008), Huber and Imhof (2019) or Kawai and Nakabayashi (2022) for some examples.

[3] See, for instance, the guidance on the use of electronic auctions in the UK (`https://www.gov.uk/guidance/eauctions`).

[4] See, for instance, `https://democracy.hertfordshire.gov.uk/Data/Cabinet/201703131400/Agenda/az1DdN6sUnwwRkqRngrhKoqUbjrPq.pdf`. For academic literature showing the benefits of two-stage auctions, see, for instance, Bhattacharya, Roberts and Sweeting (2014) and Sweeting and Bhattacharya (2015).

[5] Note that there may also be a concern about corruption if preselection criteria are discretionary (see

rigging cartel and analyze the effect of collusion on procurement costs in two-stage as well as single-stage auctions. We show that preselection by means of opening bids allows collusive bidders to reduce competition not only among themselves, as is also possible without preselection, but also from firms which are not part of the cartel. They can achieve this by coordinating their bids in the preselection stage, which helps them to qualify jointly and crowd out competitive rivals in the main auction. Second, we use the theoretical insights to develop a collusion marker to identify suspicious bidders in administrative auction data from electronic public procurement in Slovakia. We validate our collusion marker using a court-confirmed cartel case, network analysis and bidding behavior in the main auction. Finally, we quantitatively evaluate a reform that abolished a two-stage auction format (with preselection) in favor of a single-stage auction (without preselection), taking into account differential effects depending on cartel activity. We estimate a larger gap in the procurement savings with and without collusion when preselection is used. At the same time, we observe small gains from using preselection under competition, in line with the literature on two-stage auctions.

We start with a theoretical analysis of auctions with preselection. In our baseline model, bidders are risk neutral and draw their cost to provide a single good independently according to a cumulative distribution function that is common to all bidders. Bidders know their own cost realization, but not the realization of others. In the first stage, bidders submit a sealed opening bid, and a limited number of bidders with the lowest opening bids are preselected for an English descending auction in the second stage.[6] The lowest opening bid is then used as a starting price for the English auction. To reflect their purpose, we generally refer to the first stage as the *preselection stage* and to the second stage as the *main auction*.[7] We show how a partial bid-rigging cartel, i.e., a cartel that does not involve all firms in a market, may exploit preselection through opening bids. With preselection, a partial cartel large enough to fill all slots in the main auction has the ability to profitably exclude cartel outsiders from participating in the main auction, thereby eliminating competition in the main auction. Specifically, the optimal cartel strategy, which we refer to as *close bidding*, involves ensuring that sufficiently many cartel members participate and coordinate on a single cartel bid in the preselection stage. Only rival bidders who undercut the cartel bid can then proceed to the main auction. Building on this result, we consider the effect of removing pre-

Decarolis, Fisman, Pinotti and Vannutelli, 2020; Szucs, 2023). Our goal is to show that even if procurement agencies are not corrupt, restrictive procedures can be exploited by bidders (without help from the agency).

[6] In the usual representation of the English descending auction, prices decrease continuously, and bidders indicate their interest in procuring the good at any given price until a single bidder is left. See Section 2.1 for more details.

[7] We selected the auction formats in the two stages to closely mirror the actual rules on the procurement platform in Slovakia.

selection by comparing the outcomes with those under an otherwise identical auction format where all interested bidders are allowed to proceed irrespective of their opening bid. Such an auction format is equivalent to a standard English descending auction. The main outcome we consider is the savings generated in an auction, i.e., the difference in reserve price and winning bid of an auction. Removing preselection eliminates the possibility of excluding rivals and thus the gains from joint participation in the auction process. This decreases cartel profits but increases overall procurement savings, in contrast to the case where no cartel exists and the removal of preselection has no effect.

We later extend our model to incorporate the potential benefits of preselection and match the assumption usually made in the two-stage auction literature.[8] When bidders face a (nonpecuniary) entry cost for entry into the main auction and may update their cost in between the two stages, close bidding remains optimal for the cartel. In such a more complicated setting, removing preselection should still decrease joint participation of cartel members but has no clear-cut effect on procurement savings. Still, given the exploitation by the cartel, we expect the collusive harm to be larger with preselection than without preselection. Our theoretical analysis thus leads to three core predictions. First, with preselection, partial bid-rigging cartels should engage in close bidding frequently but avoid competition once competitive rivals are successfully excluded from the main auction. Second, as joint participation in the preselection stage is not beneficial for the cartel without preselection, we expect it to be less prevalent than in an auction format with preselection. Third, removing preselection eliminates the cartel's ability to exclude rivals and thus should lead to a smaller difference in savings between auctions where collusive bidders participate and auctions where they do not.

We use data from the electronic contracting system (EKS) for public procurement in Slovakia to verify our predictions. A reform in February 2017 allows us to observe outcomes for the auction formats both with and without preselection. Before the reform, only three bidders were allowed to proceed to the main auction, and the identity of these bidders was based on their opening bid in the preselection stage. After the reform, any interested bidder could participate in the main auction. Both before and after the reform, the main auctions took place as an English descending auction. The EKS serves as a platform for the purchase of goods and services by public agencies, and its use is mandatory for procuring standardized goods and services with values between EUR 5,000 and EUR 135,000.[9] Importantly, agencies cannot choose the auction design but are bound to the rules of the platform. The latter feature makes the data particularly attractive from a research perspective, since outcomes are not confounded by the endogenous auction choice of the procurement agency.

[8] See Ye (2007), Bhattacharya et al. (2014), and other papers in the literature review below.

[9] These thresholds apply to the time of the reform.

The theoretical model suggests a simple marker for identifying potential colluders: We consider firms frequently involved in bidding close to their rivals in the preselection stage to be potentially collusive. Any auction in which such bidders participate may thus be affected by collusion. For brevity, we use the terms *collusive* and *potentially collusive* as well as *colluder* and *potential colluder* interchangeably.[10] To confirm that our marker is indeed indicative of cartel membership and anticompetitive behavior, we provide three pieces of evidence. First, our markers are supported by a recent cartel case in Slovakia: On May 19, 2021, the antitrust authority convicted 6 companies of bid-rigging in prereform public procurement auctions. Despite the fact that we developed our marker before knowing the identities of the firms and our marker flags only 4% of the bidders active before the reform, we still mark five out of the six convicted cartel members.[11] Second, if frequent close bidding is happening in the context of a cartel, we should expect collusive firms to engage in close bidding with other collusive firms but not with competitive firms. We analyze close bidding among bidder pairs and show that this is indeed true. Finally, we show that in the prereform auction format with preselection, when collusive bidders participate, bidding in the main auction is less aggressive in general but particularly so if they manage to eliminate competitive bidders in the first stage. These findings give us confidence that our marker does indeed identify bidders that are likely members of a bid-rigging cartel.

Based on our theory, after the reform, when preselection is abandoned and the auction format reduces to a simple English descending auction, we should observe joint participation of colluders less frequently. To test this second prediction, we consider the effect of the reform on the probability of facing a colluder in the preselection stage. Indeed, while competitive bidders are similarly likely to face a colluder among rival bidders, for potential colluders, this probability decreases significantly and abruptly after the reform. This result confirms that cartels adjust their collusive strategy to the new auction format. Moreover, while the savings in auctions affected by collusion are approximately 3.7 percentage points lower than the savings in competitive auctions, after preselection is abandoned, this savings gap reduces to approximately 1.5 percentage points, i.e., by almost 60%. However, we do not find larger savings overall after the reform, as the savings in competitive auctions, constituting a large majority of auctions on the platform, slightly decrease. Consequently, our results underline our theoretical result that a two-stage auction design is a double-edged sword: While it may be

[10] Note that as is the case with any collusion marker, our collusion marker provides statistical evidence of collusion, which is distinct from legal evidence. Thus, only convicted cartel members are colluders without a legal doubt.

[11] The first version of the paper was made publicly available in February 2021, see `https://web.archive.org/web/20211024003724/https://reginaseibel.github.io/publication/collusion/collusion.pdf`

efficiency enhancing under competition, bid-rigging may eliminate or even overcompensate those gains. Procurement agencies should thus pay attention to suspicious behavior in past auctions and adapt their choice of auction format accordingly.

Auctions with bidder preselection have been analyzed theoretically in the literature on two-stage auctions, starting with Ye (2007). Building on Ye (2007), several scholars have shown that in private-value settings with entry costs, two-stage auctions eliminate miscoordination in the entry decision between bidders and thus may increase efficiency and decrease the procurement cost relative to those in standard one-stage auctions (Bhattacharya et al., 2014; Lu and Ye, 2014; Quint and Hendricks, 2018; Sweeting and Bhattacharya, 2015).[12] There is also a second, somewhat parallel, theoretical literature stream on a specific form of two-stage auctions that uses the term *hybrid auctions* and is mostly interested in settings with common or affiliated values. Within this setting, Dutra and Menezes (2002) and Levin and Ye (2008) show that hybrid auctions generate higher revenues than other standard auctions, assuming competitive bidders. With collusive bidders, an informal argument for the combination of one first-price sealed-bid auction stage and one descending English auction stage has been made: Sealed-bid auctions make collusion more difficult, while open descending auctions are conducive to aggressive price competition, so two-stage auctions combine the best of both formats (see Klemperer, 1998 and Maurer and Barroso, 2011). There is an interaction between the two stages, however, so this argument ignores the fact that cartel strategies and profits may well be different in two-stage and one-stage auctions, which is the focus of our formal analysis.[13] We provide the first theoretical analysis of collusion in two-stage auctions as outlined above in an independent private-value setting. Our results suggest that bid-rigging cartels may exploit two-stage auction rules, counteracting previous findings. Moreover, we support our theoretical claims with quasi-experimental evidence, which has been lacking in the literature on hybrid or two-stage auctions.

Our paper also contributes to the empirical literature on the detection of bid-rigging cartels.[14] Porter and Zona (1993, 1999) test for differences in bidding between alleged cartel members and other bidders. Without information on cartel membership, Bajari and Ye (2003) use industry experts' estimates of the cost distribution to evaluate the fit of structural competitive versus collusive models. Chassang, Kawai, Nakabayashi and

[12] An essential deviation of our model from models in this literature is that our first stage neither leads to a price directly paid for entry nor is it indicative. Instead, it leads to an endogenous reserve price in the second stage. While this modeling difference is non-trivial, under appropriate assumptions, it leads to equivalent outcomes compared to previously considered formats, which we show in Section A.6.1.

[13] The literature on premium or Amsterdam auctions extends the simple hybrid setting with a premium for proceeding to the second stage, which is intended to increase participation among very weak bidders (Goeree and Offerman, 2004). Hu, Offerman and Onderstal (2011) show that cartel profits may be lower in such auctions than in standard English auctions, but this result relies on strong asymmetries between bidders. Moreover, we are not aware of the use of premia in procurement auctions.

[14] See Harrington (2008) for a detailed survey.

Ortner (2022) describe a novel bidding pattern that is inconsistent with competition irrespective of the cost distribution.[15] Athey et al. (2011), Conley and Decarolis (2016) and Chassang and Ortner (2019) observe two different auction formats, where one is more prone to coordination than the other, which allows the authors to attribute differences in outcomes to bid-rigging. Similar to our methodology, Chassang and Ortner's (2019) approach is to develop theoretical predictions to develop a test of collusive behavior. In contrast to our test, their test is based on a prediction on the effect of an auction-rule reform instead of bidding behavior in a particular auction format. They show that the introduction of a minimum price makes it more difficult to enforce collusion and thus leads to a shift in the price distribution if cartels participate in the auctions. The average bid auction format pre-reform analyzed by Conley and Decarolis (2016) allows the authors to identify groups of firms coordinating their bids more directly.[16] Our contribution lies in providing a novel analysis of a different auction design element, preselection by means of opening bids, that is frequently used in practice and in deriving a theory-based collusion marker. In addition, observing two different auction formats allows us to quantify the losses that arise due to exploitation of preselection.

The remainder of the paper proceeds as follows. Section 2 presents the theoretical model and forms predictions that help us identify collusive bidding patterns and understand the effects of preselection. Section 3 introduces the institutional background and describes the reform and the data that we analyze. In Section 4, we develop and verify our collusion marker. Section 5 analyzes the effect of the reform on collusive and competitive auctions. Section 6 provides a discussion of our results, and Section 7 concludes.

2 Theoretical Framework

The goal of this section is to motivate the marker that we use to identify potentially collusive practices in the data and to form differential predictions on the effect of preselection for collusive versus competitive auctions. To this end, we start in Section 2.1 by introducing a simple model that captures the most important components of the auction formats in which we are interested. After analyzing this model in Sections 2.2 to 2.4, we extend the model in Section 2.5 to allow for a more flexible information structure and entry costs. This more complicated model is arguably more realistic and shows that our results, in particular on collusive exclusion, are applicable in a broad range of settings. A summary of the main empirical predictions of our model is provided in

[15] More recently, Huber and Imhof (2019) use machine-learning techniques to identify cartels; their method, similarly to that of Chassang et al. (2022), relies on the identification of peculiar bidding patterns.

[16] In an average bid auction, the bidder whose bid is closest to a trimmed average bid wins.

Section 2.6. All proofs can be found in Appendix A.

2.1 Model Setup

Consider N risk-neutral firms $i \in \{1, ..., N\}$. We refer to the set of all firms as A, hence $|A| = N > 1$. The procurer wishes to buy a single product. The cost of each firm i for providing that product is a privately known i.i.d. draw from a cumulative distribution function $F(c)$. $F(c)$ allows a density $f(c)$ that is strictly positive on the support $[\underline{c}, \overline{c}]$. Before the auction takes place, a reserve price r is publicly announced, which we assume to be above $\overline{c} < r$. [17] Moreover, the procurer announces a preselection rule $n \in \{2, ..., N\}$ before any bidding occurs. Preselection is based on a sealed opening bid $b_i \leq r$ that all firms have to place to be eligible for the main auction. We use $b_{j:N}$ to denote the j-th lowest bid among all N bids. Having submitted opening bid b_i, the preselected set of firms are those with opening bid $b_i \leq b_{n:N}$. If $n < N$, at least one firm is excluded from the main auction. If $n = N$, all firms are allowed to proceed, and effectively, no preselection takes place. Hence, the preselected set is given by $P_n = \{i : b_i \leq b_{n:N}\}$, where $|P_n| = n$ and $P_n \subseteq A$.[18] We refer to the first stage where opening bids are submitted for preselection as the *preselection stage*. Subsequently, the second stage, which we refer to as the *main auction*, takes place in the form of a descending English auction with binding opening bids. We employ the usual representation of an English auction where prices decrease continuously and bidders indicate their interest in procuring the good, e.g., by pushing a button (see Milgrom and Weber, 1982). Bidders with their button pushed are "active," and releasing the button implies that they drop out. The first price for which only one bidder remains active is the final bid, and the auction ends. However, we introduce an important modification that reflects the binding nature of the opening bids. Specifically, the starting price for the English auction is the lowest opening bid, and the bidder who submitted it has the obligation to procure the good at this opening bid if no one else is active at the beginning of the main auction. Ties are broken randomly, and we denote the lowest last bid at which firm i is active by $q_i \leq b_i$.[19]

In summary, the timeline of the model is as follows:

(0) *Auction preparation*: Preselection rule $n > 1$ and reserve price $r > \overline{c}$ are announced.

[17] We consider the reserve price to be exogenous. In our empirical setting, the reserve price is the maximal amount of resources allocated to this contract. While interesting, we are unaware of any research on optimal reserve prices in the two-stage auction literature.

[18] If multiple firms submit a bid of value $b_{n:N}$, firms are preselected at random to ensure that exactly n firms with bids weakly lower than $b_{n:N}$ are allowed to proceed.

[19] With independent private values, an English descending auction is outcome equivalent to a closed-bid second-price auction. Our modification would then be equivalent to each preselected firm having to submit a bid in the main auction that is no higher than its opening bid.

(1) *Preselection stage:* Each firm i submits a sealed bid $b_i \leq r$. Firms $i \in P_n$ are preselected.

(2) *Main auction:* Preselected firms participate in an English auction with the lowest opening bid as the starting value. The last active firm wins the auction at price $q_j = \min_{i \in P_n} q_i$.

Ultimately, we are interested in the effect of collusion and preselection on the spending of government agencies. To this end, we define the *procurement savings* as the difference between the reserve price and the lowest final bid, $s = r - \min_{i \in P_n} q_i$. We may sometimes refer to the savings based on the lowest opening bid as *preselection savings*, $s_1 = r - \min_{i \in P_n} b_i$. The savings increment through bidding in the main auction, or the *main-auction savings*, is given by $s_2 = s - s_1 = \min_{i \in P_n} b_i - \min_{i \in P_n} q_i$.

Partial cartels We are explicitly interested in partial cartels, i.e., cartels that do not comprise all firms participating in an auction. Therefore, to capture groups of firms that form a cartel and distinguish them from competitive firms, we define partitions of the set of firms $I_m \subseteq A$ such that firms within a partition coordinate their bids. Hence, if firm $i \in I_m$ is part of a cartel, $|I_m| > 1$. This notation also covers competitive firms: If firm $i \in I_{m'}$ is a competitive firm, then $|I_{m'}| = 1$. We also assume that the cost realizations of all members are known within the cartel and that, if any cartel member wins, the good is ultimately procured by the cartel member with the lowest cost. Thus, we focus on a *strong* cartel, i.e., a cartel acts like a single entity that controls multiple bidder accounts.[20] For simplicity, we abstract from questions of compensation within a cartel and assume that a cartel can enforce any policy as long as it increases the joint profits of cartel members in expectation.[21] While we generally allow for the existence of multiple partial cartels, Sections 2.4 and 2.5 focus on the case with a single partial cartel.

2.2 Main Auction

Denoting the minimal rival cost by $c_{-I_m} = \min_{i \in P_n \setminus I_m} c_i$ and minimal opening bid within the own partition by $b_{I_m} = \min_{i \in I_m} b_i$, we obtain the following result for the main auction:

Lemma 1. *Suppose $b_i > c_i \forall i \in \{1, ..., N\}$ and $n \geq 2$. Then, the firm with cost $c_j = \min_{i \in P_n} c_i$ procures the good at final bid $q_j = \min\{c_{-I_m}, b_{I_m}\}$, where I_m is such that $j \in I_m$.*

[20] This terminology has also been used, for instance, in McAfee and McMillan (1992) and Marshall and Marx (2007).

[21] This can be achieved by a pre-auction knock-out, for instance, as described by Asker (2010) or Graham and Marshall (1987). See Section 6.2 for further discussion.

Hence, as long as every firm's opening bid from the preselection stage is higher than its cost, the firm with the lowest cost of providing the good among the preselected firms wins. If this firm is competitive, the design of the main auction incentivizes it to remain active as long as the current price is above its marginal cost. Consequently, the price that it receives is either the cost of the second-lowest-cost firm or its own opening bid, whichever is lower. If the winning firm is a member of a cartel and jointly preselected with other cartel members, they should all drop out as soon as possible in the main auction so as to not decrease the final price. Avoiding competition within the cartel clearly maximizes cartel profits. Whether a cartel faces a competitive rival and thus can avoid competition from outside the cartel depends on its bidding strategy in the preselection stage, which we analyze next.

In the remainder of this section, we consider the effect of changing the preselection rule from $n < N$ to N, which effectively removes preselection.[22] Using backwards induction, we study the effect of the reform on bidding behavior—both collusive and competitive—in the preselection stage and the resulting procurement cost (or savings) of government agencies.

2.3 Removing Preselection under Competition

We refer to an auction as *competitive* if $|I_m| = 1 \ \forall m$, that is, if no firm coordinates its bid with any other firm. From Lemma 1, we know that the lowest-cost bidder among *preselected* firms wins the main auction. Hence, under rule $n < N$, firms anticipate that they will only have a chance of winning the auction if they are among the n lowest bidders in the preselection stage. We focus on symmetric equilibria of the preselection-stage game, where firms follow a symmetric bid function $\beta : [\underline{c}, \bar{c}] \to [\underline{c}, r]$. Note that we drop firm-specific subscripts for ease of notation.

Lemma 2. *In competitive auctions with preselection rule $n < N$, a bid function β constitutes a symmetric equilibrium if and only if it is strictly increasing with $\bar{c} \leq \beta(c) \leq r \ \forall c \in [\underline{c}, \bar{c}]$.*

Lemma 2 implies that there are infinitely many symmetric equilibrium bid functions. Any equilibrium bid function has to be increasing.[23] To understand why this has to be strictly the case, note that if the bid function were such that a set of firms of types $S \subset [\underline{c}, \bar{c}]$ with positive measure place the same bid, preselection would be randomized

[22] We implicitly assume that the number of potential participants in the two regimes remains the same. In our baseline model, this also leads to the same number of actual participants. However, the actual number of participants in the two regimes may be different when there are costs for participating in the main auction stage. Section 2.5 analyzes this case.

[23] Otherwise, a firm with a type corresponding to a bid on the downward-sloping part of the bid function would have an incentive to decrease its bid and undercut firms with higher cost types.

with some strictly positive probability. Hence, a firm of type $c \in S$ could profitably deviate by decreasing its bid by an arbitrarily small amount.

We denote the distribution of the n-th lowest cost among $N-1$ rivals by $F_{n:N-1}(\cdot)$ and the distribution of the lowest cost among preselected rivals by $H(\cdot|\tilde{c})$, where $\tilde{c}$ is a particular realization from distribution $F_{n:N-1}$. Facing competitive rivals that follow a strictly increasing bid function β, the maximization problem of a bidder with cost c choosing opening bid b is given by:

$$\max_b \int_{\beta^{-1}(b)}^{\bar{c}} \int_c^{\tilde{c}} (\min\{b,x\} - c) dH(x|\tilde{c}) dF_{n:N-1}(\tilde{c}) \tag{1}$$

To be preselected, a bidder has to place an opening bid lower than the n-th lowest opening bid, placed by the rival with the n-th lowest cost $\tilde{c}$. Conditional on being preselected and if the bidder has the lowest cost, the expected profits are determined by either the own opening bid or the cost of the lowest-cost rival among other entrants, whichever is lower.[24] Now, for β to be a symmetric equilibrium bid function, it has to be optimal for the bidder to follow the same bid function as its rivals, i.e., to submit $b = \beta(c)$ and thus perfectly reveal its type with its opening bid. Consider a marginal downward deviation from $b = \beta(c)$. This pushes the firm into the set of preselected firms only if $\tilde{c} = c$, but then, the bidder makes zero profits anyway. Therefore, the marginal benefit of a downward deviation is zero. The cost of a downward deviation accrues in the form of a potentially lower final price if the bidder wins. For this cost to be zero as well, an equilibrium bid function has to be such that a downward deviation does not affect the expected final price, which is only true if $\beta(c) \geq \bar{c}$. However, apart from that qualification and the requirement to be strictly increasing, the exact shape of the equilibrium bid function is irrelevant. Consequently, any strictly increasing bid function that maps into the interval $[\bar{c}, r]$ can be sustained in equilibrium.

When the preselection rule is changed to N, any opening bid allows the firms to proceed to the main auction. Hence, again, it cannot be optimal to place an opening bid below $\bar{c}$, and opening bids do not affect the final price. This leads to the following effect of the reform:

Proposition 1. *Under competition, changing the preselection rule from $n < N$ to N, i.e. removing preselection, affects neither equilibrium firm profits nor overall savings.*

In essence, Proposition 1 tells us that revenue equivalence also holds in our auction setting under competition, which may not be surprising: We assumed independent

[24] Hence, the difference from the expected profits in a second-price auction is the binding upper bound b and the updated belief about the minimum rival cost.

private values, risk neutrality, symmetry and perfect competition between bidders.[25] Bidders already have full knowledge of their cost at the beginning of the preselection stage, and entry is exogenous. With preselection rule $n < N$, opening bids do not affect the final price, as they are always above the upper bound of the cost support. Hence with and without preselection, profits and savings are equivalent to those in a standard single-stage descending English auction.

However, Proposition 1 implies not that the reform has no effect on bidding behavior but simply that any change in bidding is such that it has no effect on the final price and procurement savings whatsoever: If the reform leads to a decrease in expected savings based on the first stage s_1, the savings increment due to the main auction s_2 simply increases accordingly such that overall savings s remain unaffected.

The above result is closely related to the result on indicative bidding of Ye (2007), Proposition 2, and Corollary 1. Similarly to our model, his model considers two-stage auctions, where the first stage is used to preselect bidders. When considering indicative bids, i.e., bids which are only "cheap talk," and under the assumptions considered in this section, Ye (2007) finds that there exist infinitely many equilibria because firms have no strict incentive to deviate from a symmetric and strictly monotone bid function. This directly translates to our results since, in a symmetric equilibrium, bidding in the selection stage does not affect final prices. Ye (2007) also considers binding rules for bidding in the preselection stage, which we will refer to in more detail in Section 2.5.

2.4 Removing Preselection under Collusion

We now consider the case where there is a single cartel (i.e., there is one partition I_k with $|I_k| > 1$) while the other firms not part of this cartel are competitive (i.e., $|I_m| = 1$ for $m \neq k$). As above, we first focus on the case when the preselection rule is $n < N$. Remember that in the main auction, any competitive firm remains active as long as the price is above its costs, while at most one firm among cartel members should remain active. Considering the preselection stage, we now have two groups of bidders, cartel insiders and cartel outsiders, who differ with respect to their objective functions. Hence, a symmetric bid function that is optimal for both groups does not exist. Since competitive firms are ex ante symmetric within their group, we assume that they follow some common strictly increasing bid function $\beta : [\underline{c}, \bar{c}] \to [\underline{c}, r]$ with $\beta(c) > c \; \forall c$. In contrast, bids of cartel members may depend on the cost realization of other cartel members.

Proposition 2 (Collusive Exclusion)**.** *Under preselection rule $n < N$, suppose that there*

[25] These assumptions are central conditions for revenue equivalence, derived independently by Myerson (1981) and Riley and Samuelson (1981), to hold; see Klemperer (1999).

exists a cartel of size $|I_k| \in \{n, ..., N-1\}$ *with cost* $c_k = \min_{j \in I_k} c_j$*. In any equilibrium where competitive bidders follow a strictly increasing bid function* β*, there exists a bid function* $\beta_k : [\underline{c}, \bar{c}] \to [\beta(\underline{c}), \beta(\bar{c}))$ *such that at least* n *cartel members submit the same opening bid* $b_j = \beta_k(c_k)$*.*

Proposition 2 reflects a key insight of the theoretical analysis: Close bidding is part of the optimal collusive strategy and thus indicative of collusion. It covers the interesting case where the cartel is large enough to fill all the slots in the main auction, i.e., is weakly larger than n, but is not a complete cartel, i.e., does not cover all N bidders.[26] Then, in contrast to the main auction, it is not optimal for the cartel if all but one cartel member avoid competing and place the maximal possible bid in the preselection stage. Since only the lowest opening bid within the cartel may influence the final price in case of winning (see Lemma 1), matching the lowest bid among cartel members does not decrease the final price and therefore comes without cost. However, it enables the cartel to fill all slots in the main auction and thereby kick out all competitive rivals with a strictly positive probability. This is profitable because the exclusion of competitive rivals forestalls price competition in the main auction. Therefore, matching the lowest-cost bid among cartel members with other cartel bids strictly increases cartel profits and is a feature of the cartel bidding strategy in any equilibrium. This is true irrespective of the exact shape of the bid function that competitive rivals follow, as long as it is strictly increasing. For instance, it could be a competitive equilibrium bid function according to Lemma 2 or one where competitive bidders know that they are competing against a cartel. In turn, the exact value of the optimal cartel bid (and thus whether the cartel bids more or less aggressively than a competitive cartel outsider) depends on the outsider bid function β, the number of rivals $N - |I_k|$ and the cost distribution $F(c)$. However, we know that the optimal cartel bid has to be strictly below the highest competitive bid $\beta(\bar{c})$, since otherwise competitive rivals are not excluded with certainty, while the cartel strictly benefits from it.[27]

The above result captures the most interesting case where the cartel has the ability to kick competitive rivals out of the main auction. If the cartel is too small or complete, i.e., $|I_k| < n$ or $|I_k| = N$, then submission of the same opening bid by at least $\min\{|I_k|, n\}$ cartel members is weakly optimal. However, it is outcome-equivalent to all but one cartel member participating in the main auction because there is no gain from matching the lowest cartel bid.

When turning to the effect of the reform under the presence of a cartel, we assume

[26] Note that the two-stage auction literature explores the optimal preselection rule n^*. It is found to be relatively small, ranging from 1 to 5 (see Bhattacharya et al., 2014; Ye, 2007). Hence, cartels can be relatively small and still fill all the slots in most relevant cases.

[27] Note that this holds even if $N - |I_k| < n$, and thus, at least one cartel member would be preselected even when the cartel bid is r.

that competitive rivals are not aware of the fact that they are bidding against a cartel.[28] Consequently, with preselection rule $n < N$, they follow a bid function β that is supported in a competitive equilibrium (see Lemma 2). Cartel members, on the other hand, know that all firms outside the cartel are competitive.

Proposition 3. *Suppose that there exists a cartel of size $|I_k|$ and that competitive firms follow a bidding strategy satisfying Lemma 2 under preselection rule n. Changing the preselection rule from $n < N$ to N, i.e., removing preselection,*

(i) leaves cartel profits and savings unchanged if $|I_k| < n$ or $|I_k| = N$.

(ii) strictly decreases cartel profits and strictly increases savings if $|I_k| \in \{n, ..., N-1\}$.

From the discussion above, we know that if $|I_k| < n$ or $|I_k| = N$, there is no strict incentive to follow the collusive exclusion strategy because rivals cannot be excluded effectively or there is no rival to exclude. This implies that the cartel cannot exploit preselection rule n and cannot do better than under no preselection. The result in part (i) directly follows.

In addition, if $|I_k| \in \{n, ..., N-1\}$, the cartel can always achieve the same profits as it could without preselection: It can follow a passive strategy where all non-lowest-cost cartel members simply bid the reserve price or do not bid at all, thereby eliminating competition from firms *within* the cartel, as is also possible without preselection. However, we know from Proposition 2 that the cartel has a strict incentive to engage in collusive exclusion. This allows the cartel to also eliminate competition from firms *outside* the cartel. It is only then that the cartel can really exploit the selection rule $n < N$. Consequently, we expect the removal of preselection, which removes the possibility of excluding rivals for sufficiently large partial cartels, to strictly reduce profits.

On the flip side, government savings are strictly affected only if $|I_k| \in \{n, ..., N-1\}$, i.e., if a sufficiently large partial cartel exists to exploit the preselection rule. The increase in savings due to the removal of preselection can be decomposed into two parts. First, the reform increases efficiency. With collusive exclusion, it may not always be the lowest-cost firm that wins the contract. If the cartel uses a more aggressive bidding strategy than that of competitive rivals, it sometimes excludes a firm that otherwise would have won. If it is less aggressive, it may drop out despite being able to provide the good at lowest cost. Hence, removing preselection increases the likelihood that the firm with the lowest cost wins the government contract. Second, even conditional on

[28] Without preselection, this assumption affects neither firm profits nor savings. Furthermore, we believe that it is a reasonable assumption given that competitive rivals in a partial cartel setting are likely to be entrants or firms mostly active in adjacent markets. Such a firm lacks the insider knowledge and expertise to learn whether its rivals are colluding, particularly when the identity of the rivals is unknown during the auction, as is the case in our setting. Knowledge of a cartel's existence likely increases the aggressiveness of both cartel and competitive firms' bids and thus reduces the effect on savings.

the lowest-cost firm winning, collusive exclusion increases the price by means of elimination of competition. Thus, removing preselection leads to a transfer of rents from firms to government agencies.

2.5 Allowing for Cost Updating

The previous model is useful to illustrate collusion mechanism, which is the main contribution of this paper. However, it falls short of explaining why preselection rules may be beneficial for procurement agencies in the first place. The latter is the focus of the literature on two-stage auctions.[29] In an extension of the main model where we mirror the assumptions used in that literature, we show that our auction format is revenue equivalent to the formats previously considered and that our core insight that close biding serves as a collusive marker remains valid. The formal set-up, full set of assumptions and results can be found in Appendix A.6. In the following we provide a short summary of the results.

It is insightful to first understand the assumptions and the formats considered in the two-stage auction literature. In the seminal paper of Ye (2007), he considers a setting where competitive firms observe a signal about their valuation in the preselection stage. At the beginning of the main auction, they incur an entry cost and update their signal. Given these assumptions, firms have to submit an entry bid for participating in the main auction, which determines who gets selected. If this entry bid is binding, it determines a first payment each firm has to make. The relationship between entry bid and payment depends on the exact auction format used, but a monotone equilibrium exists under the most general assumptions when considering an all-pay auction. Due to the entry costs, bidder entry into the main auction is endogenous, and thus, preselection may help the procurement agency resolve miscoordination of the potential bidder's entry decisions.

Under competition, applying the new informational assumptions and entry costs to our setting with opening bids, our two main results are summarized in Proposition A.1 in Appendix A.6. First, we can show that, under some regularity assumptions, a unique and strictly increasing opening equilibrium bid function in the preselection stage exists, i.e., an equilibrium where competitive bidders drawing a higher signal also submit a higher opening bid. This is important to ensure efficient entry into the main auction. In turn, efficient entry is a prerequisite for procurement savings with opening bids to be equivalent to the corresponding equilibrium with an all-pay auction à la (Ye, 2007), which is our second result. Bhattacharya et al. (2014) and Sweeting and

[29] Mirroring the assumptions in that literature prevents a closed-form solution for the effect of removing preselection. This is why simulation exercises are used to show that auctioning off entry rights may have benefits (see Bhattacharya et al., 2014; Sweeting and Bhattacharya, 2015).

Bhattacharya (2015) show that two-stage auctions may increase expected revenues over those in one-stage auctions if n is chosen optimally, in particular when the first-stage cost signal is relatively precise. Because the comparison of preselection rule $n < N$ to the no-preselection case is equivalent to the comparison already done in the literature, preselection may thus also be beneficial in our setting. The gains may however be limited, as it is unlikely that the procurement agency in our setting set the preselection rule optimally. The optimal preselection rule most likely varies by product group, which is not a feature of the setting we consider.

When considering collusion, in Proposition A.2 in Appendix A.6, we show that close bidding is still optimal for a partial but large enough cartel when entry costs are not too large. The argument is very similar to that for the model without cost updating but entry costs make it costly to have multiple cartel bidders participate. However, note that depending on the interpretation of the entry cost, it may be unclear in reality whether all proceeding cartel bidders have to incur it. If we believe that entry costs reflect the (nonpecuniary) cost of bid preparation and active participation in the main auction, it may well be reasonable to assume that cartel bidders who are not "serious" do not incur those costs, which makes close bidding even more profitable. Again, as before, without preselection, there is no benefit from joint participation of cartel members anymore.

2.6 Empirical Predictions

The theoretical analysis abstracts from some real-world complexities, even when cost updating is allowed for. In practice, expecting cartel members to engage in close bidding every single time they participate in an auction may be too strict. For a variety of reasons, a cartel may not always choose the short-run optimal bidding strategy. For instance, it may be too suspicious and increase the cartel's risk of detection, in particular when auctions are held by the same auctioneer. However, a cartel may also fear the response of competitive rivals once they realize that they may be competing against a cartel. It is also conceivable that some cartels are "weak"—that is, that they may not be able to perfectly enforce their policy. This may result in either imperfect ability to coordinate bids or even no participation of other cartel members despite its usefulness for exclusion. Finally, remember that close bidding is only weakly optimal in the case of a full cartel. Some cartel members may be active in multiple product markets, in some of which they constitute a full cartel. Incorporating all these possibilities into the theoretical model is beyond the scope of this paper. Nonetheless, to avoid being too restrictive, an empirical collusion marker should allow for the possibility that collusive firms participate in close bidding frequently, but not necessarily always, to exclude competitive rivals.

Moreover, while joint participation in the preselection stage of cartel members enables close bidding and thus increases cartel profits if there is preselection, without preselection, there are no benefits of joint participation according to our model. Again, in practice, cartels may not fully adhere to the theoretically optimal strategy. Nonetheless, if cartels engage in collusive exclusion at least sometimes, we should observe a decrease in joint participation of cartel members when preselection is removed. Finally, without cost updating, removing preselection is beneficial when a cartel is present but does not matter otherwise. When cost updating is allowed for, the effect of removing preselection under either competition or collusion is generally no longer clear. In particular, we cannot be sure that procurement agencies use the optimal selection rule in our empirical setting. However, it is reasonable to expect that collusion is more harmful for public procurement when an auction format with preselection is used, which we estimate empirically.

All in all, our theoretical analysis leads to the following predictions:

1. With preselection, members of a partial bid-rigging cartel
   (a) should engage in frequent close bidding in the preselection stage.
   (b) should not compete against each other if all competitive rivals are eliminated.
2. Joint participation of cartel firms is less likely without preselection than with preselection.
3. The gap between savings with and without collusion is larger with preselection compared to without preselection.

In the remainder of the paper, we explore these predictions empirically based on the case of electronic public procurement in Slovakia. Slovakian public procurement is an ideal setting for our analysis not only because the authorities were mandated to use selective auctions with very transparent and objective preselection criteria for specific types of products but also because a reform that initiated a platform-wide change to the mandatory auction format allows a quasi-experimental analysis of the effect of removing preselection on procurement savings. We base our collusion marker on Prediction 1(a) and use Prediction 1(b) and supplemental evidence to verify it. Finally, we analyze the reform to test Predictions 2 and 3.

3 Institutional Background & Data

3.1 E-Procurement in Slovakia

We use administrative data from public procurement auctions in Slovakia, a postcommunist, OECD high-income economy in Central Europe with a population of roughly 5.5 million people. Slovakia has been a member of the European Union since 2004 and of the Eurozone since 2009. Public procurement expenditures represent more than 17% of its GDP and almost 38% of total government expenditures. These are among the highest shares in OECD countries (OECD, 2019).

Procurement law in Slovakia, as an EU member state, is shaped by the European Union's directives on public procurement. This is particularly relevant for high-value contracts, where EU rules apply directly. For lower-value contracts, national rules apply. The thresholds for contract values, which determine whether national or EU rules apply, are set at the EU level and depend on what product or service is being procured and by whom. For example, at the time of the reform that we study, the value threshold was set to EUR 135,000 for most goods typically purchased by the government and to EUR 5,350,000 for construction contracts.[30] Contracts below this threshold represented almost a half of all procurement contracts but only 24% of total procurement spending in 2019, as these contracts are typically much smaller than major bespoke project contracts such as those for highway infrastructure.[31]

National rules can vary substantially across the EU member states but are still required to be in line with the general EU principles of transparency and equal treatment. The EU has developed initiatives to transition to electronic procurement, aimed at increasing the transparency and efficiency of procurement processes (European Parliament and Council of the EU, 2014). Unlike many EU member states, Slovakia has managed to implement a broad range of e-procurement functionalities, including electronic auctions (OECD, 2017). For contracts with a value below the described thresholds, Slovak rules further define a go-to-tender threshold, below which public agencies can procure goods and services at their discretion. This lower threshold was set to EUR 5,000 for most goods and services at the time of the reform.

The source of our data is the electronic contracting system (EKS, abbreviated from *elektronický kontraktačný systém*), an electronic public procurement tool based on Slovak legal rules that regulate the public procurement process. Its key component, the elec-

[30] See `https://www.sigmaweb.org/publications/Public-Procurement-Policy-Brief-15-200117.pdf`. This threshold is subject to change, though changes are usually minor. For instance, in 2022, the threshold was changed from EUR 139,000 to EUR 140,000; see `https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1952&from=EN`.

[31] Own computations based on combining values reported in Table 5 and Table 18 of the annual public procurement reports prepared by the Slovak Public Procurement Office (UVO, 2020).

tronic marketplace (*elektronické trhovisko*), is an online auction system for supplying and purchasing common goods, construction works and services. The role of the auction system is defined by a law on public procurement, and the auction system itself is administered by the Ministry of Interior. Since the full introduction of the EKS on February 1, 2015, its use in public procurement is required for all goods, construction works and services "commonly available on the market" and with contract values below the general EU threshold but above the go-to-tender threshold. Procurers required to use the EKS platform include all government bodies at the national, municipal and regional levels and organizations falling under their administration such as public schools and hospitals.

The main method to initiate a tender in the EKS entails defining a specific order form for the good demanded by the procurer. The order form can be either fully defined by the procurer or selected on the EKS platform from a library of previously used order forms. In both cases, the same details about the good are required from the procurer, and the same auction process follows. Apart from a technical description of the ordered good, several other details are required on the EKS platform, most importantly the CPV categorization,[32] the quantity of goods ordered (in pieces, kilograms, etc., depending on the nature of the good) and the price estimate, which serves as a reserve price for the procurer. Once the order form is finalized by a procurer, the tender is published on the EKS website. Both contractors and procurers have to be registered on the EKS platform to be able to participate in the tender. Contractors receive e-mail notifications when a newly published tender matches the CPV codes that they specify in their profiles on the platform.

3.2 Auction Rules

3.2.1 Before the Reform

The original rules, which predated the reform that we study, specified a selective bidding process: Immediately after the publication of a tender, bidders would have at least 72 hours to place an opening bid for the good or service. This first stage served to preselect bidders for the main procurement auction, which started 15 minutes after the deadline of the first stage and lasted at least 20 minutes. Thus, the prereform rules described below represent a practical implementation of the theoretical setting from Section 2 with the specific preselection rule $n = 3$.

[32] The common procurement vocabulary (CPV) is a unified classification system for standardized description of procurement in the European Union. The CPV has a rich tree-like structure. Goods categories at the highest (2-digit) level are, e.g., *agricultural, farming, fishing, forestry and related products* (03) or *medical equipment, pharmaceuticals and personal care products* (33), while goods at the lowest level of the CPV categorization are, e.g., *beetroot* (03221111-7) or *surgical staples* (33141122-1).

The bidding in the preselection stage was constrained by the reserve price specified by the procurer; bidders were not able to bid above this reserve price. Before submitting its own bid, a potential bidder could see the latest bid placed for this tender and the current number of bids; however, the identities of other bidders remained hidden during the entire auction process.[33] The first stage terminated punctually at a publicly known, prespecified deadline.[34] Only bidders whose opening bids were among the three lowest were allowed to proceed to the main auction. Thus, auctions with fewer than 4 bidders were not directly affected by this preselection rule.

At the beginning of the main auction, the preselected bidders observed their ranking and the lowest opening bid from the preselection stage. The main auction took the form of a reverse English auction with the opening bid as the binding upper bound for further bids. Although the main auction regularly lasted 20 minutes, it could be extended by two minutes if there was a new bid in the last two remaining minutes; this process repeated until there were no new bids. The winning bid was the lowest bid that no one was willing to undercut. Once the main auction concluded, the platform automatically generated a contract agreement, which was published in the central register of contracts. A de-anonymized record of the entire auction was simultaneously published on the EKS website.

3.2.2 The Reform

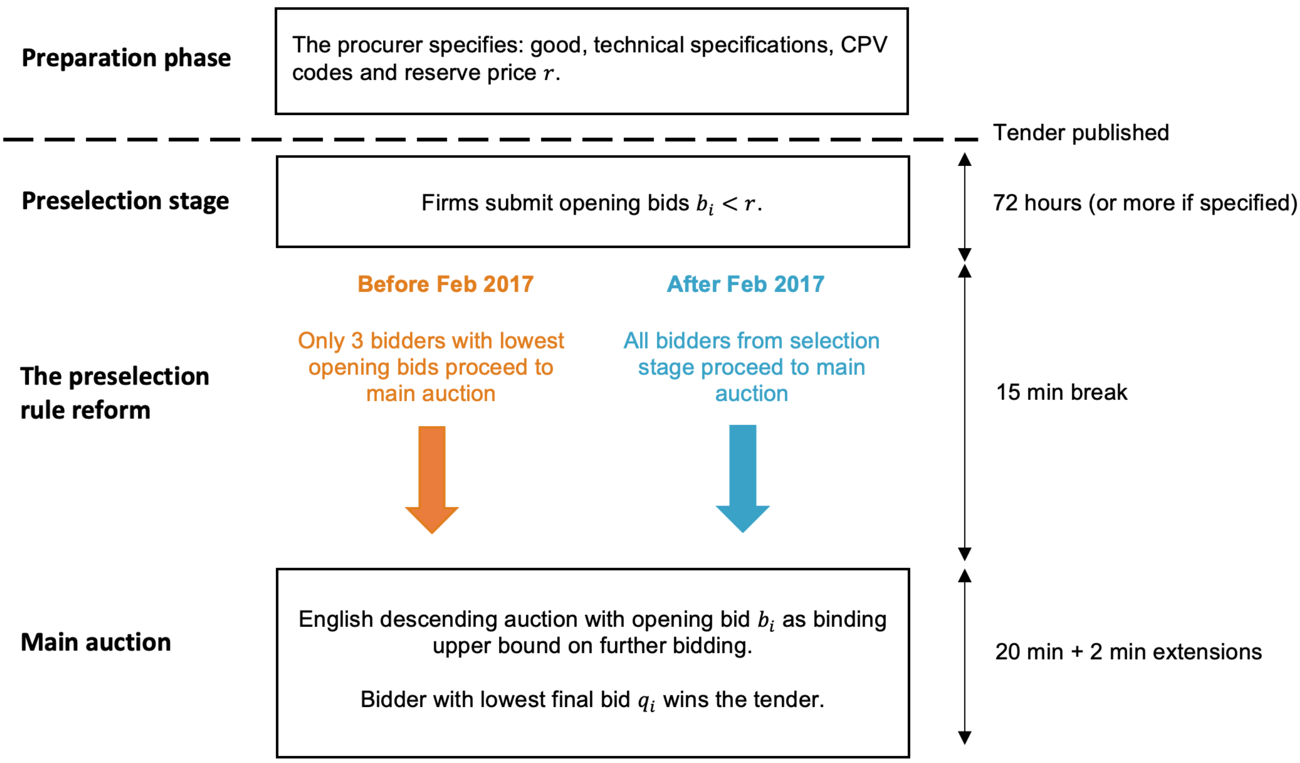
Since February 1, 2017, the bidding process has followed new auction rules announced one week prior to the date of the implementation. The key change involved the selective design of the auction process: The reform removed the preselection rule that limited the number of bidders allowed to participate in the main auction. While the first stage still exists and placing an opening bid during the first stage continues to be a requirement to participate in the auction, *all* bidders are now allowed to participate in the main auction, regardless of the value of the opening bid. The lowest opening bid, however, remains a constraint on bidding in the main auction. Hence, the postreform rules are a practical implementation of a setting without preselection as described in Section 2.

Figure 1 depicts a schematic representation of the auction rules and the reform. Further changes involved making electronic auctions on the EKS platform available not only for commonly available goods but also for services and construction works. As we do not observe these types of auctions for the period before the reform, we exclude them from our analysis. The process of placing the bid on the platform was also slightly

[33] After submitting a bid, bidders could additionally see their ranking among currently submitted bids.

[34] In both the first stage and the main auction, bidders were allowed to submit multiple bids. A sharp deadline like that in the first stage, however, has been shown to be conducive to last-minute bidding, which leads to outcomes similar to those in a first-price sealed-bid auction (Roth and Ockenfels, 2002).

Figure 1: Auction rules and the reform



modified: To prevent erroneous entries, the price now needs to be confirmed twice if it differs by more than 10% from the most recent bid. At the same time, retraction of offers by a procurer has been disabled. We exclude all prereform auctions that featured retractions from our empirical analysis for the sake of consistency with the postreform period; however, our results are robust to a reversal of this choice.

3.3 Data

Our dataset comprises all public procurement auctions performed on the EKS platform between 2015 and 2020. The EKS is used by various public agencies, including municipalities, schools and public hospitals, among others, and thus contains tenders for a large variety of products, such as office equipment, medical devices and agricultural machinery. Moreover, we can identify bidders and public procurement agencies and track them over multiple auctions.

At the time of the introduction of the platform, all procured goods that were both (i) standardized and readily available on the market and (ii) in the under-the-threshold category (with an expected contract value between EUR 5,000 and EUR 135,000 [35]) had

[35] These legal thresholds did not stay fixed during the entire period, but also did not coincide with

to be procured through the EKS platform. In addition, its use has also been available, albeit only optional, for low-value contracts falling below the go-to-tender threshold. EKS auctions are the modal type of under-the-threshold contracts but do not constitute a majority of contracts: for example, in 2019, the EKS recorded 16,186 auctions worth EUR 274 million, corresponding to 31% of under-the-threshold contracts but only 24% of contracts in terms of their value.[36]

We restrict our sample to auctions taking place between February 2016 and January 2019, corresponding exactly to a period of one year before the reform and two years after the reform. We set the length of the pretreatment period to one year, which is long enough to detect potential differential pretrends while avoiding confounding by other auction rule changes implemented shortly after the launch of the EKS platform. At the same time, using a two-year posttreatment period allows us to capture the long-term impact of the reform.[37] We process the raw data to maintain consistency in the dataset across the periods before and after the reform, which results in a sample size of 63,643 auctions.[38] We normalize all bids by dividing them by the reserve price set by the agencies. This allows us to compare auctions used to procure very different goods and quantities. Since we are ultimately interested in the cost of public procurement, we consider the savings for the procurement agency relative to the reserve price that the agency determined.

Table 1 provides summary statistics of the main auction characteristics. In the first four columns, we present basic statistics for our entire sample. The means and standard deviations are also reported separately for the periods before and after the reform in February 2017. The reported raw differences present an interesting pattern for the two periods in terms of both savings and competition. Overall savings in the postreform period are lower by one percentage point, and savings based on the lowest opening bid in the preselection stage are even lower—namely, seven percentage points lower. This suggests that final bids partly compensate for the lower aggressiveness of opening bids after the reform. A similar pattern emerges when we consider the number of bidders and bids. While after the reform, 0.35 fewer bidders participate in the preselection stage

the timing of the reform we study. In Figure D.2 we plot, for every month, the distribution of all reserve prices together with the relevant thresholds.

[36] Own computations are based on the EKS database (`https://portal.eks.sk/Reporty/Uspory`) and the 2019 statistical report prepared for the Slovak government by the Public Procurement Office (UVO, 2020). Before 2019, the reports did not include low-value and under-the-threshold contracts auctioned through the EKS platform.

[37] Our results are robust to consideration of a longer prereform period. However, in the initial auctions, savings and bid patterns were much less stable over time, which suggests that firms and agencies were still learning how to use the platform. As we do not want to draw inferences from this learning phase, we drop the data corresponding to the initial six months after the platform launch.

[38] We drop auctions for construction work and services not auctioned before February 2017. We also drop the 6.4% of auctions with retracted bids. Furthermore, we do not include auctions in which procurement agencies failed to set a reserve price (1% of the auctions).

on average, more of them remain active in the main auction, leading to a larger number of bids submitted. More generally, we observe that the reserve price and the average winning bid increase in lockstep after the reform. Figure D.1 in Appendix D shows that this increase is almost linear, without a jump at the time of the reform. In all our empirical specifications, we normalize bids by the reserve price, such that our results should not be affected, and include year–month fixed effects.

We enrich our EKS platform auction dataset with data from the Register of Financial Statements (RFS), which provides annual financial information on the universe of Slovak firms. Every year, all accounting units registered in Slovakia (i.e., primarily firms) are obliged to submit financial statements, which are then published in the RFS. The firms' financial information is publicly accessible and searchable on the RFS website `www.registeruz.sk`, and the underlying data can be accessed through a public API. The stated purpose of the RFS is to "improve and simplify the business environment and reduce the administrative burden on business." We match the financial information (such as sales, accounting profit and profit data) from the RFS to the auction data using a firm identifier that is common across the datasets.

Table 1: Summary statistics

	(1) Full Sample				(2) Before Feb 2017		(3) After Feb 2017		(4) (3) − (2)
	Mean	SD	min	max	Mean	SD	Mean	SD	Diff
Savings	0.14	0.17	0.00	1.00	0.15	0.17	0.13	0.17	-0.01***
Preselection savings	0.06	0.12	0.00	1.00	0.10	0.15	0.03	0.08	-0.07***
Reserve price (in k EUR)	14.94	36.73	0.00	1860	10.80	30.27	17.40	39.87	6.60***
Winning bid (in k EUR)	13.81	34.64	0.00	1855	9.93	28.71	16.11	37.53	6.18***
# preselection bidders	3.15	2.16	1.00	24.00	3.37	2.44	3.02	1.96	-0.35***
# main auction bidders	1.54	1.45	0.00	11.00	1.20	1.16	1.74	1.56	0.53***
# main auction bids	25.15	54.80	0.00	2185	17.94	42.67	29.42	60.46	11.47***
Observations	63643				23701		39942		

Notes: The table summarizes auction-level variables for the sample used in our analysis, covering auctions on the EKS platform from February 2016 to January 2019. Savings are expressed relative to the reserve price. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4 Collusion Marker

Our goal is to identify firms that are likely members of bid-rigging cartels. According to Prediction 1(a), such firms should engage in frequent close bidding in the preselection stage before the reform.

Before moving to the firm level, we need to define close bidding at an auction level. According to our theory, cartel members should submit the exact same bid, which should happen with zero probability under competition. In practice, however, cartels may be wary of detection and therefore introduce noise into their bids. To still be able to detect more sophisticated cartels, we allow for a margin of error. Specifically, we refer to *close bidding* if, in the preselection stage of an auction, at least three opening bids, normalized by the reserve price, are within a value range of 0.1% of each other. Despite this very small value range, we observe close bidding in 18.5% of auctions with at least three bidders before the reform (or 30.3% if weighted by value). Nonetheless, allowing for a margin of error comes at a cost. Under the assumptions of our model, close bidding, as we define it, may happen by chance every now and then, even if bidders are competitive. We explore this possibility in more detail in Section 4.4, where we provide a counterfactual analysis of how much close bidding we expect to observe under competition. There, we find that the probability of close bidding under competition should only be 1.5%, which is significantly different from the observed occurrence of close bidding at the 1% significance level.

Ultimately, our goal is not to detect auctions in which close bidding occurred, however, but to identify collusive firms. In our main specification, we mark firms as potential colluders if they are involved in close bidding in a group of three more frequently than 90% of the firms participating in more than ten auctions in our pre-reform sample. This results in 172 out of 4,121 bidders being marked as collusive. Despite only a few bidders being marked, these are firms that are very active on the platform: They participated in 19.8% of auctions (28.5% by value) before the reform. Clearly, this is an arbitrary percentile, and our collusion marker necessarily flags false positives and misses false negatives. However, our results do not change qualitatively if we consider different bid value ranges (0.5%, 0.05%) or different firm percentiles (85th, 95th percentile). We report the results from these robustness checks in Appendix E. We believe that our method strikes the right balance, an argument that we support with three pieces of evidence outlined below.

4.1 Overlap with Convicted Cartel Members

First, we compare the firms that we identify as collusive based on our collusion marker with members of a convicted cartel. In contrast to many papers on cartel detection, our collusion marker is derived from theoretical predictions, without relying on auctions known to be affected by collusion. Luckily, in May 2021, several months after the first version of this paper was made public, the Anti-Monopoly Office of the Slovak Republic (AMO SR) convicted 6 companies of bid-rigging in public procurement auctions published on the EKS in the years 2015 to 2017.[39] While our study was not preregistered, the publishing of the cartel case details after our collusion markers were defined allows us to convincingly validate our measure.[40] We can directly compare the collusive behavior implied by the theory to confirmed cartel behavior and check whether we detected the convicted cartel.

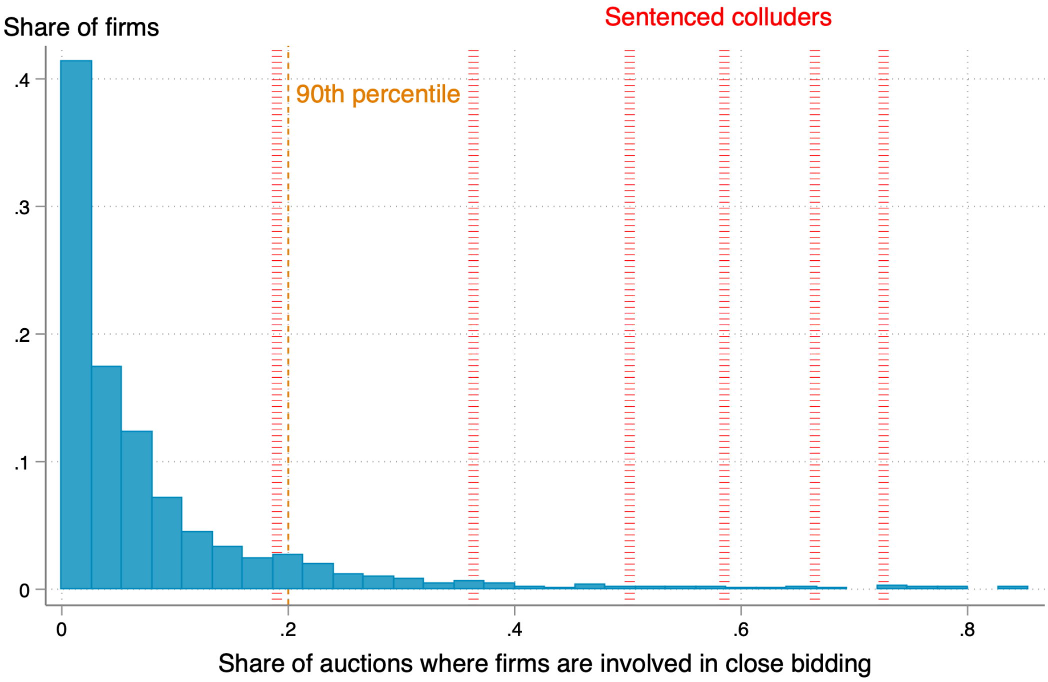
The cartel case concerned coordination of bids in a way that exploited the preselection rule and was based on 276 auctions run on the EKS. More specifically, the evidence consisted of a combination of suspicious observations—for instance, that the focal companies repeatedly participated in tenders in groups of three and submitted their opening bids simultaneously in the first stage. Moreover, they did not bid against each other in the main stage when jointly preselected; rather, as soon as a noncartel participant was preselected, they changed their behavior strikingly. The final, and legally most important, piece of evidence was the fact that they submitted their bids from the exact same IP address. Most of these alleged behaviors align with the theoretically optimal cartel behavior. In addition, we could confirm this cartel behavior by locating and analyzing 274 out of the 276 auctions on which the conviction was based in our data set. For a detailed analysis of these auctions and details on the cartel case, see Appendix C.

Our collusion markers successfully identify five out of the six convicted cartel members. Figure 2 shows the distribution of involvement in close bidding relative to the number of auctions that a firm participated in for firms engaged in more than ten auctions before the reform. While the majority of firms never submitted a close bid, the distribution has a long right tail. In our main specification, we mark firms as collusive if they are to the right of the orange dashed line marking the 90th percentile. In addition, we indicate the location of the convicted cartel members in this distribution. Five convicted cartel members are to the right of the 90th percentile, but we missed one out of the six firms by a small margin. Upon closer inspection, we find that this firm's involvement in cartel activity in our dataset is very small: It participated in only 10 out of the 276 collusive auctions on which the sentence was based and won an auction only once, for a contract worth only EUR 5,900. By comparison, the most active cartel member won contracts worth more than EUR 900,000.

[39] For further details, see https://www.antimon.gov.sk/data/att/e1d/2171.64e3dd.pdf?csrt=3756949773301016497 on the first decision and https://www.antimon.gov.sk/data/att/691/2170.cc3422.pdf?csrt=3756949773301016497 on the final decision.

[40] The first version of the paper was made publicly available in February 2021, see https://web.archive.org/web/20211024003724/https://reginaseibel.github.io/publication/collusion/collusion.pdf

Figure 2: Distribution of relative participation in close bidding across firms and location of sentenced colluders



Notes: Close bidding is defined as the occurrence of three opening bids within a value range of 0.1% of each other relative to the reserve price. We consider auctions in which a firm participated in close bidding as a share of all prereform auctions. The close bidding share corresponding to the 90th percentile of the distribution is indicated by the orange dashed line, and the close bidding share of the sentenced colluders is indicated by the red long-dashed lines.

4.2 Stable Cartel Rings

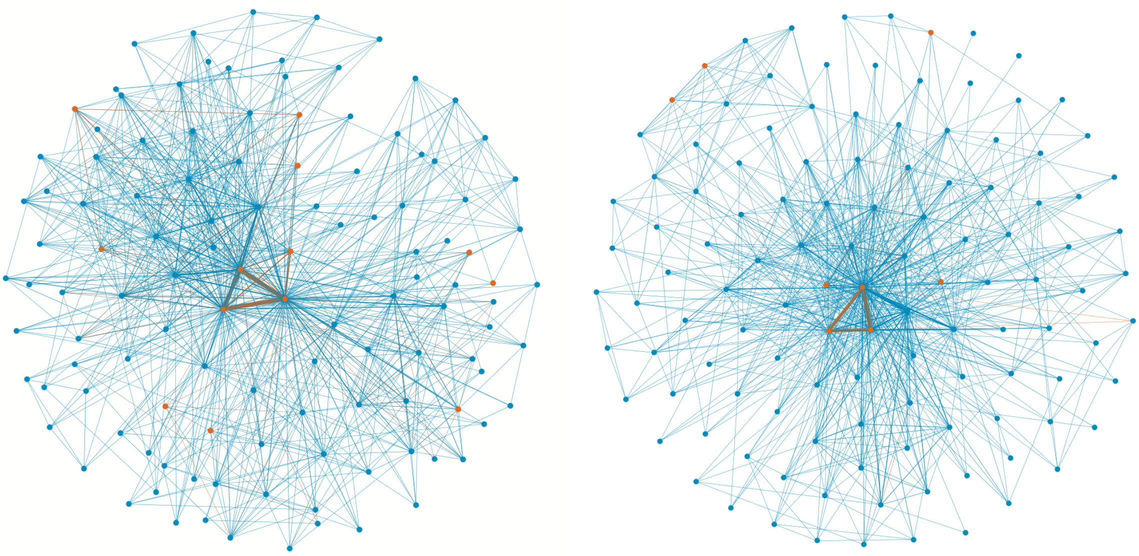
Second, we dig deeper into the idea that a cartel is a stable group of firms and, as such, can be expected to display repeated suspicious interactions between the same firms over time. While our collusion measure identifies single firms that we believe are likely members of a cartel, it does not explicitly rely on repeated interactions within a stable group of likely cartel members. Refining our measure to take this into account would require us to make more arbitrary decisions: How frequently do we have to observe the same group engaging in close bidding to consider it "stable"? How should we take into account varying sizes of cartels, where members of large cartels may take turns in joint participation, as in the case of the convicted cartel? To circumvent these and similar related questions, we decide to refrain from further refining our collusion measure in our baseline specification.[41] Nonetheless, we show that our fairly simple

[41] We do incorporate a refinement as a robustness exercise, however. Appendix Section E includes results for a marker that, in addition to our baseline specification, requires firms to be part of a stable close bidding group more often than 50% of potential colluders. The results are similar to those in the baseline.

marker actually does capture mostly stable groups, even though it was not explicitly constructed to do so.

Network visualization techniques have the potential to reveal the stable group structures that are a strong indication of the existence of a cartel. Visually detecting all potential cartels in the unwieldy full auction network would be difficult, however. Figure 3 shows two example subnetworks, where we focus on two collusive bidders and the network of other bidders that they interacted with. On the left, we depict the network of a convicted cartel member, while on the right, we can see the network of a bidder that we mark as potentially collusive but that was not convicted. We chose a bidder selling construction material as the construction sector is known to be prone to collusion. Bidders are represented as nodes, and two bidders are connected if they jointly participated in an auction at least once. The connection thickness is proportional to the frequency of joint participation. Moreover, collusive bidders are color-coded as orange, while bidders which we do not mark as collusive appear in blue. The connection between two bidders is shaded in a stronger shade of orange the larger is the share of auctions in which the two bidders bid close to each other in the preselection stage.

Figure 3: Convicted (l.) and nonconvicted (r.) cartel networks

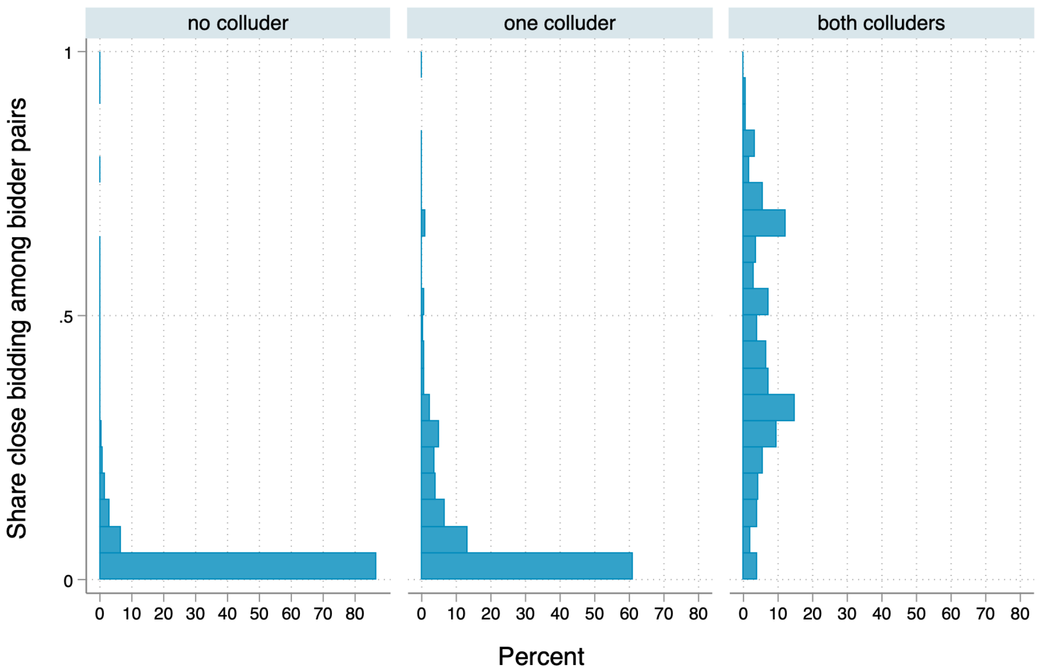


Notes: Bidders (nodes) are colored orange if they are potential colluders. Two bidders are connected if they jointly participated in auctions. The thickness of the edges represent the frequency of joint participation, and the intensity of the color represents the share of close bidding that happened between the bidders, where a deeper orange reflects more close bidding. The left network is the network of the convicted cartel. The right network is the network of a bidder that we mark as collusive but that was not convicted. We use the algorithm of Fruchterman and Reingold (1991) for the network layout.

The similarities between the two graphs are quite evident. Even though we zoom in on the connections of only one firm, there is at least one orange triangular shape in the center. This implies that a collusive bidder frequently participates in auctions with at least two other collusive bidders and bids close to them. Connections to noncollusive bidders are largely blue, however, so it does appear that close bidding happens in stable groups and not indiscriminately. We interpret these orange triangles as a manifestation of a cartel structure. Clearly, we cannot show the networks of all potential colluders, but most of them look similar to the ones shown.

This is corroborated by Figure 4, which shows that our measure does a good job in identifying groups on average. It depicts the distribution of the share of close bidding among bidder-pair connections, weighted by the number of auctions in which bidder pairs participate jointly.[42] Connections between two potential colluders rarely exhibit a low share of close bidding. In contrast, the distribution of interactions between potentially collusive and competitive bidders looks much more similar to connections between two competitive bidders, with a vast majority exhibiting no close bidding whatsoever. This means that marked colluders usually engage in close bidding with *other colluders*, but not with competitive rivals.

Figure 4: Distribution of the share of close bidding among bidder pairs (weighted)



Notes: Close bidding is defined as the occurrence of three opening bids within a value range of 0.1% of each other relative to the reserve price. We consider auctions in which a bidder pair was involved in close bidding as a share of all prereform auctions in which a bidder pair participated, weighted by the total number of these auctions.

[42] The unweighted graph looks very similar; see Figure D.3 in Appendix D.

4.3 Limited Competition in the Main Auction

Finally, we analyze competition in the main auction when potential colluders participate. Out of the 23,701 auctions taking place in the year before the reform, collusive bidders participate in 4,690, representing 28.5% of the total contract value awarded before the reform. Our collusion marker is based on close bidding in the preselection stage, and if it indeed captures cartel membership, we generally expect little competition between collusive bidders in the main auction. However, in line with Prediction 1(b), the optimal collusive strategy of a cartel in an auction with preselection is even more nuanced: As the goal is to exclude competitive rivals to eliminate competition in the main auction, bidding in the main auction should be very different when collusive exclusion is achieved in comparison to when it is not. Table 2 shows that this is already apparent in the raw data. Focusing on auctions where at least three collusive bidders participate, indicating an attempt to exclude competitive rivals, we see stark differences between the number of active bidders and the number of submitted bids in the main auction. This also translates into much larger savings when collusive exclusion is not successful, amounting to a difference of nine percentage points. A substantial share of these large savings is a result of already quite aggressive opening bids.

Table 2: Bidding in the main auction with preselection

	(1)		(2)		(3)		(4)	
			<3 coll. bidders		>=3 coll. bidders			
	Coll. auction		Rivals not excl.		Rivals not excl.		Rivals excl.	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Savings	0.17	0.18	0.16	0.18	0.25	0.18	0.16	0.14
Preselection Savings	0.14	0.16	0.13	0.16	0.22	0.17	0.15	0.13
Reserve price (in k EUR)	15.6	33.9	16.7	36.3	12.9	23.0	9.8	23.2
# preselection bidders	5.35	2.98	4.72	2.62	8.33	3.31	6.40	2.40
# main auction bidders	1.37	1.13	1.42	1.11	1.63	1.11	0.53	0.94
# main auction bids	19.12	46.30	21.06	50.21	18.75	32.47	2.25	9.92
# collusive bidders	1.93	1.09	1.53	0.78	3.39	0.78	3.34	0.78
Observations	4690		3661		621		408	

Notes: The table summarizes auction-level variables for auctions on the EKS platform before the reform (February 2016 to January 2017) in which at least one collusive bidder participates.

To make sure that these difference are not due to other auction characteristics, we run the following regression:

$$
\begin{aligned}
Y_a = {} & \alpha_0 + \alpha_1 \mathbb{1}(\geq 1 Colluder)_a + \alpha_2 \mathbb{1}(\geq 3 Colluders)_a + \alpha_3 \mathbb{1}(RivalExcluded) \qquad (2) \\
& + \beta_1 \mathbb{1}(\geq 2 Bidders)_a + \beta_2 \mathbb{1}(\geq 3 Bidders)_a + \beta_3 \mathbb{1}(\geq 4 Bidders)_a + \beta_4 \mathbb{1}(\geq 5 Bidders)_a \\
& + \gamma_{t(a)} + \delta_{p(a)} + \theta_{c(a)} + \epsilon_a
\end{aligned}
$$

where an auction a is the unit of observation. Y is either the number of active bidders, number of bids or probability of any further bid in the main auction. $\mathbb{1}(\geq 1 Colluder)$ and $\mathbb{1}(\geq 3 Colluder)$ are dummy variables that indicate whether at least one and three potential colluders participate in the preselection stage of an auction, respectively. Similarly, $\mathbb{1}(\geq 2 Bidders)$, $\mathbb{1}(\geq 3 Bidders)$, $\mathbb{1}(\geq 4 Bidders)$ and $\mathbb{1}(\geq 5 Bidders)$ are dummy variables that indicate whether at least two, three, four and five bidders in total participate in the preselection stage of an auction; hence, an auction with a single bidder is the baseline.[43] When at least three potential colluders participate, we want to differentiate between auctions where they could take up all slots in the main auction and those where they could not, which is captured by $\mathbb{1}(RivalsExcluded)$, an indicator taking one if no competitive rival proceeds to the main auction. The term $\gamma_{t(a)}$ refers to year–month fixed effects, $\delta_{p(a)}$ to procurer fixed effects and $\theta_{c(a)}$ captures CPV category code fixed effects.

The choice of the exact CPV category code is at the discretion of the procurement agent. Which code fits best may be ambiguous, and procurement agents may also indicate multiple categories.[44] We therefore show two versions of the fixed effect. First, we control for the two-digit CPV category code and include only contracts where all indicated CPV categories for a contract share the same first two digits. This allows us to group similar products at a higher level and the same products with different or multiple codes indicated. While this specification leads to a relatively large sample size, it may be too broad. Therefore, we consider a second specification where we control for the full code but drop contracts where multiple codes are indicated. This substantially reduces the sample size but may arguably be more accurate.

The first three columns in Table 3 show the specification where we control for CPV categories at the 2-digit level, while Columns 4 to 6 show the same specification but with full CPV category fixed effects. The results are very similar despite the different sample sizes and show that a general increase in the number of bidders in the preselection stage also increases bidding activity in the main auction: There are more active

[43] About one-tenth of auctions in our dataset have six or more bidders in the preselection stage. These auctions are also captured by the $\mathbb{1}(\geq 5 Bidders)$ term, which equals one if the auction has five or more bidders and zero otherwise.

[44] Procurement agents may pick different levels of granularity: for instance, in need of armchairs, they may simply pick the code for "chair" or the more granular code for "armchair."

bidders, more bids and higher savings. While the coefficients for the second and third bidder confirm the general insight that a larger numbers of participants in an auction has positive but decreasing returns for procurement agencies, the coefficients for the fourth and fifth or more bidders deserve some discussion. Adding a fourth bidder to the auction barely affects competition in the main auction, which is due to the specific auction design that allows only three bidders to proceed.

Table 3: Bidding in the main auction with preselection

	Competition in the Main Auction Stage:					
	#Bidders	#Bids	Savings	#Bidders	#Bids	Savings
≥1 colluders	-0.27***	-5.85***	-0.02***	-0.25***	-6.11***	-0.02***
	(0.03)	(1.18)	(0.00)	(0.04)	(1.54)	(0.00)
≥3 colluders	0.05	3.44	-0.01***	-0.09	-0.92	-0.01*
	(0.05)	(1.90)	(0.00)	(0.07)	(2.62)	(0.00)
Rivals excl.	-1.15***	-21.35***	-0.01***	-0.95***	-15.57***	-0.02**
	(0.07)	(1.86)	(0.00)	(0.10)	(2.74)	(0.01)
≥2 bidders	1.11***	16.61***	0.06***	1.07***	13.22***	0.06***
	(0.02)	(0.65)	(0.00)	(0.02)	(0.91)	(0.00)
≥3 bidders	0.66***	11.03***	0.02***	0.65***	11.83***	0.02***
	(0.02)	(1.10)	(0.00)	(0.03)	(1.37)	(0.00)
≥4 bidders	0.05	1.36	-0.00	0.10*	4.07*	-0.00
	(0.03)	(1.46)	(0.00)	(0.04)	(1.87)	(0.00)
≥5 bidders	0.09**	-0.02	-0.01***	0.08*	-0.00	-0.01***
	(0.03)	(1.37)	(0.00)	(0.04)	(1.93)	(0.00)
Constant	0.04	1.09	-0.01**	0.09	1.28	-0.01*
	(0.03)	(1.65)	(0.00)	(0.05)	(2.28)	(0.00)
Month FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
Procurer FE	yes	yes	yes	yes	yes	yes
CPV FE (2-digit)	yes	yes	yes	no	no	no
CPV FE (full)	no	no	no	yes	yes	yes
Adj. R2	0.42	0.13	0.14	0.44	0.19	0.18
Avg. Outcome	1.20	17.94	0.04	1.20	17.94	0.04
N	18055	18055	18055	11123	11123	11123

Notes: All specifications are estimated by OLS and include fixed effects indicated at the bottom of the table. Bidder covariates refer to bidders in the preselection stage. Outcome variables are the number of active bidders (#Bidders), number of bids (#Bids) and additional savings (Savings) generated in the main auction stage. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Looking at the main auction outcomes in the presence of potential colluders shows that our collusive marker is strongly correlated with reduced competition. Auctions with at least one colluder have a significantly lower number of active bidders and a significantly larger probability of no further bidding in the main auction.[45] It is worth noting that the coefficients on the number of active bidders and no-bid probability in the main auction for the third colluder captures both the cases where all slots in the main auction are taken by potential colluders and those where some slots are taken by competitive bidders. It turns out that competition in the main auction is lower only when all slots are taken by potential colluders, as the coefficients for $RivalsExcluded$ are large and highly significant across all specifications.[46] Still, this result should be interpreted with caution. As mentioned, even though our marker captures some collusive bidders, we may miss some others, so the exact count of collusive versus competitive bidders may be noisy.

4.4 Ruling out Competitive Explanations for Close Bids

In an independent private cost setting with competitive firms normalized bids may fall within a value range of 0.01% of each other by chance. To rule out that this affects the majority of auctions where close bidding happens, we provide two separate analyses.

First, we compute the close bidding probability in a counterfactual scenario where bidders are competitive. This also allows us to test whether the observed occurrence of close bidding aligns with competitive bidding. Specifically, our null hypothesis is that bidders are competitive, and therefore they bid independently of each other according to a strictly increasing bid function. Since costs are independent random variables and the bid function is strictly increasing, the composition of both these measurable functions and hence bids are also independent random variables. Therefore, if bids allow for a continuous density, we can calculate the probability of close bidding, assuming the bid distribution resulted from competitive bidding. To this end, we fit a continuous function to the realized bid distribution. To allow for heterogeneity in the distribution of costs and the bid function, we define auction groups over which we allow the fitted bid distribution to differ. Auctions in an auction group are in the same CPV category and have the same number of bidders participating in the auction.[47] Averaging over

[45] The presence of even a single colluder is correlated with significantly lower competition in the main auction. This may simply be due to cartel membership itself: If a cartel member can win auctions at high margins when acting in a group, he may be less willing to engage in harsh competition even when acting alone against many competitors. Another reason may be that our collusion measure simply does not capture all cartel members and, in fact, there are often other cartel members active in those auctions as well.

[46] The fact that collusive harm is particularly large in auctions where preselection is binding and thus rivals can be excluded can also be seen graphically in Figures D.4–D.6 in Appendix D.

[47] While bidders may not perfectly know the total number of bidders at the time of the opening bid

all auction groups, we find that close bidding should only happen in 1.5% of auctions on average. Moreover, we find p-values of below 0.01 in 61.4% of auction groups. We provide details of the calculations and results in Appendix B.

Second, we consider main-auction competition in auctions where close bidding happened in the preselection stage. We estimate the main auction to be substantially less competitive, with a significantly larger probability of no further bidding and lower savings (see Table D.1 in Appendix D). If a large majority of close bidding resulted from rather harsh competition, we would expect bidders to continue competing in the main auction. Moreover, it is particularly hard for this alternative explanation to rationalize why collusive bidders only stop competing once they manage to exclude competitive rivals after close bidding.

Further competitive explanations for close bids require the incomplete information assumption to be violated in practice. If firms perfectly know each other's cost already in the preselection stage, we would expect that the lowest-cost firm places a bid slightly below the bid of the second-lowest-cost firm. However, this does not explain why a third firm would place an equal bid as well. Finally, in the extreme case where products are fully homogeneous, firms could, in principle, have almost identical costs. This may lead to more than two firms placing very close bids that are equal to their cost of procuring the good. However, it is hard to rationalize why, within the same auction, only a subset of firms participating in the auction would place the same bid or why, across auctions, this set of firms appears to be stable. Consequently, explanations relying on competitive bidding cannot mimic the collusive patterns that we observe.

5 The Effect of the Reform

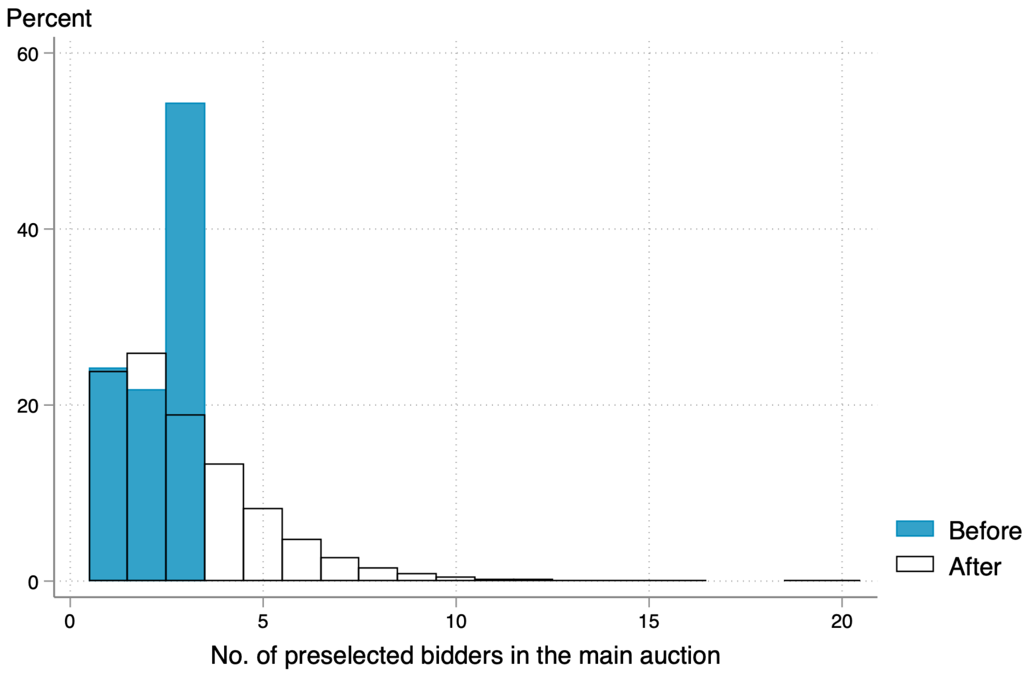
Based on the evidence from the previous section, we are confident that our collusion marker identifies suspicious groups of firms that likely form a cartel.[48] Thus, we can move to an analysis of the reform. Remember that the reform lifted preselection for participation in the main auction such that all bidders who participate in the preselection stage, not only three, are now allowed to proceed to the main auction. Hence, if preselection was binding, mechanically, we should observe more than three bidders participating in the main auction after the reform. Note that participants do not necessarily actively bid in the main auction but are able to bid. Figure 5 confirms that there is no bunching at three bidders after the reform. However, it should be recognized that

submission, it could contain information on the profitability of the contract, which may affect the bid function.

[48] One may wonder whether, instead of being part of a real cartel, the collusive bidders are actually a single firm with multiple accounts on the platform. In addition to administrative hurdles, we show that such an interpretation is not supported in our data in Section 6.3.

there is also a substantial number of auctions with only one or two bidders, both before and after the reform.

Figure 5: Mechanical effect of lifting the preselection rule



Notes: The graph depicts the distribution of preselected bidders in the main auction before and after the preselection rule was abolished in February 2017.

5.1 The Effect on Cartel Strategy

After the reform, cartels lost the ability to exclude competitive rivals from the main auction. As a result, they should have adapted their cartel strategy. According to Prediction 2 in Section 2.6, we expect cartel firms to participate jointly in the preselection stage less frequently, as the reform eliminated the gain from joint participation. One should note that this reasoning assumes that the cartel has continued to exist after the reform. There is also the possibility that under the new auction rules, a cartel is not worth preserving. If a cartel breaks down in response to the reform, previous cartel members become genuine competitors. Then, we should expect a decrease in joint participation only if cartel members were previously aiding each other to win contracts that they would not have competed for as independent bidders. This could be due to either imperfect product portfolio overlap or capacity constraints. Either way, a decrease in joint participation of the firms that we tag as potentially collusive is a clear indicator of exclusionary practices before the reform and a change in cartel behavior after the reform.

To analyze joint participation with (other) potential colluders, we restrict the sample to auctions with at least 2 bidders and consider the following linear probability model:

$$\begin{aligned} CollusiveOpponent_{ia} = {} & \alpha_0 + \alpha_1 Post_t + \alpha_2 Colluder_i \times Post_t \\ & + \beta_1 \mathbb{1}(\geq 3Bidders)_a + \beta_2 \mathbb{1}(\geq 4Bidders)_a \\ & + \beta_3 \mathbb{1}(\geq 5Bidders)_a + \gamma_{t(a)} + \delta_{p(a)} + \theta_{c(a)} + \omega_i + \epsilon_{ia} \end{aligned} \tag{3}$$

where the outcome variable is equal to one if bidder i faces a collusive bidder as a rival in the preselection stage of the auction a. $Colluder_i$ indicates whether bidder i is itself a potential colluder, and *Post* is a dummy variable indicating whether the auction takes place after the reform. While we again include year–month, procurer and CPV category fixed effects, note that the regression is at the bidder–auction level, such that we can also control for bidder identity. Moreover, as the sample includes only auctions with at least two bidders, we add fixed effects for at least three, four and five bidders. Finally, we cluster standard errors at the bidder level.

Table 4: Effect of the reform on the probability of facing a potential colluder in the preselection stage

	(1) OLS	(2) OLS	(3) OLS	(4) OLS
Post	-0.037**	-0.013	0.014	0.044**
	(0.012)	(0.012)	(0.015)	(0.015)
Colluder × Post		-0.221***		-0.213***
		(0.040)		(0.043)
≥3 bidders	0.050***	0.050***	0.050***	0.049***
	(0.007)	(0.007)	(0.006)	(0.006)
≥4 bidders	0.050***	0.052***	0.049***	0.053***
	(0.003)	(0.003)	(0.004)	(0.004)
≥5 bidders	0.160***	0.158***	0.161***	0.158***
	(0.006)	(0.006)	(0.007)	(0.007)
Constant	0.117***	0.118***	0.147***	0.147***
	(0.013)	(0.013)	(0.014)	(0.013)
Bidder FE	yes	yes	yes	yes
Month FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes
Procurer FE	yes	yes	yes	yes
CPV Category FE (2-digit)	yes	yes	no	no
CPV Category FE (full)	no	no	yes	yes
Adj. R2	0.37	0.38	0.47	0.47
Avg. Outcome	0.22	0.22	0.22	0.22
N	140368	140368	87004	87004

Notes: Fixed effects included in the specifications are indicated at the bottom of the table. Standard errors in parentheses are clustered at the bidder level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

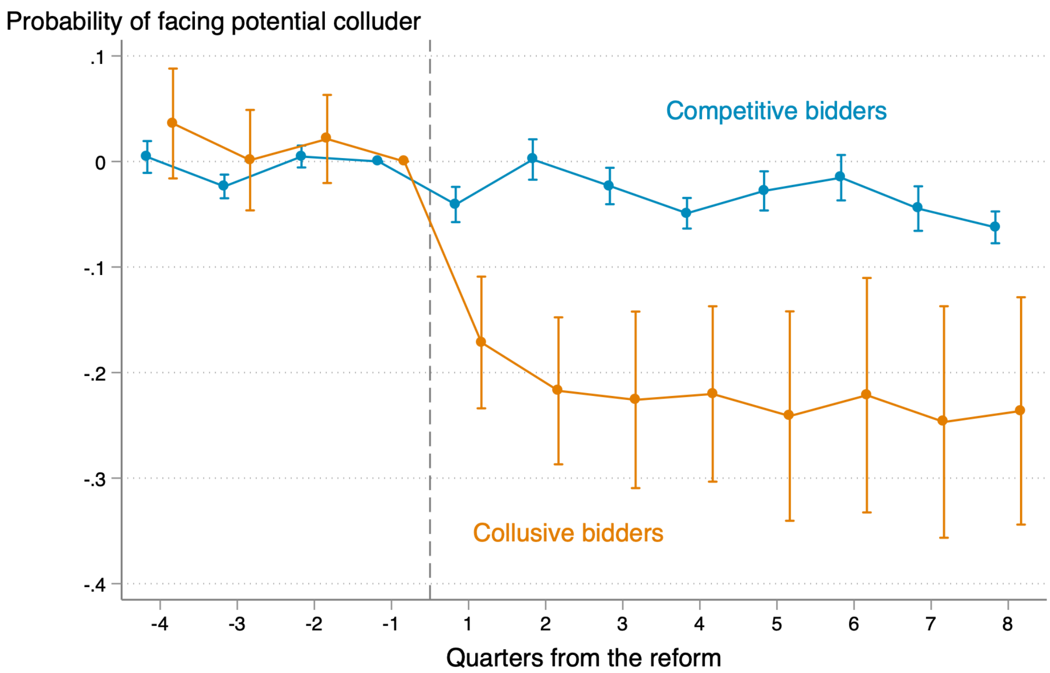
Table 4 shows that colluders are less likely to face a collusive opponent in the preselection stage. This reduction in probability is not only significant but also sizeable. The pre-reform probability of a colluder participating jointly with other colluders is 76.2%, while the corresponding probability of a competitor is only 24.5%. Based on Column 4, where we control for the full CPV category, this probability does not change substantially for competitive bidders.[49] Relative to the change for competitive bidders, the probability for collusive bidders drops by an additional 20.9 percentage points. To show the overall effect more clearly, Figure 6 illustrates the finding in the form of an event study–style graph. Here it is even more evident that the drop for collusive bidder happens immediately after the introduction of the reform. One might be concerned that part of the effect is mechanical, as the reform coincides with the end of the period used

[49] Note that the coefficient of $Post_t$ shows the effect only for auctions with two bidders.

to define colluders. To address this concern, we provide a robustness analysis, where we only use auctions happening before August 2016 to define colluders. Figure D.7 in Appendix D shows that the drop for collusive bidders nonetheless occurs in the quarter after the reform.

All in all, this finding strongly supports the idea that with preselection, cartel members participate jointly to exclude competitive rivals. One should note that a decrease in the probability of facing a potential colluder in the preselection stage could also be due to colluders dropping out of the procurement platform altogether. However, the fact that we do not observe a similar sudden decrease for competitive bidders contradicts this interpretation. Moreover, we do not observe differential exit rates for collusive and competitive bidders after the reform (see Figure D.8 in Appendix D).

Figure 6: Effect on the probability of facing a potential colluder in the preselection stage

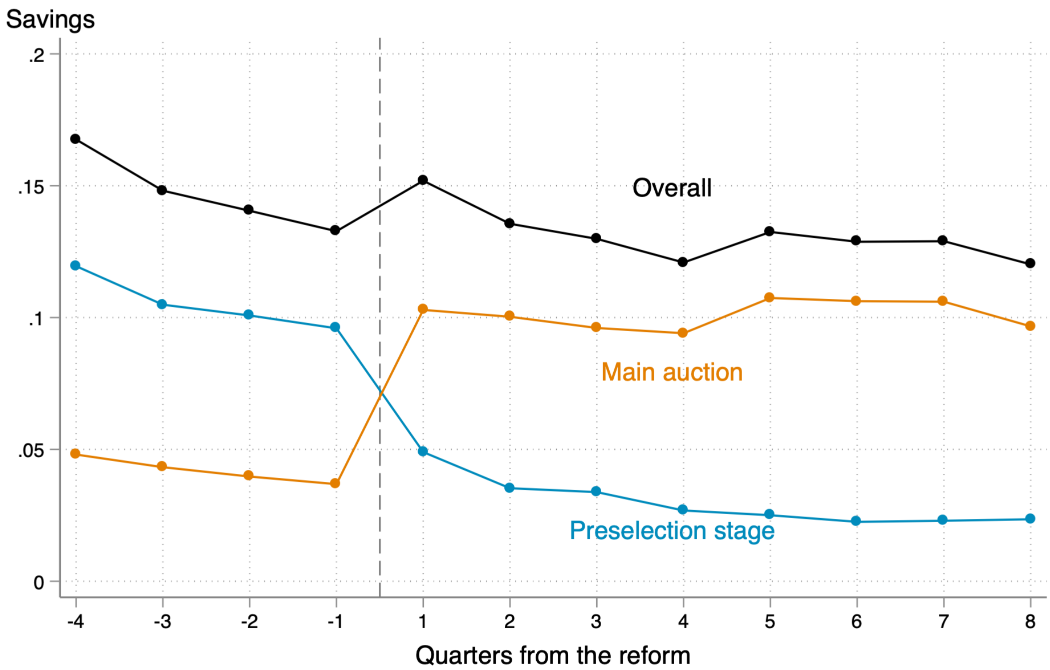


Notes: The graph plots event study coefficients from a regression of an indicator taking the value one if a bidder faces a potential colluder on the full set of quarter indicators and bidder, procurer, and CPV category fixed effects. The omitted category is one quarter before the reform. The model is estimated separately for potentially collusive and competitive bidders.

5.2 The Effect on Savings

Before we move to the overall effect on savings, it is instructive to describe how the reform affected bidding in the two stages. Even without an overall effect on savings, the reform may still have changed bidding substantially, as bids in the preselection stage play no role without preselection. Thus, after the reform, bidders should bid much closer to the reserve price. In Figure 7, we see a large shift in competition from the preselection stage to the main auction. The reform decreased the distance between the reserve price and lowest opening bid but increased the distance between the lowest opening bid and the winning bid. This translates to decreased savings realized based on opening bids and increased additional savings generated by final bids in the main auction. While before the reform, savings accruing in the preselection stage accounted for roughly two-thirds of the overall savings, the reform led to a swap in the share of savings attributable to the preselection stage and the main auction. Overall, however, the reform does not seem to have had a large effect.

Figure 7: Effect of the reform on savings in each auction stage



Notes: The graph shows average savings by quarter for overall savings and savings by stage. The reform shifted competition from the preselection stage to the main auction but seemingly did not affect overall savings. Confidence intervals are omitted because of the high precision of the estimates.

To test Prediction 3 from Section 2.6 and evaluate the differential effect of the reform on collusive versus competitive auctions, we need to identify collusive auctions before and after the reform in a consistent manner. We have seen in the previous section that joint participation happened less frequently after the reform. Thus, we consider the participation of at least one potential colluder to be sufficient for an auction to be collusive before and after the reform. Moreover, as we consider the overall savings realized in an auction, our unit of observation is an individual auction. This leads to the following regression specification.

$$
\begin{aligned}
Savings_a = {} & \alpha_0 + \alpha_1 Collusive_a + \alpha_2 Post_t + \alpha_3 Collusive_a \times Post_t \\
& + \beta_1 \mathbb{1}(\geq 2 Bidders)_a + \beta_2 \mathbb{1}(\geq 3 Bidders)_a \\
& + \beta_3 \mathbb{1}(\geq 4 Bidders)_a + \beta_4 \mathbb{1}(\geq 5 Bidders)_a \\
& + \gamma_{t(a)} + \delta_{p(a)} + \theta_{c(a)} + \epsilon_a
\end{aligned} \tag{4}
$$

where $Collusive_a$ is a dummy variable indicating whether at least one potential colluder participates in auction a and $Post_t$ is a dummy variable indicating whether the auction takes place after the reform. As before, $\gamma_{t(a)}$ refers to year and month fixed effects and $\delta_{p(a)}$ refers to fixed effects for the procurer setting up the auction and $\theta_{c(a)}$ indicates fixed effects of the CPV category of the procured good. Again, we consider our two different specifications for the CPV fixed effects, the CPV category code at the 2-digit level and the full CPV category code.

Column 4 of Table 5 presents the results of our main specification. It shows that adding more bidders to the preselection stage has a significantly positive, though decreasing, effect on savings.[50] Moreover, the overall effect of the reform on savings is slightly negative but insignificant. Our primary interest, however, lies in the effect of collusion. In Column 4, auctions affected by collusion have 3.7 percentage points lower savings before the reform. This corresponds to about 26% lower savings relative to the average savings of 14%. After the reform abolished preselection, savings were still lower for collusive auctions, but the difference to average savings decreased by about 2.2 percentage points, almost 60% of the prereform savings gap. This suggests that 60% of the collusive harm before the reform resulted from the ability to exploit the preselection rule and exclude competitive rivals, which is no longer possible after the reform. Controlling for broader CPV categories does lead to a larger gap between collusive and competitive auctions, which is in line with a broader category subsuming different products among which collusive bidders seem to target relatively lower-savings ones. The effect of the reform is remarkably stable in terms of percentage points, however. This result supports our claim that partial cartels enjoy larger cartel gains in auctions with bidder preselection.

[50] Note that the last bidder category includes five or more bidders; hence, the coefficient can be interpreted as the average effect of adding at least a fifth bidder.

Table 5: Effect of the reform on overall savings

	(1) OLS	(2) OLS	(3) OLS	(4) OLS
Post	-0.015*	-0.020**	-0.002	-0.007
	(0.007)	(0.007)	(0.008)	(0.008)
Collusive		-0.057***		-0.037***
		(0.003)		(0.004)
Collusive × Post		0.022***		0.022***
		(0.004)		(0.004)
≥2 bidders	0.083***	0.085***	0.082***	0.084***
	(0.001)	(0.001)	(0.002)	(0.002)
≥3 bidders	0.072***	0.076***	0.073***	0.074***
	(0.002)	(0.002)	(0.003)	(0.003)
≥4 bidders	0.043***	0.045***	0.040***	0.041***
	(0.003)	(0.003)	(0.003)	(0.003)
≥5 bidders	0.080***	0.086***	0.071***	0.076***
	(0.003)	(0.003)	(0.003)	(0.003)
Constant	0.004	0.009	0.013*	0.017**
	(0.005)	(0.005)	(0.006)	(0.006)
Month FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes
Procurer FE	yes	yes	yes	yes
CPV Category FE (2-digit)	yes	yes	no	no
CPV Category FE (full)	no	no	yes	yes
Adj. R2	0.38	0.39	0.45	0.45
Avg. Outcome	0.14	0.14	0.14	0.14
N	48400	48400	30469	30469

Notes: Fixed effects included in the specifications are indicated at the bottom of the table. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

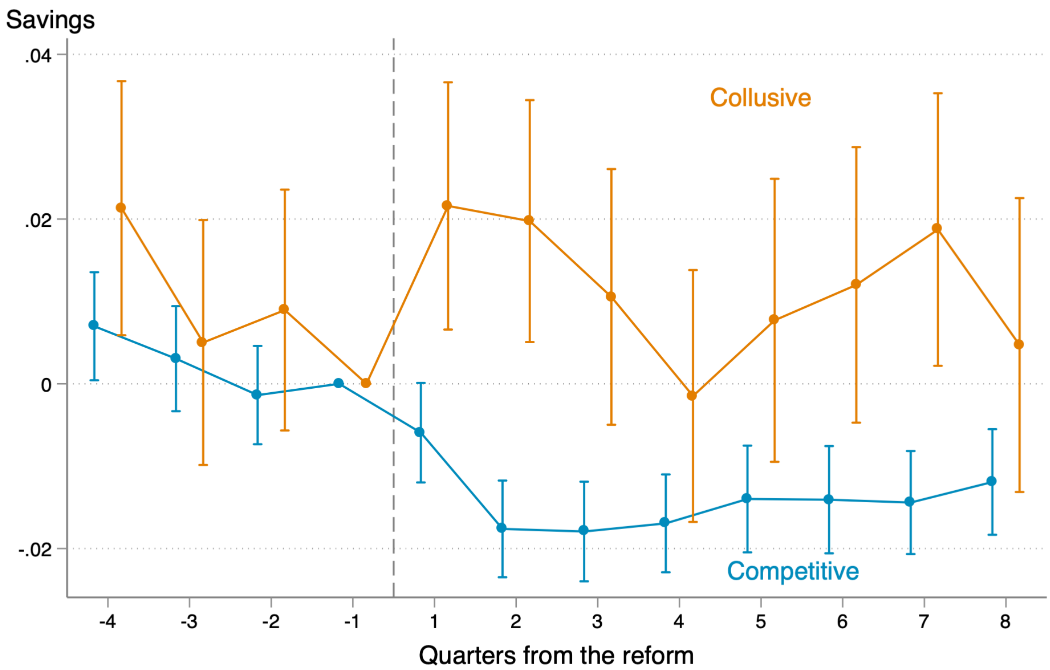
To put these numbers into perspective, consider a scenario where the reform was implemented one year earlier. In the year before the reform, contracts with a total value of EUR 256 million were published on the EKS. Among these, collusive bidders participated in auctions tendering contracts worth EUR 73.1 million. Procurement agencies ended up paying EUR 63.6 million for these contracts, hence generating savings amounting to EUR 9.5 million. If we take the estimates at face value, had the reform been implemented one year earlier, then the savings on these contracts would have been 11.6% (or EUR 1.10 million) higher.[51] However, in the majority of auctions, only

[51] Note that this number reflects the net effect, taking into account the increase in savings due to limiting collusion and the overall slightly negative effect of the reform. As the number of bidders participating

competitive bidders participated. Disregarding the fact that the effect is insignificant, for these auctions, implementing the reform one year earlier would have led to a decrease in savings by 6.0% (or EUR 1.28 million). Hence, overall, these two effects cancel each other out almost perfectly.

Figure 8 depicts an illustration of our finding in the form of an event study–style graph, where the effect is relative to one quarter before the reform. It shows that before the reform, competitive auctions and collusive auctions were trending similarly, but after the reform, collusive auctions have higher savings by about 2 percentage points, but with a seasonal pattern. This seasonal pattern seems to be driven by the time around the Christmas holidays, where we generally observe fewer auctions, fewer bidders and lower savings.

Figure 8: Effect on auctions potentially affected by collusion



Notes: The graph plots event study coefficients from a regression of savings on the full set of quarter indicators, *Bidder*#2 to *Bidder*#5 dummies, procurer fixed effects and CPV category fixed effects. The omitted category is one quarter before the reform to show changes in savings relative to the last prereform quarter. The model is estimated separately for potentially collusive and competitive auctions.

To sum up, our results suggest that bid-rigging was more profitable for cartels but more harmful for procurement agencies before the reform. After the reform, since they are no longer able to exploit competitive rivals, savings in auctions where potential

in collusive auctions is above average, this baseline negative effect is smaller in size than in the average competitive auction.

colluders participate have increased. Still, this finding does not refute the results of existing literature on two-stage auctions: For competitive auctions, we do find a slight negative effect of the reforms. This underlines that auctions with preselection are not a one-size-fits-all approach to improving procurement outcomes. Thus, mandating one auction format is unlikely to maximize surplus. Instead, procurement agencies should have the discretion to make use of preselection when appropriate. Standard criteria involve the cost of bidding in the main auction and information that firms have about their cost. We add another dimension to the decision problem by showing that collusion may undo all potential gains that preselection might bring.

6 Discussion

6.1 Distance of bids and cartel activity in the literature

The distance of bids as an indicator for cartel activity has been used in some other empirical papers on cartel detection. However, these studies exclusively consider standard first-price auctions. In such auctions, an efficient cartel avoids all competition among cartel members by letting only one cartel member bid in the auction, while all other cartel members either do not participate or place the highest possible bid. However, there are several reasons why a cartel may not be able to entirely avoid competition among cartel members: the cartel may need to hide its existence from antitrust authorities by letting cartel members submit phony bids, or it may need to rely on dynamic punishment schemes due to the riskiness of side payments (McAfee and McMillan, 1992). Marshall and Marx (2007) show that when a cartel has only limited control over cartel bids in a first-price auction, it could be optimal to let two cartel members place almost the same bid. More recent empirical papers have found the opposite, however. Both Wallimann, Imhof and Huber (2022) and Chassang et al. (2022) find that the distribution of bids is skewed when cartels are present in first-price auctions such that winning bids are isolated, a phenomenon that Chassang et al. (2022) dub "missing bids." In contrast, based on our model with a different auction rule, we provide evidence that collusive bids are close and not distant. Moreover, the irregularity in the bid distribution does not arise due to limited control; we assume throughout that the cartel can exactly determine each member's bid. Therefore, to our knowledge, we provide the first explanation for why close bids may be optimal for a bid-rigging cartel without any enforcement constraints. Moreover, while the mentioned papers consider the distance between two bids, in our context, it is important that three firms bid close to each other.

6.2 Partial Cartels and Endogenous Cartel Formation

Several empirical (e.g., Athey et al., 2011; Bajari and Ye, 2003; Wallimann et al., 2022) but also theoretical papers (e.g., Marshall and Marx, 2007; McAfee and McMillan, 1992) cover and describe partial cartels. In fact, the seminal papers by Porter and Zona (1993) and Pesendorfer (2000) exploit the parallel existence of collusive and competitive bidders to detect differences in their bidding behavior. Given that there is entry and exit of firms, it is reasonable to assume that eventually, a new participant unaffiliated with the pre-existing cartel will appear in an auction. In contrast, some firms may infrequently participate in auctions within the cartelized market, which makes affiliation not worthwhile. Consequently, partial cartels are likely to be as common if not more common than full cartels.

This raises the question of how cartels are formed and what determines whether there is a partial or full cartel or maybe even multiple cartels.[52] Rigorously answering this question in our setting is beyond the scope of this paper because it would require taking a stance on the internal operation of the cartels, be it through side payments or a rotation scheme that minimizes deviation incentives. For instance, consider the case of a cartel enforced by means of side payments. Whether admitting an outside firm is profitable for the cartel depends on the competitive threat that firm poses relative to the payment that it would receive according to the cartel's internal compensation scheme. An interesting study by Asker (2010) suggests that weak members profit most from cartel membership: They would pose a relatively low competitive threat, but their frequency of receiving side payments is as high as that of other cartel members.[53] This suggests that cartel outsiders should be weaker than insiders, but this insight is, of course, specific to the compensation scheme and auction format analyzed. With preselection, even a firm posing a very low competitive threat may be a viable cartel member as it can help to crowd out strong rivals. For this reason, we take cartel membership as given in the theoretical analysis.

6.3 Competitors versus Colluders

Our results imply that a large part of the collusive gains before the reform resulted from colluders being able to control multiple bids in the preselection stage. That said, if it were possible to open up multiple accounts on the procurement platform, the collusive bidders may actually have been fake firms instead of real firms forming a cartel. Some peripheral results already contradict this interpretation. If the cartel firms were mainly

[52] The activity of multiple cartels in a single market has rarely been observed and we are not aware of a paper describing it.

[53] "Weak" refers to high-cost firms in our setting but to low-value firms in the buyer auction setting of Asker (2010).

fake firms, we should not observe similar exit rates after the reform, for instance. In addition, the reform should have eliminated the savings gap entirely, not only partially.

Here, we provide further evidence suggesting that the vast majority of marked colluders are real firms, as they generate revenues and sales. Generally, bidding on the EKS requires a registration on the platform itself involving documentation on the firm name and location, which presents some hurdles to registering a fake firm. Moreover, when we compare the prereform distribution of revenues generated on the platform, if anything, noncollusive firms have lower revenues and a larger probability of not generating any sales at all. This also applies to the postreform revenue distributions; see Figure D.10. To obtain a full picture of the firms participating on the EKS, we also analyze their overall economic activity based on data from the RFS. First, one should note that the RFS provides annual financial information only on Slovak firms. Foreign and international firms are not obliged to provide their financial information in this register. Thus, missing information could indicate that the company is either foreign based or nonexistent. Among the set of firms active before the reform, we fail to match 41% to the register. However, this share is much smaller for collusive bidders, where we fail to match only 7% of firms. This suggests that the vast majority of collusive bidders not only are real but also are registered in Slovakia. We provide summary statistics on firms found in the register in Table D.2. The sales and asset distributions do look fairly similar, even though collusive firms have lower total sales and assets on average. The size in terms of employees is strikingly similar, however. Hence, we do not see any indication that collusive firms are likely to be "fake."

6.4 Heterogeneity in Bid-Rigging by Sector

The literature has identified and analyzed cartels in many different sectors: for instance, timber, school milk, stamps and, most notably, construction. This suggests that cartels are relevant across the board, and consistent with this conjecture, we find collusive firms in most sectors (CPV categories at the 2-digit level) in our dataset. The two exceptions are repair/maintenance services and business services. However, we do see large variation in the savings gaps that collusive bidders are able to generate in different sectors, which we interpret as their effectiveness; see Figure D.11. Collusive bidders were most successful before the reform in the chemical products, food and beverages sectors as well as in construction and the textile sector. Were these cartels hit hardest by the reform? On average, it turns out that this is the case. We find a correlation of -0.569 between the coefficient of $Collusive_a$ and $Collusive_a \times Post_t$ from Equation (4) across sectors, which is significant at the 1% level. This suggests that the procurement agency could reclaim most of the savings in sectors where collusive bidders caused the largest distortions before the reform.

7 Conclusion

In this paper, we analyze bid-rigging in public procurement auctions with bidder preselection and compare the outcomes in this setting to those in auctions without bidder preselection. We develop a theoretical model to show that the optimal strategy of a partial bid-rigging cartel involves close bidding by sufficiently many cartel members in the preselection stage. Such a strategy allows the cartel to reduce the probability of facing any competitive rivals in the main auction stage. Hence, in contrast to standard auctions without preselection, bid-rigging causes additional harm to procurement agencies, as it reduces competition not only between cartel members but also from competitive rivals. This counteracts the potential benefits from using auctions with preselection. We then take the model to the data and derive a collusion marker that closely mirrors the optimal cartel behavior, based on administrative data from public procurement in Slovakia. These data are quite attractive for our analysis, as we observe a reform that removed the preselection stage. We then mark bidders as potentially collusive if they frequently participated in close bidding groups in the preselection stage before the reform. We show that our collusion marker captures anticompetitive behavior well by showing that we identify a majority of convicted cartel members, that collusive bidders are selective in whom they bid close to, and that competition in the main auction is much lower when collusive bidders participate. The exclusionary strategy of cartels is specific to auctions with preselection; hence, we observe a significant drop in joint participation of collusive bidders after the reform. Finally, the savings gap between collusive and competitive auctions is significantly lower by 60% after the reform. At the same time, the savings in competitive auctions are slightly lower after the reform.

Our results suggest that there is an overlooked cost to using auctions with bidder preselection based on sealed opening bids. While they may increase savings in a competitive environment by increasing efficiency or allowing to gather information, they are vulnerable to excessive bid-rigging, which may undo all those gains. Public procurement agencies should thus be careful in their choice of auction format. Beyond adding an additional criterion to the choice problem of procurement agencies and providing a method to detect collusion, our result may also help to find alternative auction formats combining the strengths of auctions with and without preselection. In future research, it might be interesting to analyze the use of our collusion marker as an integral part of the auction design: When preselection is believed to be beneficial under competition, procurement agencies could condition the implementation of it in the main auction on the occurrence of close bidding in the preselection stage. A cartel will readjust its optimal strategy when facing such a new auction format. The optimal definition of close bidding for this purpose will have to trade off the risk of flagging false positives or missing false negatives in addition to considering the behavioral response of cartels and competitive firms.

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A Theoretical Appendix

A.1 Proof of Lemma 1

Proof. W.l.o.g., suppose that firm j has the lowest cost, hence, $c_j = \min_{i \in P_n} c_i$. As costs are drawn from a continuous distribution function, firm j is unique almost surely.

First, consider the case when j is competitive, i.e., $\{j\} = I_k$. Since $n \geq 2$, there exists a firm m which has the second-lowest cost, hence, $c_m = \min_{i \in P_n \setminus j} c_i$. Note that $c_j < c_m$ almost surely. If $c_m > b_j$, by assumption, $b_j < \min_{i \in P_n \setminus j} b_i$; hence, firm j has to procure the good at its opening bid if no other firm is active at the beginning of the main auction. Indeed, firm m will not be active at the beginning of the main auction. As no other firm is active at the beginning of the main auction, firm j wins at final bid b_j. If $c_m \leq b_j$, bidder m is active at the beginning of the main auction. Moreover, bidder j will find it optimal to be active as well. Then, the process is as in a standard English descending auction, and bidder m will drop out at c_m. As bidder j is the last remaining bidder at c_m, this will be the final price.

Second, consider the case when j is part of a cartel, i.e., $j \in I_k$ with $|I_k| > 1$. Suppose the lowest opening bid has been submitted by a cartel member.[54] Then, no other selected cartel member should be active at the beginning of the main auction, as this will decrease the final price received, which reduces joint profits. If no firm was selected along with cartel members, the price received by the cartel will thus be $min_{l \in I_k} b_l$. However, if a competitive firm was selected along with the cartel members, there exists a firm m that has the lowest cost among cartel outsiders, i.e., $c_m = \min_{i \in P_n \setminus I_k} c_i$. Again, $c_j < c_m$ almost surely, and the argument follows the same logic as above in the competitive case, with the exception that the case distinction has to consider whether $c_m > min_{i \in I_k} b_i$ or $c_m \leq min_{i \in I_k} b_i$ (instead of $c_m > b_j$ or $c_m \leq b_j$). $\square$

A.2 Proof of Lemma 2

Proof. Note that it can never be optimal for any firm to bid below its cost in the preselection stage (since the expected payoff is then weakly negative). We will start with the "only if" direction and prove it in two steps. The "if" direction constitutes a simple final observation we will mention in the end.

Step 1: Any equilibrium bid function has to be strictly increasing. It is easy to see that the optimal bid function has to be weakly increasing. Suppose it is not and there is a downward-sloping part of the bid function. Then, any firm with cost corresponding

[54] Firm j will procure the good irrespective of the identity of the winner if the winner is a cartel member; hence, the relevant cost is c_j, and this assumption is w.l.o.g.

to that downward sloping part would have a strict incentive to decrease its bid. This is because, if such a decrease allows the cartel to just qualify for the main auction, the marginal benefit is strictly positive. On the other hand, if such a decrease is irrelevant for qualification, it comes without cost (firms with higher cost submit lower opening bids hence the own opening bid will not be binding).

Moreover, any optimal bid function cannot have plateaus; i.e., it can never be optimal to bid the same amount for a set of costs with positive measure. By contradiction, suppose there exists an interval $[a, b] \subseteq C$ and a bid x such that the optimal bid function satisfies $\beta(c) = x \; \forall c \in [a, b]$. This implies that a firm i of type c_i, where $c_i \in [a, b]$, which follows bid function β, faces the following probability P of being among the lowest-bidding firms in the preselection stage:

$$P \equiv \Pr(b_{1:N-1} \geq x) = \sum_{t=0}^{N-1} \binom{N-1}{t} (F(b) - F(a))^t (1 - F(b))^{N-1-t}$$

Note however that if more than n bidders place opening bid x, n are selected at random to proceed to the main auction. Hence, firm i has a strictly positive expected profit from being preselected, while the probability is strictly lower than P. Firm i could profitably deviate by bidding $x - \epsilon$ for arbitrarily small ϵ and thereby increase its probability of proceeding by ΔP:

$$\Delta P = \sum_{t=n}^{N-1} \binom{N-1}{t} \frac{t+1-n}{t+1} (F(b) - F(a))^t (1 - F(b))^{N-1-t} > 0$$

The strict inequality follows from the fact that $n \leq N - 1$.

Step 2: Any strictly increasing bid function has to map to $[\bar{c}, r]$. From Step 1, it follows that we can focus on strictly increasing bid functions. When equilibrium bid function β is strictly increasing, we can consider the direct revelation mechanism where firms directly reveal their type c_i. We denote the distribution of the n-th lowest cost $\tilde{c}$ among $N - 1$ rivals by $F_{n:N-1}(\tilde{c})$ and the distribution of the lowest-cost rival conditional on its cost being lower than $\tilde{c}$ as $H(\cdot|\tilde{c})$. Given that rival firms follow the same bid function β, their opening bid reveals their cost, and we can write the expected profits of a firm if it chooses bid b as follows (dropping the firm-specific subscripts):

$$\Pi(b, c; \beta) = \int_{\beta^{-1}(b)}^{\bar{c}} \int_{c}^{\tilde{c}} (\min\{b, x\} - c) dH(x|\tilde{c}) dF_{n:N-1}(\tilde{c})$$

The FOC evaluated at $b = \beta(c)$ is then given by:

$$\frac{\partial \Pi}{\partial b}_{|b=\beta(c)} = \int_c^{\bar{c}} 1 - H(\min\{\beta(c), \tilde{c}\}|\tilde{c}) dF_{n:N-1}(\tilde{c})$$

In a symmetric equilibrium, the marginal profit of increasing the own bid at $b = \beta(c)$ has to equal 0. It is easy to see from the above equation that this only holds $\forall c$ if $\beta(c) \geq \bar{c}$.

Finally, for the "if" direction, we only need to see that any strictly increasing bidding function with $\beta(c) \geq \bar{c}\ \forall c$ satisfies the above FOC. □

A.3 Proof of Proposition 1

Proof. First, note that without selection (selection rule N), for any opening bid strictly below $\bar{c}$, a firm has a strict incentive to increase the bid since this does not reduce its likelihood of proceeding but strictly increases its expected profits irrespective of the bidding strategy of the firm's rivals. Hence, bidding any $b \in [\bar{c}, r]$ is a weakly dominant strategy for any firm i, and the equilibrium does not require that firms bid according to a symmetric and strictly increasing bid function. The expected profit with selection rule N and any combination of optimal opening bids $(b_i, b_{-i}) \in [\bar{c}, r] \times [\bar{c}, r]^{N-1}$ is thus[55]

$$\Pi^{F*}(c) = \int_c^{\bar{c}} (x - c) dF_{1:N-1}(x)$$

With selection rule $n < N$, the expected profit of firm i when all firms including the bidding firm itself follow an optimal bid function β as described in Lemma 2 is given by

$$\begin{aligned}\Pi^{S*}(c) &= \int_c^{\bar{c}} \int_c^{\tilde{c}} (x - c) dH(x|\tilde{c}) dF_{n:N-1}(\tilde{c}) \\ &= \int_c^{\bar{c}} (x - c) dF_{1:N-1}(x) = \Pi^{F*}(c)\end{aligned}$$

where the second equality follows from the law of iterated expectations.

The expected procurement savings with selection rule N for any combination of optimal opening bids $\boldsymbol{b}^F \in [\bar{c}, r]^N$ is given by:

$$\mathbb{E}(s^F) = r - \int_{\underline{c}}^{\bar{c}} x dF_{2:N}(x)$$

With selection rule n, the expected savings when firms follow an optimal bid func-

[55] We use F to denote "free entry" or "no selection."

tion β can be written as:

$$\mathbb{E}(s^S) = r - \int_{\underline{c}}^{\bar{c}} \int_{\underline{c}}^{x} \min\{\beta(c), x\} dF_{1:2}(c|x) dF_{2:N}(x)$$

Since $\beta(c) \in [\bar{c}, r]\ \forall c$, it follows that $\mathbb{E}(s^S) = \mathbb{E}(s^F)$. □

A.4 Proof of Proposition 2

Proof. A cartel has to coordinate multiple bids, which makes the decision problem generally more complicated than that of a single competitive firm. Note that the cartel profits are given by the lowest final bid of any cartel member less the cost of the lowest-cost cartel member (assuming efficient reallocation within the cartel). Hence, w.l.o.g., we assume that the cartel member with cost c_k always submits the lowest final cartel bid b_k (otherwise, the tender can be subcontracted to the member with the lowest cost) and, therefore, its profits are equivalent to cartel profits. We refer to this cartel member as the cartel winner. Consequently, by definition, the bids of all other cartel members are weakly higher than the bid of the cartel winner: $b_j \geq b_k\ \forall j \in I_k$.

With this assumption in mind, the proof is structured in two steps: First, taking the lowest cartel bid b_k as given, we show that it is optimal for at least n cartel members to bid $b_j = b_k$, while remaining cartel members may bid more. Second, we show that there exists a function such that $b_k = \beta_k(c_k)$ that has to lie in the interval $[\beta(\underline{c}), \beta(\bar{c}))$.

Step 1: Close bidding is optimal for the cartel. When $|I_k| \in \{n, ..., N-1\}$, the cartel has at least n bids at its disposal and faces at least one competitive rival. Since the cartel does not care about the identity of bidders, we use b_I to denote the n-th lowest cartel bid; i.e., there exist exactly $n-2$ cartel members j such that $b_k \leq b_j \leq b_I$. Hence, the value of b_k determines whether at least one cartel member is allowed to proceed to the main auction, and the value of b_I affects the probability with which competitive firms are jointly selected with cartel members. The vector collecting all cartel bids is then denoted by $\boldsymbol{b}_k$. If $n \leq N - |I_k|$, there are enough cartel outsiders to allow for the possibility that not a single cartel member is selected for the main auction. Cartel profits are given by:

$$\Pi_k^S(\boldsymbol{b}_k, \beta) = \int_{\beta^{-1}(b_k)}^{\bar{c}} \left[\int_{c_k}^{\beta^{-1}(b_I)} (\min\{b_k, x\} - c_k)^+ dH(x|\tilde{c}) + \int_{\beta^{-1}(b_I)}^{\tilde{c}} (b_k - c_k) dH(x|\tilde{c}) \right] dF_{n:N-|I_k|}(\tilde{c})$$

If $n > N - |I_k|$, at least one cartel member proceeds irrespective of the value of b_k with certainty. Cartel profits are given by:

$$\Pi_k^S(\boldsymbol{b}_k, \beta) = \int_{c_k}^{\beta^{-1}(b_I)} (\min\{b_k, x\} - c_k)^+ dF_{1:N-|I_k|}(x) + \int_{\beta^{-1}(b_I)}^{\bar{c}} b_k - c_k dF_{1:N-|I_k|}(x)$$

In both cases, b_I determines the probability of rivals being jointly selected with cartel members. Conditional on some b_k, note that $\beta^{-1}(b_I) \geq b_k$ will lead to no relevant exclusion of rivals: Those that would be excluded by such a bid are firms with costs larger than b_k and that would, hence, pose no competitive threat in the main auction anyway. Thus, if $b_k < \bar{c}$, $b_I \in [\beta(b_k), \beta(\bar{c})]$ are minima of the cartel's profit function.

Moreover, reducing b_I as long as $\beta(b_k) > b_I \geq b_k$ leaves profits in the main auction unaffected but may exclude additional rivals that would potentially reduce the price received by the cartel. The FOC of the cartel with respect to b_I, $\frac{\partial \Pi_k^S}{\partial b_I}$, can be rewritten as:

$$(\min\{b_k, \beta^{-1}(b_I)\} - c_k)^+ - (b_k - c_k) < \min\{b_k, \beta^{-1}(b_I)\} - b_k < 0$$

Consequently, it is always optimal for the cartel to set a bidding scheme where $b_I = b_k$, whether $n \leq N - |I_k|$ or $n > N - |I_k|$.

Step 2: There exists an optimal cartel bid function with support $[\beta(\underline{c}), \beta(\bar{c}))$**.** First, note that except for the n lowest bids, the value of other bids by cartel members is irrelevant as long as they are weakly larger. Hence, effectively, the cartel decides on a single strategic variable: the lowest bid coordinated on by at least n of its members b_k. Moreover, the bid support and profits are bounded, and the expected cartel profits do not depend on the cost of cartel members other than the member with the lowest cost c_k. Hence, a single optimal bid function for the cartel $b_k = \beta_k(c_k)$, where $\beta_k : C \to [\underline{c}, r]$, always exists (though it may not be unique). Now, we show that optimal bids cannot be smaller than the lower bound of the competitive bid image support. Suppose that there exists some c_k such that $\beta_k(c_k) < \beta(\underline{c})$. Clearly, increasing the cartel bid by at most $\beta(\underline{c}) - \beta_k(c_k)$ would increase the expected price received upon winning the main auction but would not change the amount and identity of rivals selected. Hence, $\beta_k(c_k) < \beta(\underline{c})$ cannot be optimal.

If $n > N - |I_k|$ and $N > |I_k| \geq n$, cartel profits can be written as:

$$\Pi_k^S(b_k, c_k; \beta) = \int_{c_k}^{\beta^{-1}(b_k)} (x - c_k)^+ dF_{1:N-|I_k|}(x) + \int_{\beta^{-1}(b_k)}^{\bar{c}} (b_k - c_k) dF_{1:N-|I_k|}(x)$$

The condition that has to hold for an interior solution is then:

$$\frac{\partial \Pi_k^S(b_k, c_k; \beta)}{\partial b_k} = \Big[\mathbb{1}_{\beta^{-1}(b_k)>c_k}(\beta^{-1}(b_k) - c_k) f_{1:N-|I_k|}(\beta^{-1}(b_k)) - (b_k - c_k) f_{1:N-|I_k|}(\beta^{-1}(b_k))\Big]$$
$$* \frac{\partial \beta^{-1}(b_k)}{\partial b_k} + (1 - F_{1:N-|I_k|}(\beta^{-1}(b_k))) = 0$$

Note that whether the cartel bids more or less aggressively than a competitive firm, i.e., whether $\beta_k(c_k) < \beta(c_k)$ or $\beta_k(c_k) \geq \beta(c_k)$, depends both on the bidding strategy of competitive firms β and the distribution of cost $F(c)$. However, the cartel always bids strictly below the highest bid on the competitive rival's bid support $\beta(\bar{c})$:

$$\frac{\partial \Pi_k^S(b_k, c_k; \beta)}{\partial b_k}\Big|_{b_k=\beta(\bar{c})} = (\bar{c} - c_k) f_{1:N-|I_k|}(\bar{c}) - (\beta(\bar{c}) - c_k) f_{1:N-|I_k|}(\bar{c}) + (1 - F_{1:N-|I_k|}(\bar{c}))\beta'(\bar{c})$$
$$= -(\beta(\bar{c}) - \bar{c}) f_{1:N-|I_k|}(\bar{c}) < 0$$

In case of $n \leq N - |I_k|$ and $N > |I_k| \geq n$, the analysis is similar. □

A.5 Proof of Proposition 3

Proof. We show the effect on the two types of auction participants stated in the proposition in turn.

Effect on cartel profits (i) When $|I_k| = N$, the analysis is trivial since with both selection rules, all cartel members will simply bid r and achieve the maximum possible final price.

With preselection rule N and $|I_k| < N$, similarly to the analysis in the competitive case, any bid scheme $\boldsymbol{b}_C k^F \in [\bar{c}, r]^{|I_k|}$ is a weakly dominant strategy for the cartel and leads to optimal profits:

$$\Pi_k^{F*}(c_k) = \int_{c_k}^{\bar{c}} (x - c_k) dF_{1:N-|I_k|}(x)$$

Remember from Lemma 2 that with preselection rule $n < N$, it is weakly optimal for the cartel to let all cartel members place the same opening bid, i.e., $b_j = \beta_k(c_k)$ for all $j \in I_k$, and we can denote the cartel profits by $\Pi_k^S(c', c_k; \beta)$ assuming that rivals bid according to β where $c' = \beta^{-1}(\beta_C(c_k))$. If $|I_k| < n$ and $n \leq N - |I_k|$, cartel profits are given by:

$$\Pi_C^S(c', c_k; \beta) = \int_{c'}^{\bar{c}} \int_{c_k}^{\tilde{c}} (\min\{\beta(c'), x\} - c_k) dH(x|\tilde{c}) dF_{n:N-|I_k|}(\tilde{c})$$

Note that this is essentially the same problem as the one that a competitive firm faces, with the exception that the relevant rival distribution is $F_{n:N-|I_k|}$ instead of $F_{n:N-1}$. Hence, it is optimal for the cartel to follow the same bid function as competitive firms and report $c' = c_k \ \forall c_k \in C$. If $n > N - |I_k|$, at least one cartel member will proceed for sure, and hence, the value of opening bids does not matter for the cartel: Any $c' \in C$ and thus any $\beta_k(c_k) = \beta(c') \in [\bar{c}, r]$ can be supported in equilibrium. In both cases, cartel profits are the same as with selection rule N, meaning that changing the selection rule does not affect the cartel's profits.

(ii) Now we come to the more interesting case, when $n \leq |I_k| < N$. The optimal cartel bid will depend on β and $F(c)$; however, notice that $\Pi_k^{S*} = \Pi_k^S(c^*, c_k; \beta_S) \geq \Pi_k^S(\underline{c}, c_k; \beta_S)$, i.e., the optimal cartel profits have to be at least as high as the cartel profits when one member is reported to be of the lowest type. If $n \leq N - |I_k|$, reporting $c' = \underline{c}$ will lead to the following cartel profits:

$$\begin{aligned}\Pi_k^S(\underline{c}, c_k; \beta) &= \int_{\underline{c}}^{\bar{c}} \left[\int_{\underline{c}}^{\tilde{c}} (\beta(\underline{c}) - c_k) dH(x|\tilde{c}) \right] dF_{n:N-|I_k|}(\tilde{c}) \\ &\geq \int_{\underline{c}}^{\bar{c}} \left[\int_{\underline{c}}^{\tilde{c}} (\bar{c} - c_k) dH(x|\tilde{c}) \right] dF_{n:N-|I_k|}(\tilde{c}) \\ &= \bar{c} - c_k > \int_{c_k}^{\bar{c}} (x - c_k) dF_{1:N-|I_k|}(x) = \Pi_k^{F*}(c_k)\end{aligned}$$

In addition, if $n > N - |I_k|$, reporting $c' = \underline{c}$ will lead to an increase in cartel profits through exploitation of the selection rule, even though the cartel profit does not require bidding on anything below r for at least one member to be preselected:

$$\begin{aligned}\Pi_k^S(\underline{c}, c_k; \beta) &= \int_{\underline{c}}^{\tilde{c}} (\beta_S(\underline{c}) - c_k) dF_{1:N-|I_k|}(x) \\ &\geq \bar{c} - c_k > \int_{c_k}^{\bar{c}} (x - c_k) dF_{1:N-|I_k|}(x) = \Pi_k^{F*}\end{aligned}$$

Hence, in either case, $\Pi_k^{S*} > \Pi_k^{F*}$ if $n \leq |I_k| < N$.

Effect on procurement savings (i) Again, if $|I_k| = N$, the analysis is trivial since government savings are zero with both selection rules.

Analyzing the effect on procurement savings if $|I_k| < N$ requires some additional notation: We denote the joint distribution of the i-th and j-th lowest cost among n by $F_{i,j:n}(x_i, x_j)$. The expected procurement savings with selection rule N for any combination of optimal opening bids $\boldsymbol{b}^F \in [\bar{c}, r]^N$ (where we do not have to distinguish between cartel and noncartel bids) is given by:

$\mathbb{E}(s_k^F) =$

$$r-\int_{\underline{c}}^{\bar{c}}\left\{\int_{\underline{c}}^{c_k}\frac{1}{F_{1:N-|I_k|}(x_1)}\left[\int_{x_1}^{\bar{c}}x_2 dF_{2,1:N-|I_k|}(x_2,x_1)+(1-F_{2,1:N-|I_k|}(c_k,x_1))c_k\right]dF_{1:N-|I_k|}(x_1)\right.$$
$$\left.+\int_{c_k}^{\bar{c}}x_1 dF_{1:N-|I_k|}(x_1)\right\}dF_{1:|I_k|}(c_k)$$

Here, the the expected price paid by the government agency has to take two cases into account: Either the cartel does not include the lowest-cost firm among participants (represented by the term in square brackets), or it does, and the cartel wins the contract at a price equal to that of the lowest-cost firm among the competitive rivals (represented by the last part in the equation).

When we consider selection rule $n < N$ and $|I_k| < n$, it is trivial to see that the procurement savings are not affected by the reform: As derived above, the cartel follows the same bid function as competitive rival firms and can never exclude the lowest-cost rival firm. Hence, Proposition 1 extends to the case when a cartel with less than n members participates in the auction.

(ii) When $n \leq |I_k| < N$, to show the effect on savings, we use the previously described fact that for each minimum cost level among cartel members c_k, the cartel reports to be of type $c' = \beta^{-1}(\beta_k(c_k))$; hence, the cartel report can be written as a function $c' = \gamma(c_k)$ with $\gamma : C \rightarrow C$. Remember that it depends on the bidding strategy of competitive firms β and the distribution of costs $F(c)$ whether the cartel will locally choose to bid more or less aggressively than a competitive firm, i.e., whether $c' < c_k$ or $c' \geq c_k$. If a cartel bids more aggressively than a competitive firm, it may exclude rivals that could otherwise have won. If a cartel bids less aggressively, it may not be selected for the main auction even though its lowest-cost member would have won the auction. In both cases, in addition to potential reallocation of rents between firm and agency, cartel behavior introduces inefficiency in the case of selection rule $n < N$. Abstracting from this inefficiency can be viewed as an upper bound on savings and simplifies the equations: We consider a hypothetical world where the opening bids are as with preselection but if the lowest-cost firm is not among selected bidders, it will be included ex post. Since increasing the set of selected firms conditional on opening bids always increases savings, $\mathbb{E}(s_k^H) \geq \mathbb{E}(s_k^S)$, where $\mathbb{E}(s_k^H)$ denote the savings in the hypothetical case:

$$\mathbb{E}(s_k^H) =$$
$$r-\int_{\underline{c}}^{\bar{c}}\left\{\int_{\underline{c}}^{c_k}\frac{1}{F_{1:N-|I_k|}(x_1)}\left[\int_{x_1}^{\bar{c}}x_2 dF_{2,1:N-|I_k|}(x_2,x_1)+(1-F_{2,1:N-|I_k|}(c_k,x_1))c_k\right]dF_{1:N-|I_k|}(x_1)\right.$$
$$\left.+\int_{c_k}^{\max\{c_k,\gamma(c_k)\}}x_1 dF_{1:N-|I_k|}(x_1)+\int_{\max\{c_k,\gamma(c_k)\}}^{\bar{c}}\beta_k(c_k)dF_{1:N-|I_k|}(x_1)\right\}dF_{1:|I_k|}(c_k)$$

By Lemma 2 (ii), $\gamma(c_k) \in [\underline{c}, \bar{c})$. Since $\beta_k(c_k) \geq \beta(\underline{c}) \geq \bar{c} \; \forall c_k \in C$, $\mathbb{E}(s_k^F) > \mathbb{E}(s_k^H)$, and changing the selection rule strictly increases savings. □

A.6 Allowing for cost updating

A.6.1 Model Set-up

In the baseline model, we made the common assumption that a cartel knows the ex-ante cost realization of its members. With cost updating, however, new information is revealed during the auction, and the final cost may differ from the ex ante signal. To our knowledge, cartel behavior has not been modeled in such an environment. Thus, to be as general as possible, we introduce the notion of a higher-level organizational entity. Such an approach has been taken without cost updating when partial cartels are explicitly considered.[56] In our case, this approach nests the setting where the action-relevant signal and cost is the minimum among cartel members but also allows updating to be limited or selective.

Specifically, consider M organizational entities $m \in \{1, ..., M\}$, each of which controls at least one bidder. Overall, there are N risk-neutral bidders $i \in \{1, ..., N\}$, who participate in a two-stage bidding process, with $N \geq M$. As such, the entities partition the set of firms into different groups I_m, where firm i is controlled by entity m if $i \in I_m$. As in the baseline model, before the auction takes place, the procurer sets the reserve price r and the preselection rule $n \in \{1, ..., N\}$, which determines the available slots for participation in the second stage. At the beginning of the first stage, each entity m draws a signal S_m of its cost C_m to provide the good.[57] Based on this signal, the entities decide how many of the bidders under their control submit an opening bid and the value of these bids, i.e., $b_i \in [0, r] \cup \emptyset$. This set-up reflects that in the presence of a cartel, decisions are made at the entity level, not at the bidder level. Moreover, in a world where cartels are perfectly enforceable, this set-up is without loss of generality.

We denote the set of bidders who end up submitting an opening bid by A, where $|A| = a$.[58] The n bidders with the lowest opening bids among those who chose to submit are then selected for participation in the main auction. Note that bidders are excluded from participating in the main auction only if more bidders decide to submit

[56] Then, the cost usually follows the distribution of the minimal cost among cartel members (see Baldwin, Marshall and Richard, 1997; Graham and Marshall, 1987 or Bajari and Ye, 2003).

[57] Note that this assumption differs from the approach in the baseline model, where we assumed that costs are drawn at the bidder level. Sticking to this assumption here, under cost updating, would require us to take a stance on how new information is shared among cartel members as the auction progresses. We are not aware of previous research considering cartels in such a setting, and thus, there are no precedents on such an assumption. Therefore, we opt for a more general approach.

[58] Note that this is another difference from the baseline model set-up, where all bidders submit an opening bid, hence $A = N$, as there is no entry cost.

a bid in the main auction than is allowed by the preselection rule, hence, if $a > n$. Therefore, using $b_{j:a}$ to denote the j-th lowest bid among a submitted bids, bidder i is preselected if $b_i \leq b_{n:a}$. Hence, the preselected set of bidders is given by $P_n = \{i : b_i \leq b_{n:a}\}$, where $|P_n| \backslash n$ and $P_n \subseteq A$.[59] Proceeding to the main auction involves the payment of entry cost $K \geq 0$. Once in the main auction, bidders learn their actual cost c_i and the lowest opening bid $b_{1:a}$. Outcomes are determined based on an English descending auction with the opening bids as a starting value, as in the baseline model.

Moreover, we make the following distributional assumptions:

Assumption A.1. *The cost–signal pairs of each entity m are drawn from a joint cumulative distribution $G_m(c, s)$ such that:*

- *S_m follows an an independent cumulative distribution function $F_m(s)$ that is continuous on the bounded support $[\underline{s}, \bar{s}]$.*
- *Conditional on signal realization s, costs C_m are drawn from a conditional cumulative distribution function $G_m(c|s)$, which is continuous on the support $[\underline{c}, \bar{c}]$ $\forall s$.*
- *The conditional distribution of C_m is stochastically ordered in S_m: $s' \geq s$ implies $G_m(c|s') \leq G_m(c|s)$.*

Assumption A.1 ensures that all (conditional) distributions are continuous on a bounded support and that a higher signal implies first-order stochastic dominance of the conditional cost of procuring the good.

A.6.2 Competition

In the case of competition, we assume that $|I_m| = 1$ $\forall m$, such that each bidder acts independently and maximizes its own profit. Moreover, the distributions are symmetric, i.e., $G_m(c, s) = G(c, s)$ $\forall m$.

As in the simple model, we focus on symmetric equilibria of the preselection-stage game, where firms follow a symmetric bid function $\beta : [\underline{s}, \bar{s}] \rightarrow [\underline{c}, r]$. Moreover, denote the c.d.f. of the n-th lowest signal $\tilde{s}$ among $N - 1$ signals by $F_{n:N-1}(\tilde{s})$ and the c.d.f. of the lowest cost among the preselected bidders by $H(\cdot|\tilde{s})$.[60]

With the above notation, a firm facing $N - 1$ symmetric potential rivals, who bid according to a strictly increasing bid function $\beta(s)$ in the preselection stage, solves the

[59] If multiple bidders submit a bid of value $b_{n:a}$, bidders are preselected at random to ensure that exactly n are allowed to proceed. Note that this is a boundary case that does not happen in equilibrium if $n < N$, as we see later.

[60] Effectively, the equivalent equations in the simple model result when we assume $S_i = C_i$.

following maximization problem:

$$\max_b \int_{\beta^{-1}(b)}^{\bar{s}} \left\{ \int_{\underline{c}}^{\bar{c}} \left[\int_{c}^{\bar{c}} (\min\{b, x\} - c) dH(x|\tilde{s}) \right] dG(c|s) - K \right\} dF_{n:N-1}(\tilde{s}) \tag{A.1}$$

Equation (A.1) is very similar to Equation (1), with two important differences. First, bidders face an entry cost K upon entering the main auction. Second, bidders face uncertainty about their own cost even conditional on their first-stage signal. This also implies that a bidder may win the auction despite not being the bidder with the lowest opening bid.

Using integration by parts and changing of the order of integration, we can rewrite the maximization problem as:

$$\max_b \int_{\beta^{-1}(b)}^{\bar{s}} \left\{ \int_{\underline{c}}^{\bar{c}} G(c|s)(1 - H(c|\tilde{s}))dc - \int_{b}^{\bar{c}} \int_{c}^{\bar{c}} G(x|s)h(x|\tilde{s})dxdc - K \right\} dF_{n:N-1}(\tilde{s}) \tag{A.2}$$

Equation (A.2) shows that expected profits can be decomposed into two parts: The first part is the expected value of participating in the main auction if opening bids are not binding. The second part represents the effective reduction in the value of winning due to the opening bid and hence can be viewed as the price for entry into the main auction.

Assumption A.2. *Denote* $\int_{\underline{c}}^{\bar{c}} G(c|s)(1 - H(c|s))dc := \Omega(s)$*:*

(a) $\Omega'(s) < 0$

(b) $\Omega(\bar{s}) = K$

Assumption A.2(a) implies that the expected value of participation in the main auction when a bidder has the n-th lowest signal is decreasing in its own signal. While the assumption is not guaranteed to be satisfied for arbitrary distributions, Ye (2007) establish that it is necessary for some first-stage auction formats that he considers, and thus, it is common in the literature. Assumption A.2(b) ensures that under preselection rule $n < N$, it is optimal for all potential bidders to submit an opening bid, including the bidder with the highest signal, i.e., $a = N$. Note that in the two-stage auction literature, this assumption is replaced by the assumption that the procurement agency fully subsidizes entry such that all bidders still prefer to participate in the auction.[61] We prefer not to make such an assumption, as such an arrangement is rarely seen in practice and does not match our empirical application.

The maximization problem as stated in Equation (A.2) makes the parallels between the two-stage auction that we consider and the auction formats previously considered

[61] See Bhattacharya et al. (2014); Sweeting and Bhattacharya (2015).

in the literature particularly salient. In particular, the most popular specification for the first stage is an all-pay auction, where each bidder pays what it bids but only the n bidders with the highest bids are allowed to proceed.[62] Hence, the price for entry is simply the first-stage bid. In our setting, the opening bid reduces the prices that can be achieved in the main auction, and this reduction effectively represents the price for entry. Hence, in our setting, the price for entry is not paid directly but *implied by the opening bid.*

Proposition A.1. *Consider the competitive setting under preselection rule $n < N$:*

(i) When the first stage involves opening bids and Assumption A.2 is satisfied, there exists a unique and strictly increasing equilibrium bid function $\beta(s)$.

(ii) The equilibrium when the first stage involves opening bids and the corresponding equilibrium with an all-pay auction in the first stage à la Ye (2007) result in the same procurement savings.

Proof. (i) Consider the maximization problem as stated in A.2, and suppose that rivals follow a symmetric bid function β. For β to be an equilibrium bid function, the following condition has to hold:

$$-\left\{\int_{\underline{c}}^{\bar{c}} G(c|s)(1-H(c|s))dc - K\right\} f_{n:N-1}(s)$$
$$+\left\{\int_{\beta(s)}^{\bar{c}}\int_{c}^{\bar{c}} G(x|s)h(x|s)dxdc\right\} f_{n:N-1}(s) + \beta'(s)\int_{s}^{\bar{s}}\int_{\beta(s)}^{\bar{c}} G(x|s)h(x|\tilde{s})dx f_{n:N-1}(\tilde{s})d\tilde{s} = 0$$

Rearranging to obtain $\beta'(s)$:

$$\beta'(s) = \frac{\Omega(s) - K - \int_{\beta(s)}^{\bar{c}}\int_{c}^{\bar{c}} G(x|s)h(x|s)dxdc}{\int_{s}^{\bar{s}}\int_{\beta(s)}^{\bar{c}} G(x|s)h(x|\tilde{s})dx f_{n:N-1}(\tilde{s})d\tilde{s}} f_{n:N-1}(s)$$

It is easy to see that the sign of the bid function's slope depends on the sign of $\Omega(s) - K - \int_{\beta(s)}^{\bar{c}}\int_{c}^{\bar{c}} G(x|s)h(x|s)dxdc$. Let us define an alternative bid function $\tilde{\beta}$ such that:

$$\tilde{\beta}: \qquad \Omega(s) - K = \int_{\tilde{\beta}(s)}^{\bar{c}}\int_{c}^{\bar{c}} G(x|s)h(x|s)dxdc := P(\tilde{\beta}(s), s)$$

From this definition, it follows directly that if $\beta(s) > \tilde{\beta}(s)$, we must have $\beta'(s) > 0$, and if $\beta(s) < \tilde{\beta}(s)$, we must have $\beta'(s) < 0$. Moreover, note that at $s = \bar{s}$, we have that $\beta(\bar{s}) = \tilde{\beta}(\bar{s})$.

[62] Other auctions considered are a uniform-price and discriminatory price auction for entry. Ye (2007) shows that these are all equivalent in terms of profits and revenues for the auctioneer.

Consequently, $\beta(s)$ can never cross $\tilde{\beta}(s)$ and has to reach the same value at $s = \bar{s}$. This means, as long as $\tilde{\beta}'(\bar{s}) > 0$, $\beta'(s) > 0 \; \forall s \in [\underline{s}, \bar{s}]$.

The slope of $\tilde{\beta}$ is given as follows:

$$\frac{\partial \Omega(s)}{\partial s} = \frac{\partial P(\tilde{\beta}(s), s)}{\partial \tilde{\beta}(s)} \frac{\partial \tilde{\beta}(s)}{\partial s} + \frac{\partial P(\tilde{\beta}(s), s)}{\partial s}$$
$$\Leftrightarrow \frac{\partial \tilde{\beta}(s)}{\partial s} = \left(\frac{\partial \Omega(s)}{\partial s} - \frac{\partial P(\tilde{\beta}(s), s)}{\partial s} \right) / \frac{\partial P(\tilde{\beta}(s), s)}{\partial \tilde{\beta}(s)}$$

It is obvious that the expected price is decreasing in the opening bid, hence, the denominator $\frac{\partial P(\tilde{\beta}(s),s)}{\partial \tilde{\beta}(s)} < 0$, but the sign of $\frac{\partial \Omega(s)}{\partial s} - \frac{\partial P(\tilde{\beta}(s),s)}{\partial s}$ is not clear in general. By Assumption A.2(b), $\Omega(\bar{s}) - K = 0$, hence, $\tilde{\beta}(\bar{s}) = \bar{c}$ and $\frac{\partial P(\tilde{\beta}(s),s)}{\partial s}_{|s=\bar{s}} = 0$. As $\Omega'(s) < 0$ (by Assumption A.2(a)), it follows that $\tilde{\beta}'(\bar{s}) > 0$, which concludes that $\beta'(s) > 0$ $\forall s \in [\underline{s}, \bar{s}]$.

(ii) Formally, with an all-pay auction as the preselection stage, the equilibrium bid function π has to solve for all s:

$$\pi(s) = \arg\max_{p} \int_{\pi^{-1}(p)}^{\bar{s}} \left\{ \int_{\underline{c}}^{\bar{c}} G(c|s)(1 - H(c|\tilde{s}))dc - K \right\} dF_{n:N-1}(\tilde{s}) - p \tag{A.3}$$

There, bids are simply the price paid for entry. Note that in contrast to our setting, the price paid for entry is increasing in the first-stage bid. From the first-order conditions to Equations (A.2) and (A.3), we obtain:

$$\begin{aligned} -\pi'(s) = & \int_{\beta(s)}^{\bar{c}} \int_{c}^{\bar{c}} G(x|s)h(x|s)dxdc f_{n:N-1}(s) + \\ & \beta'(s) \int_{s}^{\bar{s}} \int_{\beta(s)}^{\bar{c}} G(x|s)h(x|\tilde{s})dx f_{n:N-1}(\tilde{s})d\tilde{s} := P(s; \beta) \end{aligned}$$

The equivalence of the expected price paid for entry then directly follows from the boundary condition $\pi(\bar{s}) = 0$.

Due to the same expected price paid for entry, the expected profits are the same. Moreover, since both auctions result in the same winner of the tender, the procurement agent's surplus is also the same. □

The revenue equivalence with respect to previously considered two-stage auctions implies that the results from this literature translate to our setting as well. Bhattacharya et al. (2014) and Sweeting and Bhattacharya (2015) show that two-stage auctions may increase expected revenues over those in one-stage auctions with endogenous entry, in particular when the first-stage cost signal is relatively precise. In addition, the authors make two crucial assumptions. The procurement agent fully subsidizes entry and is able to choose the preselection rule optimally based on the parameters of the data generating process. In practice, both of these assumption are rarely met. As entry costs are not necessarily pecuniary, bidders are rarely reimbursed for the time and effort that it takes to prepare bids and participate in the bidding process. Moreover, even if we abstract from the fact that procurement agents may not be very well informed about the underlying parameters, auction rules do usually not vary on a case-by-case basis, in particular when an electronic platform is used. This may result in nonoptimal preselection rules, which limits the gains that can be attained from them.

To conclude, the two-stage auction with opening bids in the first stage is outcome equivalent to the conventional two-stage auction formats analyzed in the literature. Hence, the comparison of preselection rule $n < N$ to the no-preselection case is equivalent to the comparison already done in the literature if n is chosen optimally.

A.6.3 Collusion

We now allow for the existence of the cartel and assume that it has exactly the appropriate size to exploit the preselection rule, hence, $\exists k : |I_k| = n$. While we still assume that for competitive bidders $G_m(c,s) = G(c,s), \forall m : |I_m| = 1$, we allow the signal and cost of the cartel entity to be distributed differently, i.e., $G_k(c,s) \neq G(c,s)$.

Since competitive firms are again ex ante symmetric, we assume that they follow a common strictly increasing bid function $\beta : [\underline{s}, \bar{s}] \to [\underline{c}, r]$.

Proposition A.2. *Under preselection rule $n < N$, suppose that there exists a cartel of size $|I_k| = n$. There exists an entry cost threshold $\tilde{K}$ such that if $K < \tilde{K}$, in any equilibrium where competitive bidders follow a strictly increasing bid function β, the cartel bid policy $(b_j) : j \in I_k$ is such that all n cartel bids are equal, i.e., $b_j = \beta_k(s_k)$, $j \in I_k$.*

Proof. First, suppose that $n = 2$. As there are sufficiently many bidders under the cartel's control to kick out all competitive rivals from the main auction, its profit maximization is given by:

$$\max_{b_j, j \in I_k} \int_{\beta^{-1}(b_k)}^{\bar{s}} \left\{ \int_{\underline{c}}^{\bar{c}} \left[\int_{\underline{c}}^{\beta^{-1}(b_I)} \int_{c}^{\bar{c}} (\min\{b_k, x\} - c) dG(x|s_1) - KdF(s_1|\tilde{s}) \right.\right.$$
$$\left.\left. + \int_{\beta^{-1}(b_I)}^{\tilde{s}} (b_k - c - 2) KdF(s_1|\tilde{s}) \right] dG_k(c|s_k) \right\} dF_{n:N-n}(\tilde{s})$$

For close bidding to be optimal, the FOC of the cartel w.r.t. b_I has to be weakly negative at the optimal $b_k = \beta_k(s_k)$. Hence, the condition is:

$$K < \underbrace{f(\beta^{-1}(b_I)|\tilde{s}) \int_{\underline{c}}^{\bar{c}} \left[\int_{c}^{\bar{c}} (\min\{\beta_k(s_k), x\} - c) dG(x|\beta^{-1}(b_I)) - (\beta_k(s_k) - c) \right] dG_k(c|s_k)}_{:=\tilde{K}}$$

In equilibrium, $\beta_k(s_k) \geq \mathbb{E}[c|s_k]$ has to hold; otherwise, the cartel would make losses with certainty. Hence, $\tilde{K} \geq 0$. The argument for $n > 2$ follows a similar logic. □

The logic of the argument is very similar to that for the simple model without cost updating, but now cartel bidders have to incur an entry cost when allowed to proceed to the main auction. If that entry cost is not too large, it is again optimal for the cartel to ensure that n cartel members participate in the preselection stage and submit bids that are close to each other. Note that depending on the interpretation of the entry cost, it may be unclear in reality whether all proceeding cartel bidders have to incur it. If we believe that entry costs reflect the (nonpecuniary) cost of bid preparation and active participation in the main auction, it may well be reasonable to assume that cartel bidders that are not "serious" do not incur those costs, which makes close bidding even more profitable. Again, as before, without preselection, there is no benefit from joint participation of cartel members anymore.

B Testing Competition

Probability of close bidding under competition Suppose N bidders randomly draw a bid from some symmetric distribution: $b_i \sim F^\gamma$, where $b_i \in [0,1]$ and γ indicates the auction group. The n-th lowest bid is denoted by B_n. Define $T_{k,n,N}$ as the distance between the n-th and the $(n+k-1)$-th lowest bids among N bids. Hence

$$T_{k,n,N} = B_{n+k-1} - B_n \text{ where } n + k - 1 \leq N.$$

The probability that $T_{k,n,N} \leq t$ is given by (we have to take care a little because the support is bounded!)

$$Pr(T_{k,n,N} \leq t|\gamma) = \int_0^{1-t} Pr(T_{k,n,N} \leq t|B_n = x, \gamma) f_n^\gamma(x)dx + \int_{1-t}^{1} f_n^\gamma(x)dx$$

where $f_n^\gamma(x)$ is the n-th order statistic given by

$$f_n^\gamma(x) = \frac{N!}{n-1!N-n!} f^\gamma(x) F^\gamma(x)^{n-1} (1 - F^\gamma(x))^{N-n}.$$

$Pr(T_{k,n,N} \leq t|B_n = x, \gamma)$ is equal to the c.d.f. of the $k-1$-th order statistic among

$N - n$ i.i.d. random variables with truncated distribution:

$$Pr(T_{k,n,N} \leq t | B_n = x, \gamma) = \sum_{j=k-1}^{N-n} \frac{N-n!}{j!(N-n-j!)} \left(\frac{F^{\gamma}(x+t) - F^{\gamma}(x)}{1 - F^{\gamma}(x)} \right)^{j} \left(\frac{1 - F^{\gamma}(x+t)}{1 - F^{\gamma}(x)} \right)^{N-n-j}$$

Combining those two expressions above, we get $Pr(T_{k,n,N} \leq t|\gamma)$. However, we are not done yet, as we are interested in the distance of *any* k consecutive bids, not only the n-th and the $n+k-1$-th, being smaller than t. Now, if $N > k$, then there are multiple sequences of k bids which might be close. Note however, that events $T_{k,n,N}$ and $T_{k,n+1,N}$ are not necessarily mutually exclusive, so we have to correct for overlaps (i.e., more than three bids being in a given interval). The final expression for the probability of close bidding, i.e. that the distance of at least three bids is smaller than 0.001, in an auction with N total bidders is therefore:

$$\rho_N^{\gamma} = \sum_{n=1}^{N-2} Pr(T_{3,n,N} \leq 0.001|\gamma) - \sum_{n=1}^{N-3} Pr(T_{4,n,N} \leq 0.001|\gamma)$$

Hypothesis testing H_0 is that costs are drawn independently, and bidders are following a strictly increasing competitive bid function, such that bids are i.i.d realization from distribution F^{γ}. Suppose we observe close bidding among at least three bidders in m out of M auctions. We reject the null hypothesis if the probability of observing the occurrence of close bidding in at least m auctions is below 1%.

The p value is:

$$P(\text{reject } H_0 | H_0, \gamma) = \sum_{k=m}^{M} \frac{M!}{m!(M-m)!} (\rho_N^{\gamma})^m (1 - \rho_N^{\gamma})^{M-m}$$

Fitting the bid distribution Since normalized bids are bounded between 0 and 1, we chose a beta distribution to fit to the bid distribution. To this end, for each CPV category on the 3 digits level, we assume that $b_i^{\gamma} \sim Beta(a^{\gamma}, b^{\gamma})$. Moreover, we chose a beta regression parameterization:

$$\mu(X_i^{\gamma}, \beta_1^{\gamma}) = \frac{a^{\gamma}}{a^{\gamma} + b^{\gamma}} = \frac{\exp(X_i^{\gamma} \beta_1^{\gamma})}{1 + \exp(X_i^{\gamma} \beta_1^{\gamma})}$$
$$\phi(\beta_2^{\gamma}) = a^{\gamma} + b^{\gamma} = \exp(\beta_2^{\gamma})$$

To allow for bid distributions to be different depending on the number of bidders participating, we chose X_i^{γ} to be a set of dummies indicating whether at least four, five, six or seven bidders participate in the auction (in addition to a constant). Using this parameterization, Table B.1 shows the aggregate observed and counterfactual close bidding probability for each CPV category. The last column (# p values < 0.01) reports how many p values out of the total number of number-of-bidder groups in each CPV category are below 0.01.

Table B.1: Counterfactual close bidding probabilities and p values

CPV Category (3-digit)	# auctions	Share w. close bidding (%)	Counterfactual probability (%)	# p values < 0.01
Office machinery	11998	17.99	1.36	14/15
Computer equipment and supplies	6339	24.69	2.42	15/15
Furniture	3150	27.11	0.50	15/18
Medical equipments	2168	24.49	1.90	7/9
Personal care products	1508	15.78	0.30	10/11
Miscellaneous transport equipment	1417	16.65	0.32	8/11
Cleaning and polishing products	1210	20.50	0.81	11/12
Domestic appliances	1127	14.82	0.58	9/10
Parts and accessories for vehicles	1069	3.84	0.14	5/7
Furnishing	883	19.37	0.84	10/10
Construction materials	632	31.49	0.58	9/10
Pharmaceutical products	624	24.20	4.23	3/5
Textile articles	494	39.07	0.17	11/11
Lighting equipment and electric lamps	466	15.02	0.13	6/10
Optical instruments	424	30.19	5.04	9/10
Animal products	419	4.30	0.62	2/9
Accumulators, cells and batteries	386	20.98	0.22	5/10
Occupational clothing	383	29.50	1.62	9/11
Motor vehicles	368	36.41	8.11	4/5
Receivers and recorders	352	24.43	2.85	5/8
Miscellaneous equipment	342	35.96	1.15	7/8
Tools, locks, keys, etc.	306	16.99	0.15	5/9
Instruments for checking physical char.	299	8.70	0.41	3/7
Miscellaneous machinery	276	19.57	0.65	3/7
Harvesting machinery	238	39.50	9.74	5/7
Basic inorganic and organic chemicals	224	4.46	0.45	2/5
Paints, varnishes and mastics	221	10.86	0.95	3/5
Printed books, brochures and leaflets	209	12.44	1.93	3/5
Machinery for mechanical power	202	26.73	1.56	6/10
Miscellaneous fabricated products	194	12.89	0.28	3/8
Stamps, cheque forms, banknotes, etc.	192	14.06	0.13	3/8
Measuring instruments	187	13.37	0.07	3/8
Emergency and security equipment	183	7.10	0.82	2/8
Miscellaneous food products	182	17.58	1.57	3/6
Document creation, drawing, imaging, etc.	178	30.34	2.76	5/8
Dairy products	171	7.02	1.41	1/6
Leather, textile, rubber and plastic waste	164	43.90	0.59	8/8

Footwear	154	31.82	1.27	5/8
Networks	152	24.34	1.36	5/7
Telecommunications equipment	151	10.60	1.05	2/6
Sports goods and equipment	146	32.19	0.90	5/6
Fertilisers and nitrogen compounds	142	33.10	3.76	5/5
Machine tools	139	9.35	0.70	2/8
Electric motors, generators, transformers	136	8.09	0.90	1/8
Information systems and servers	136	42.65	9.15	5/10
Machinery for textile production	135	46.67	2.47	5/7
Cable, wire and related products	124	8.87	0.44	2/6
Tanks, boilers, etc.	119	23.53	2.17	3/6
Software package utilities	119	31.93	0.31	3/9
Fine and various chemical products	116	12.93	0.63	2/5
Cooling and ventilation equipment	116	32.76	0.42	4/8
Tractors	110	22.73	3.81	3/5
Structural products	105	41.90	2.70	4/8
Fruit, vegetables and related products	89	3.37	0.80	0/5
Electrical equipment and apparatus	89	8.99	0.48	1/8
Checking and testing apparatus	88	11.36	1.11	1/5
Special clothing and accessories	86	33.72	0.31	4/7
Agricultural and forestry machinery	84	30.95	0.70	4/6
Garments	71	32.39	0.99	3/6
Textile fabrics and related items	70	54.29	1.38	6/6
Networking, Internet and intranet software	65	15.38	4.03	2/6
Transmission apparatus for radiot & TV	57	0.00	1.43	0/4
Printed stationary	56	14.29	0.10	1/6
Luggage, saddlery, sacks and bags	55	27.27	2.82	2/5
Construction machinery and equipment	52	48.08	2.68	3/5
Lifting and handling equipment and parts	51	15.69	0.80	2/5

C Cartel Conviction by the Antimonopoly Office of the Slovak Republic

While the lion's share of cases of cartel behavior originate in public procurement, only recently was a cartel convicted for bid-rigging in public procurement auctions on the EKS. On June 6, 2017, a case was opened against 6 firms suspected of coordinating bids from January 2015 to April 2017 on the EKS platform in public procurement auctions involving delivery of furniture, medical equipment, clothes and textile. In December 2019, the AMO SR imposed a fine of EUR 1,181,441 for this collusive behavior, but as the verdict was not yet legally binding, the details of the case remained scant, and the identities of bidders were unknown. Finally, in May 2021, the case was concluded with a confirmation of the verdict, and the authorities released the firms' names and auctions affected.

Out of the 276 auctions analyzed by the antitrust authority, we can locate 274 in our dataset. Table C.1 summarizes these auctions and splits them into those conducted before and after the reform. As in our previous, more general analysis, a shift in the decomposition of savings generated in the preselection stage in comparison to that in the main auction can be observed. However, the number of postreform auctions investigated is very low, so any comparison should be made with caution. Interestingly, in all postreform investigated auctions, a cartel member won the contract, and the number of cartel members participating substantially decreased.

Table C.1: Investigated auctions

	(1) All		(2) Before the reform		(3) After the reform	
	Mean	SD	Mean	SD	Mean	SD
Savings	0.14	0.15	0.14	0.15	0.10	0.12
Preselection Savings	0.11	0.13	0.12	0.14	0.02	0.05
Reserve price (k EUR)	10.60	16.63	10.41	16.80	12.60	14.75
Winning bid (k EUR)	10.31	16.27	10.12	16.42	12.41	14.68
Preselection bidders	4.46	2.49	4.57	2.50	3.17	1.99
Main auction bidders	0.85	1.19	0.75	1.08	2.00	1.68
Main auction bids	11.24	32.98	9.58	29.07	29.39	59.32
Cartel bidders in preselection	2.35	0.88	2.46	0.84	1.17	0.39
Cartel winner	0.82	0.38	0.80	0.40	1.00	0.00
Observations	274		251		23	

Notes: The table summarizes auction-level variables for the 274 auctions in our dataset that were investigated by the antimonopoly authority.

Finally, we will focus on auctions that took place before the reform. Due to the investigation, we know which companies are cartel members. This gives us more confidence in decomposing the collusive auctions into cases where the cartel faces competition versus cases where it does not. Table C.2 shows that while the number of cartel bidders in auctions where rivals participated (Columns 2–4) is similar to the number where they did not (Column 1) , there is a stark difference in the average savings. The difference in savings is conducive to the conclusion that bidding in the main auction is much more aggressive, supported by the much larger numbers of bids and bidders. However, this is not the whole story, as the savings based on the preselection stage are already substantially higher. This suggests that cartels must also anticipate larger interest in an auction and therefore start with a more aggressive opening bid. The fact that the reserve price for these auctions is substantially higher corroborates this conclusion.

Table C.2 also sheds light on how outcomes change when the cartel is successful at excluding rivals. Clearly, when fewer than 3 cartel bidders participate, they are not able exclude any rivals, which is summarized in Column 4. Columns 2 and 3 both summarize cases where the cartel is large enough to exclude rivals, but it is only successful in Column 2. Most strikingly, when a cartel successfully excludes rivals, none of the three cartel members submit any further bids in the main auction. Moreover, the cartel seems more likely to be successful when the contract value is rather high.

Table C.2: Success and failure of exclusion

	(1) no rivals present		(2) rivals excluded		(3) rivals not excluded		(4) rivals present	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Savings	0.03	0.04	0.12	0.12	0.28	0.13	0.20	0.18
Preselection Savings	0.03	0.04	0.12	0.12	0.24	0.14	0.14	0.15
Reserve Price (k EUR)	7.53	6.66	12.14	22.35	10.24	15.44	11.92	18.36
Winning bid (k EUR)	7.31	6.61	11.90	22.24	9.83	14.60	11.55	17.58
Preselection bidders	2.53	0.77	5.67	2.32	6.02	2.50	4.66	2.54
Main auction bidders	0.19	0.54	0.05	0.37	1.57	1.15	1.66	1.06
Main auction bids	0.32	1.13	0.05	0.37	16.39	26.12	27.15	49.69
Cartel bidders in preselection	2.53	0.77	3.01	0.12	3.02	0.15	1.31	0.47
Cartel winner	1.00	0.00	1.00	0.00	0.27	0.45	0.72	0.45
Observations	73		73		44		61	

Notes: The table summarizes auction-level variables for the 251 investigated auctions run in the prereform period.

Shortly after the reform abolishing the preselection rule, the Antimonopoly Office of the Slovak Republic initiated investigations into a supposed cartel composed of six companies: ARTRA, ČECHOVO, JANOLI, JASTA Slovakia, Ing. Jaroslav Marinica – MARINI and PMB Slovakia. The allegation concerned coordination of bids in a way that exploited the preselection rule. The evidence was based on a detailed investigation of 276 electronic auctions.[63] The bid-rigging affected various procurement categories, namely, furniture, medical equipment, clothing, footwear and textile products.

An interesting observation is that the cartel members were highly asymmetric in size, with ARTRA being the largest in revenue terms by far. However, this did not reflect the involvement in cartel activity. In our dataset, we can track 274 out of the 276 auctions investigated. In all of them, at least one cartel member participated. ARTRA participated in only 14 and won only a single auction. On the other hand, the strong core of the cartel appears to have been JANOLI, ČECHOVO and MARINI. JANOLI participated in 181 auctions, 98 of which it won; ČECHOVO participated in 218, 94 of which it won. While both JANOLI and ČECHOVO have received their fair share of wins, MARINI mostly lost: It participated in 170 auctions but won only 17. This suggests that it was largely helping the others, while being compensated through side payments instead of a rotation scheme. JASTA played a similar role but participated less frequently (in 53 auctions), and PMB played only a minor role.[64]

Since the fines imposed by the antimonopoly authority were designed to be proportional to annual revenues, they stood in stark contrast to the gains from bid-rigging, at least when we focus on the 250 contracts in our dataset. While ARTRA won contracts with a total value of only EUR 6,194, its fine amounted to EUR 900’069. In contrast, the two most active members, JANOLI and ČECHOVO, won contracts worth EUR 1,055,131 and EUR 674,957 in those collusive auctions but were fined EUR 162,247 and EUR 8,621, respectively.[65]

[63] For further details, see `https://www.antimon.gov.sk/data/att/e1d/2171.64e3dd.pdf?csrt=3756949773301016497` on the first decision and `https://www.antimon.gov.sk/data/att/691/2170.cc3422.pdf?csrt=3756949773301016497` on the final decision.

[64] Among the 26 contracts not in our data, we could find 20 on the EKS website. All 20 were won by either ČECHOVO or JANOLI, even though 7 faced competition from noncartel rivals in the main auction. Unfortunately, we cannot observe all firms that participated in the preselection stage since they appear in the documentation only if they proceeded to the main auction.

[65] In the 274 auctions contained in our data and investigated by the antimonopoly authority, the contract values for the remaining cartel members were as follows: Marini EUR 470,042; JASTA, EUR 111,770; and PMB EUR 37,100. In contrast, their fines, in the same order, amounted to EUR 12,455, EUR 10,807 and EUR 50,236.

D Supplementary Figures and Tables

Figure D.1: Average reserve price and winning bid over time

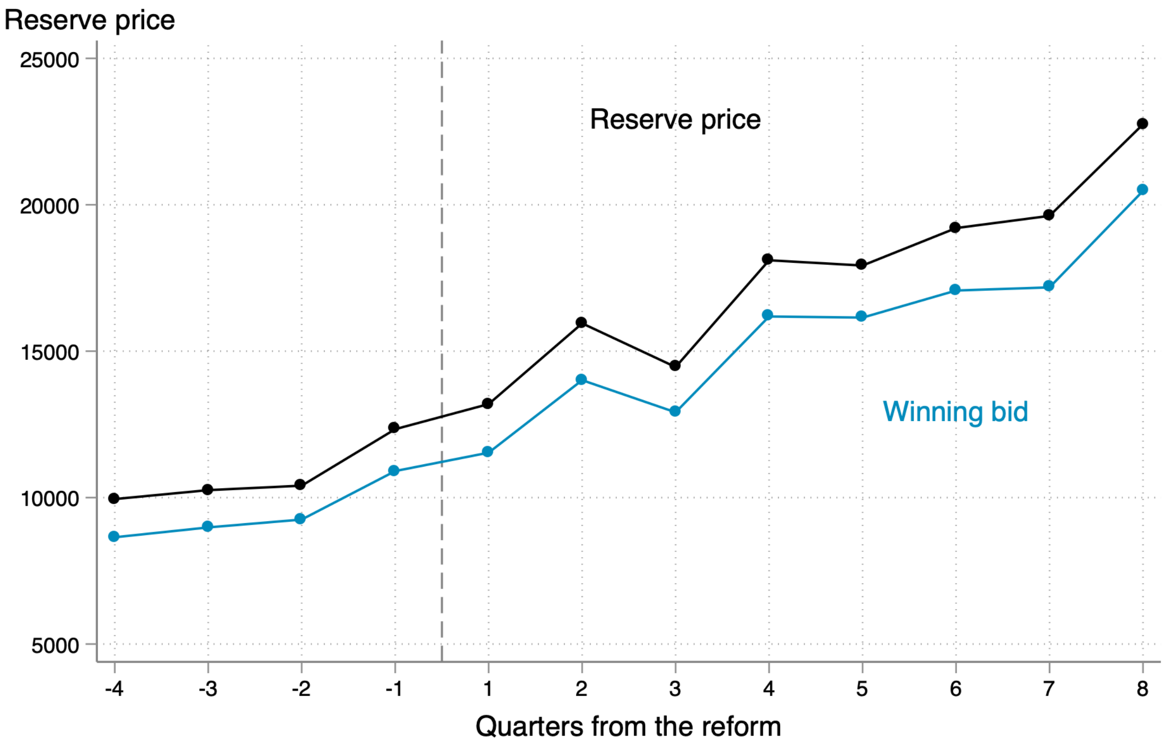
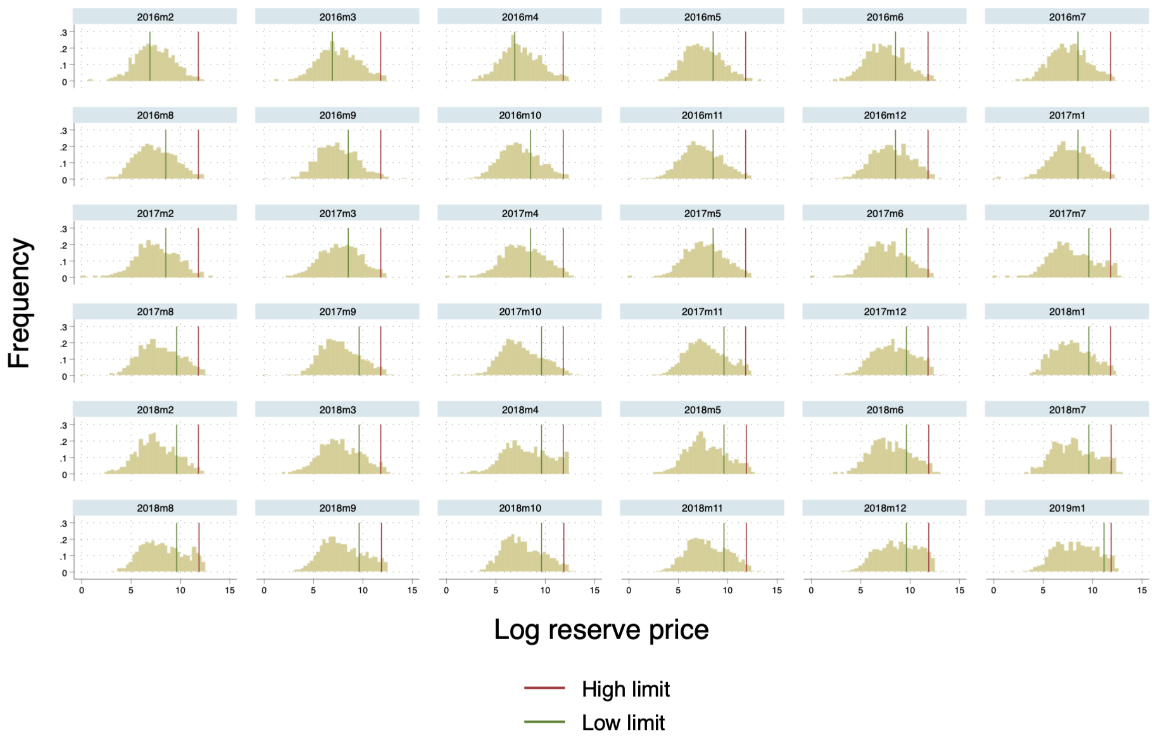


Figure D.2: Distributions of the reserve prices and the corresponding legal thresholds, by month



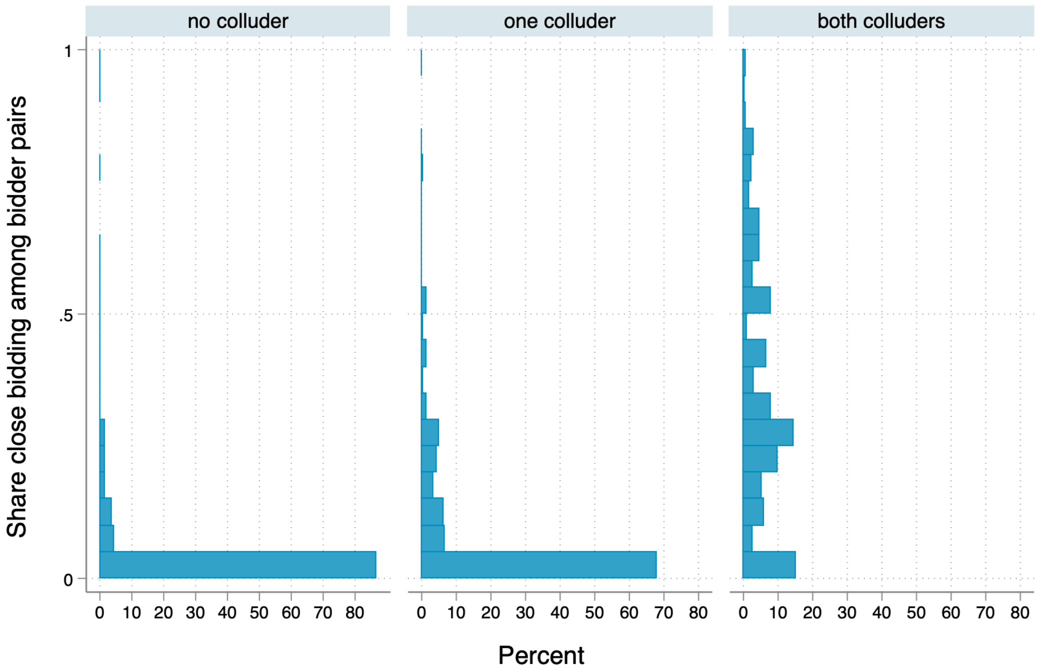
Notes: High limit corresponds to the definition of under-the-threshold contracts for which the use of EKS auctions was mandatory. Low limit corresponds to the definition of low value contracts, for which the use of EKS was optional.

Table D.1: Bidding in the main auction with preselection

	Competition in the Main Auction Stage:					
	Bidders	Bids	Add. savings	Bidders	Bids	Add. savings
(mean) vclose_auction	-0.29***	-3.60**	-0.02***	-0.26***	-1.64	-0.02***
	(0.03)	(1.36)	(0.00)	(0.04)	(2.02)	(0.00)
≥2 bidders	1.10***	16.33***	0.06***	1.06***	12.96***	0.06***
	(0.02)	(0.65)	(0.00)	(0.02)	(0.91)	(0.00)
≥3 bidders	0.67***	11.05***	0.02***	0.65***	11.47***	0.02***
	(0.02)	(1.10)	(0.00)	(0.03)	(1.36)	(0.00)
≥4 bidders	0.00	0.47	-0.01	0.06	3.28	-0.00
	(0.03)	(1.45)	(0.00)	(0.04)	(1.85)	(0.00)
≥5 bidders	0.05	-0.82	-0.02***	0.03	-1.45	-0.01***
	(0.03)	(1.40)	(0.00)	(0.04)	(1.97)	(0.00)
Constant	0.04	0.99	-0.01**	0.09	1.15	-0.01*
	(0.03)	(1.65)	(0.00)	(0.05)	(2.28)	(0.00)
Month FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
Procurer FE	yes	yes	yes	yes	yes	yes
CPV FE (2-digit)	no	no	no	yes	yes	yes
CPV FE (full)	0	0	0	0	0	0
Adj. R2	1.20	17.94	0.04	1.20	17.94	0.04
Avg. Outcome	18055.00	18055.00	18055.00	11123.00	11123.00	11123.00

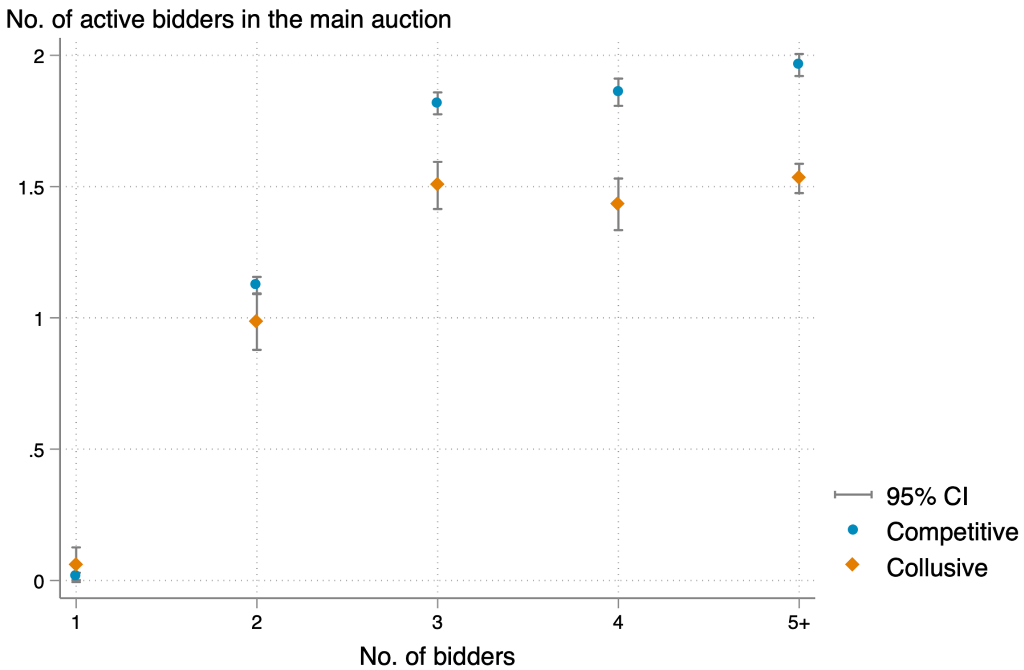
Notes: All specifications include the fixed effects indicated at the bottom of the table. Stage 1 and Stage 2 refer to the preselection stage and the main auction, respectively. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure D.3: Distribution of the share of close bidding among bidder pairs (unweighted)



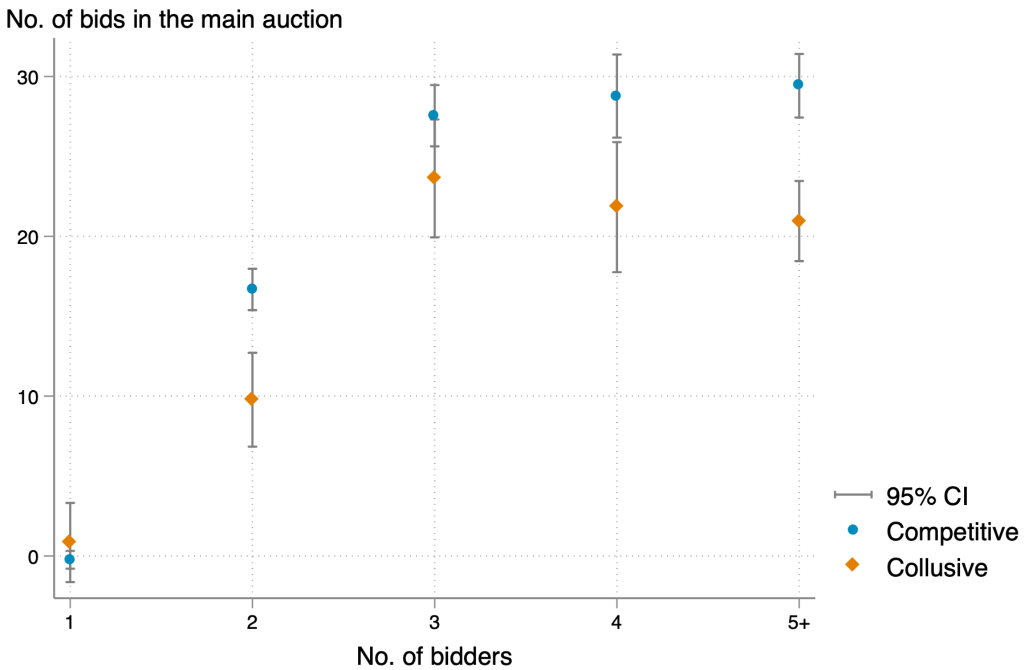
Notes: Close bidding is defined as the occurrence of three opening bids within a value range of 0.1% of each other relative to the reserve price. We consider the share of close bidding among prereform auctions in which a bidder pair participated.

Figure D.4: Heterogeneity of the collusion effect: Number of bidders



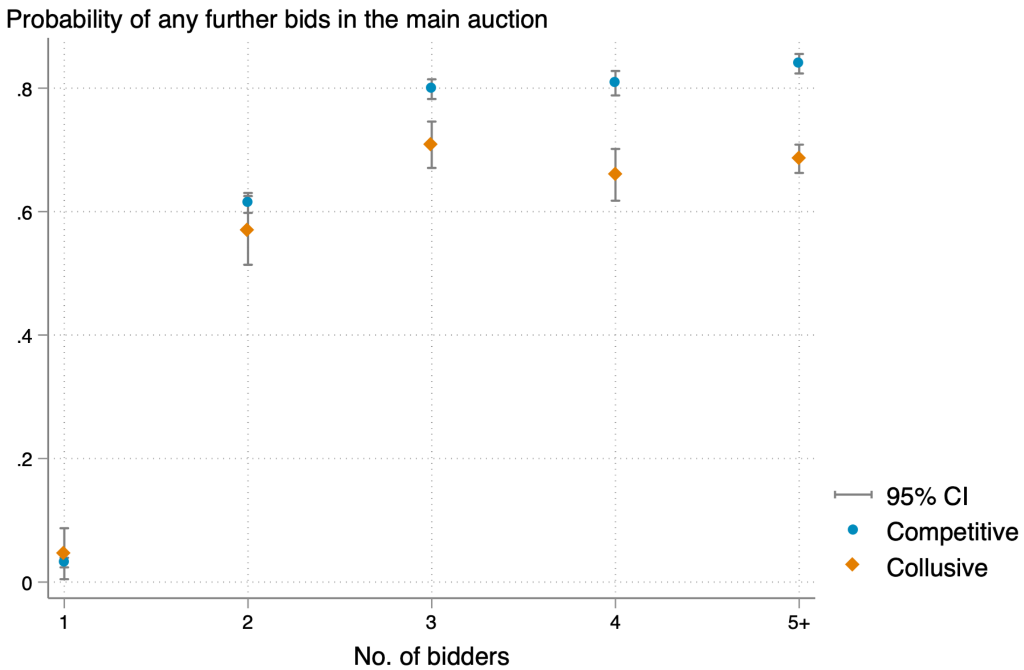
Notes: The graph plots estimates of number of active bidders in the main auction from a regression with full interactions between the number of bidders and an indicator for a potentially collusive auction, while controlling for a set of CPV-category, procurer, year–month fixed effects. The value 5+ on the x-axis captures auctions with 5 or more bidders.

Figure D.5: Heterogeneity in the collusion effect: Number of bids



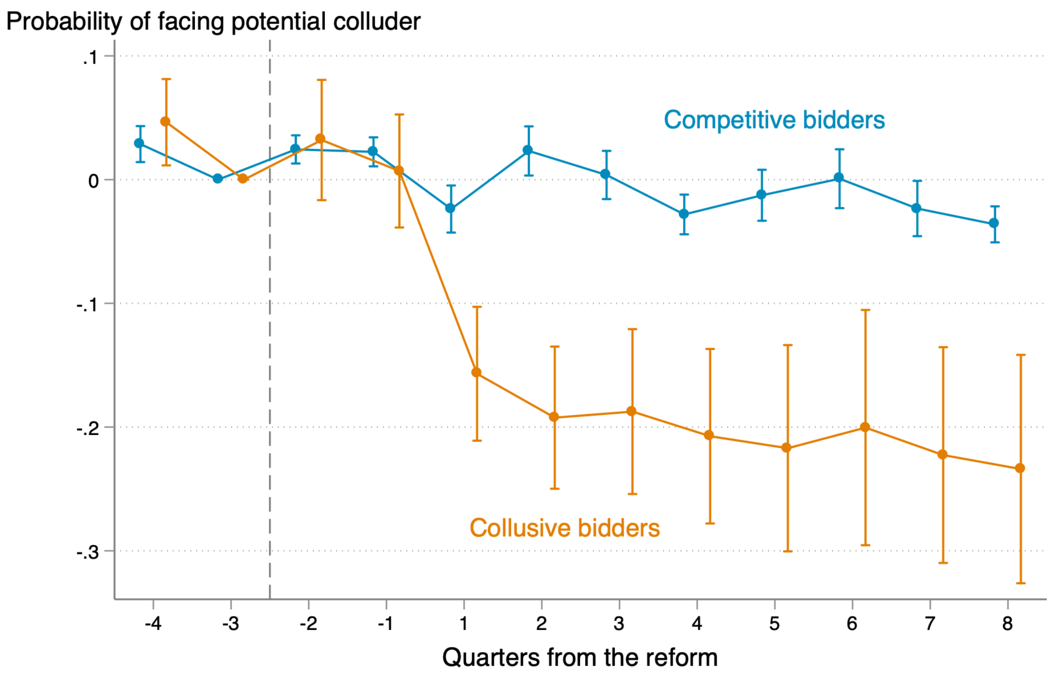
Notes: The graph plots estimates of number of bids in the main auction from a regression with full interactions between the number of bidders and an indicator for a potentially collusive auction and a set of CPV category, procurer, and year–month fixed effects. The value 5+ on the x-axis captures auctions with 5 or more bidders.

Figure D.6: Heterogeneity in the collusion effect: Any bids



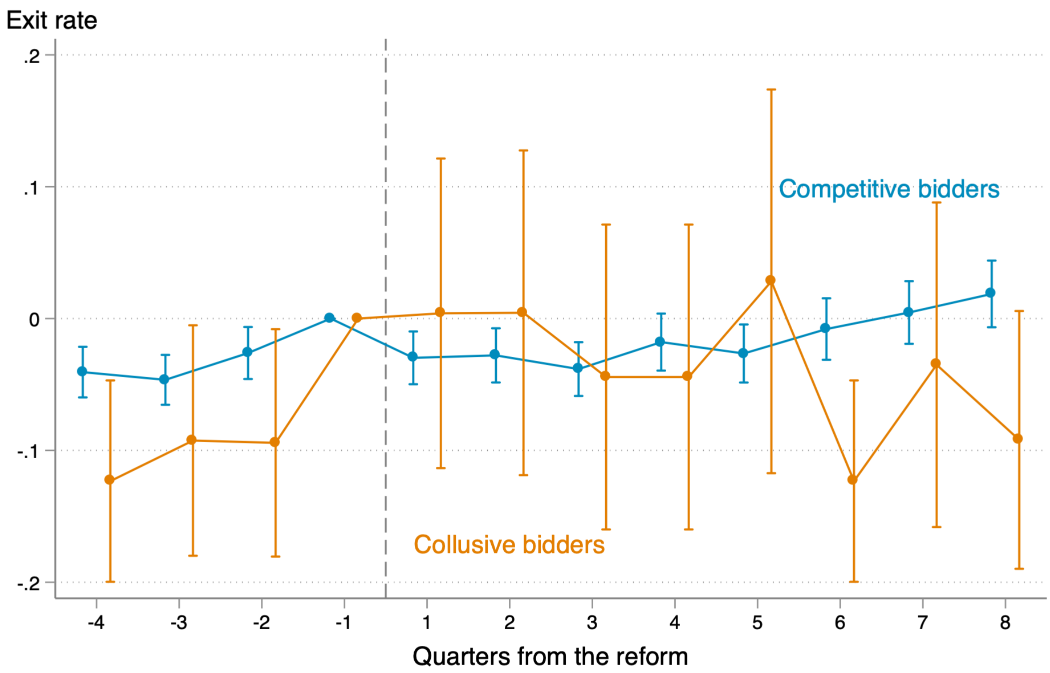
Notes: The graph plots estimates of the probability of no further bids in the main auction from a regression with full interactions between the number of bidders and an indicator for a potentially collusive auction and a set of CPV category, procurer, and year–month fixed effects. The value 5+ on the x-axis captures auctions with 5 or more bidders.

Figure D.7: Effect on the probability of facing a potential colluder in the preselection stage (Placebo)



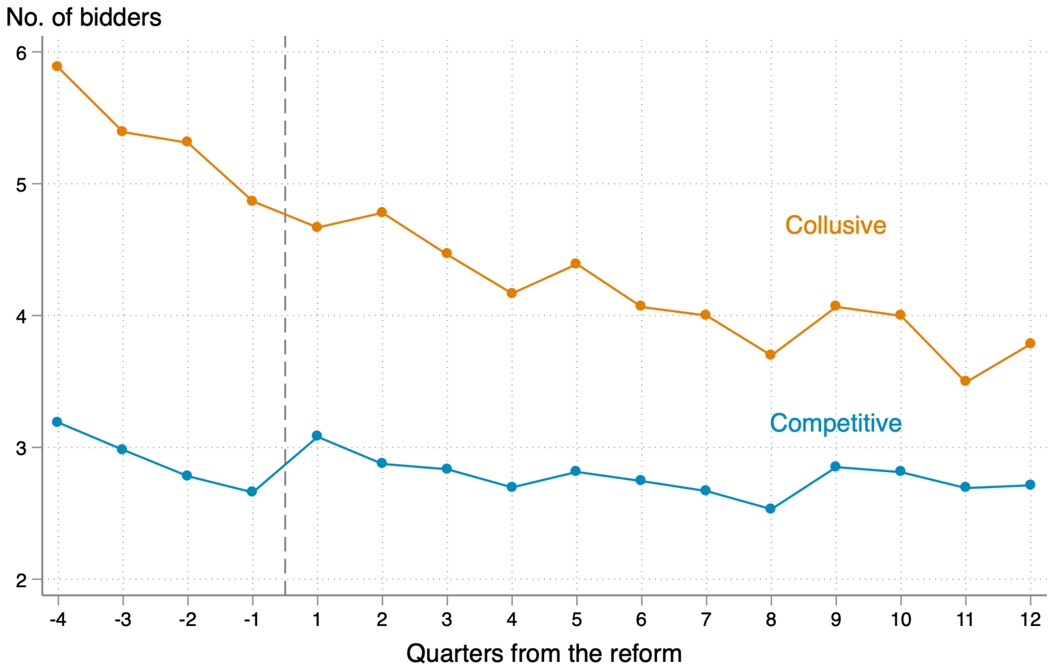
Notes: The graph plots event study coefficients from a regression of an indicator taking the value one if bidder faces a potential colluder the full set of quarter indicators and bidder, procurer, and CPV category fixed effects. The omitted category is three quarters before the reform and collusive bidders are only defined based on data before August 2016. The model is estimated separately for collusive and competitive bidders.

Figure D.8: Effect of the reform on the exit rate



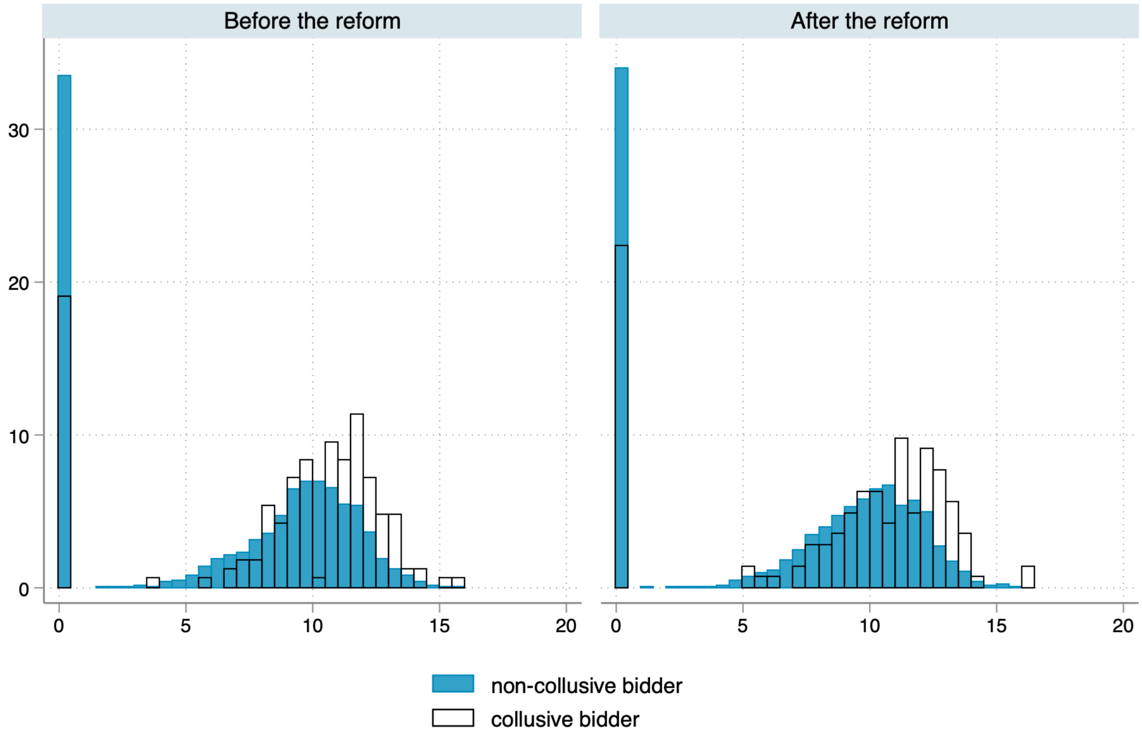
Notes: The graph plots event study coefficients from a regression of exit rates on the full set of quarter indicators. The omitted category is one quarter before the reform to show changes in the exit rate relative to the last prereform quarter. The model is estimated separately for collusive and competitive bidders.

Figure D.9: Effect of the reform on the number of bidders



Notes: The graph shows the average number of bidders by quarter separately for potentially collusive auctions and competitive auctions.

Figure D.10: Log revenue distribution on the EKS platform



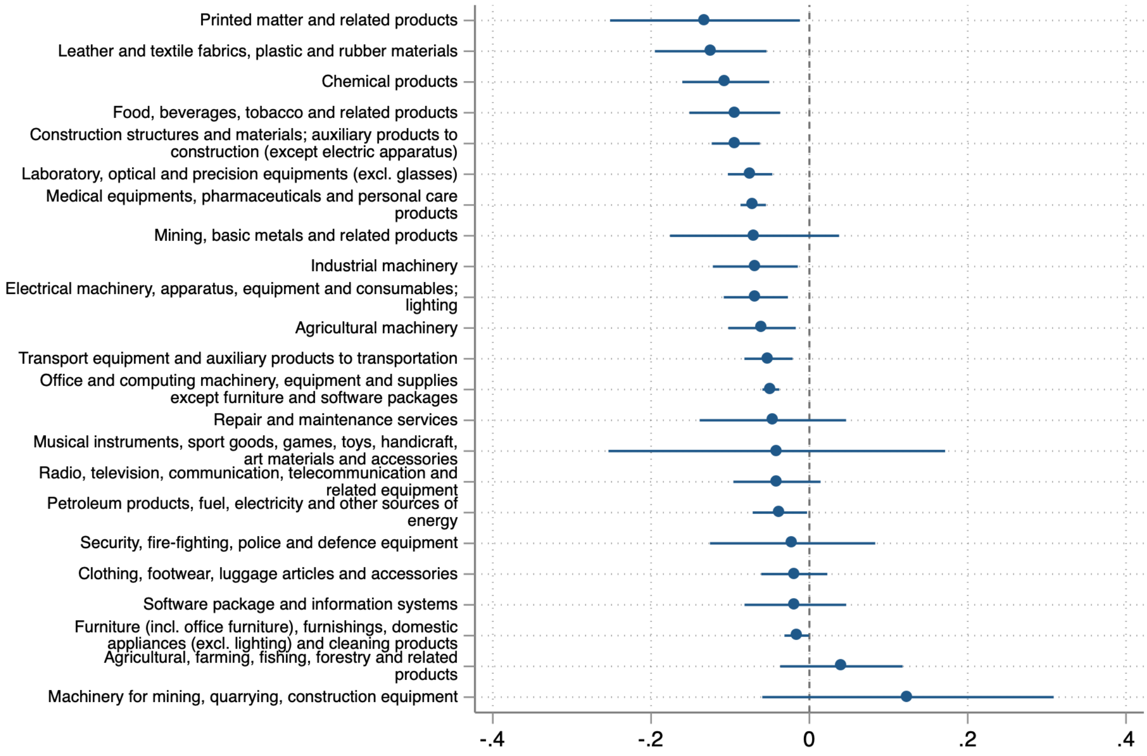
Notes: The graph plots the distribution of log revenues generated on the EKS platform for collusive and competitive bidders one year before (l.) and one year after the reform (r.).

Table D.2: Overall economic activity of bidders registered in the RFS

	(1) Full Sample		(2) Competitive Bidders		(3) Collusive Bidders		(4) (2) − (3)
	Mean	SD	Mean	SD	Mean	SD	Diff
Total Sales (million EUR)	11.4	92.4	12.0	95.5	3.6	11.6	8.4***
Total assets(million EUR)	8.1	99.7	8.5	103.1	3.0	8.2	5.4*
Profits (pre-tax) (k EUR)	566.3	9291.4	593.7	9601.3	166.4	686.2	427.3
# employees <5	0.35	0.48	0.34	0.47	0.41	0.49	-0.07
$5 \leq$ # employees <20	0.31	0.46	0.31	0.46	0.32	0.47	-0.01
$20 \leq$ # employees <100	0.34	0.47	0.34	0.47	0.31	0.46	0.04
$100 \leq$ # employees	0.06	0.23	0.06	0.24	0.04	0.19	0.02
Observations	2022		1891		131		

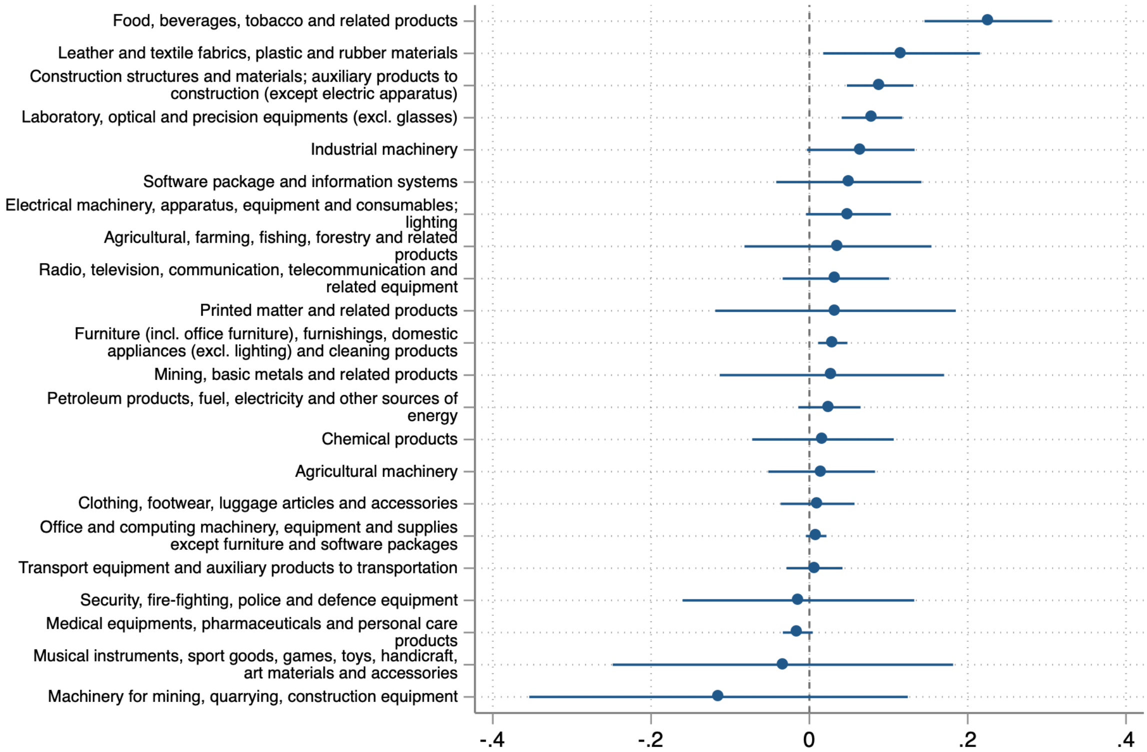
Notes: The table summarizes firm-level variables for the firms in our sample that were registered in the RFS in Slovakia. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure D.11: Savings gap before the reform by CPV category



Notes: The graph plots the coefficient and 95% confidence interval of *Collusive* in regression specification (4) run separately for each CPV category at the 2-digit level.

Figure D.12: Effect of the reform on collusive auctions by CPV category

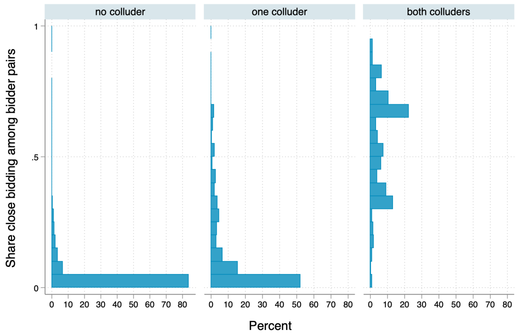


Notes: The graph plots the coefficient and 95% confidence interval of $Collusive \times Post$ in regression specification (4) run separately for each CPV category at the 2-digit level.

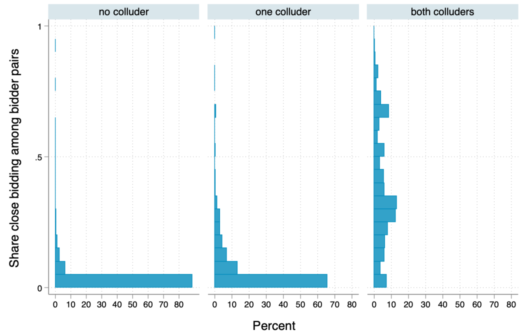
E Robustness

E.1 Close bidding among bidder pairs

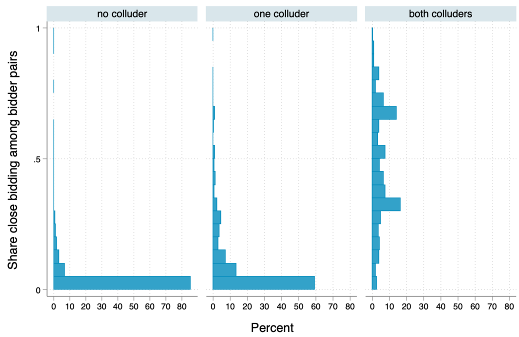
Figure E.1: Distribution of the share of close bidding among bidder pairs (weighted)



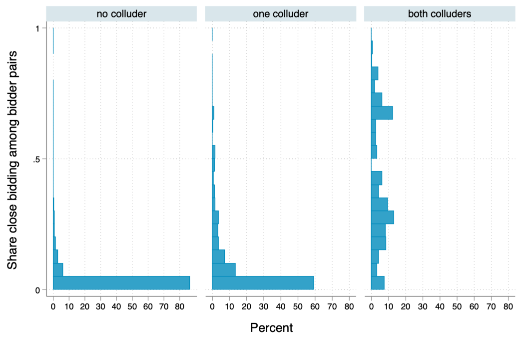
(a) 95th firm percentile



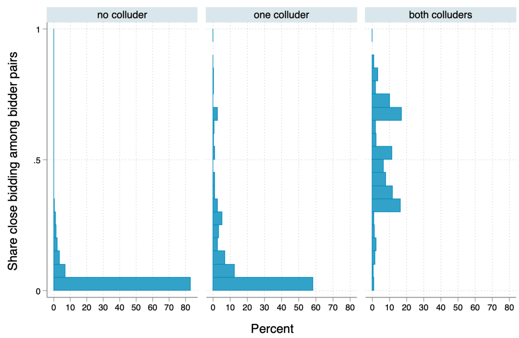
(b) 85th firm percentile



(c) Bid range of 0.05%



(d) Bid range of 0.5%



(e) 90th firm percentile and stable groups

Notes: We consider the share of close bidding in prereform auctions in which a bidder pair participated and weight by the number of these auctions.

E.2 Effect on Cartel Strategy

Table E.1: Effect of the reform on the probability of facing a cartel member in the preselection stage

	Add. criterion	Firm percentile		Bid range	
	(1)	(2)	(3)	(4)	(5)
	stable group	95th	85th	0.05 %	0.5 %
Post	0.008	0.037*	0.011	0.032*	0.039*
	(0.014)	(0.014)	(0.016)	(0.016)	(0.017)
Pot. Colluder × Post	-0.147**	-0.217***	-0.184***	-0.200***	-0.251**
	(0.054)	(0.063)	(0.033)	(0.042)	(0.079)
≥3 bidders	0.024***	0.021***	0.087***	0.050***	0.059***
	(0.005)	(0.005)	(0.012)	(0.006)	(0.013)
≥4 bidders	0.023***	0.027***	0.062***	0.046***	0.069***
	(0.003)	(0.003)	(0.005)	(0.004)	(0.019)
≥5 bidders	0.113***	0.124***	0.175***	0.144***	0.160***
	(0.008)	(0.008)	(0.007)	(0.008)	(0.011)
Constant	0.089***	0.099***	0.159***	0.112***	0.139***
	(0.011)	(0.012)	(0.016)	(0.012)	(0.014)
Bidder FE	yes	yes	yes	yes	yes
Month FE	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes
Procurer FE	yes	yes	yes	yes	yes
CPV Category FE (full)	yes	yes	yes	yes	yes
Adj. R2	0.48	0.47	0.48	0.47	0.44
Avg. Outcome	0.14	0.14	0.27	0.20	0.22
N	87004	87004	87004	87004	87004

Notes: Fixed effects included in the specifications are indicated at the bottom of the table. Standard errors in parentheses are clustered at the bidder level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

E.3 Effect on Savings

Table E.2: Effect of the reform on overall savings

	Add. criterion	Firm percentile		Bid range	
	(1)	(2)	(3)	(4)	(5)
	stable group	95th	85th	0.05 %	0.5 %
Post	-0.005	-0.005	-0.010	-0.006	-0.010
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Collusive	-0.024***	-0.029***	-0.039***	-0.032***	-0.046***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)
Collusive × Post	0.019***	0.021***	0.026***	0.019***	0.035***
	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)
≥2 bidders	0.083***	0.083***	0.084***	0.084***	0.084***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
≥3 bidders	0.073***	0.073***	0.075***	0.074***	0.075***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
≥4 bidders	0.040***	0.040***	0.041***	0.041***	0.041***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
≥5 bidders	0.073***	0.074***	0.076***	0.075***	0.077***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Constant	0.015*	0.015*	0.017**	0.016**	0.017**
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Month FE	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes
Procurer FE	yes	yes	yes	yes	yes
CPV Category FE (full)	yes	yes	yes	yes	yes
Adj. R2	0.45	0.45	0.45	0.45	0.45
Avg. Outcome	0.14	0.14	0.14	0.14	0.14
N	30469	30469	30469	30469	30469

Notes: Fixed effects included in the specifications are indicated at the bottom of the table. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

F Supplementary Information

F.1 The Competition Authority and Legal Framework

The Antimonopoly Office of the Slovak Republic (AMO SR) is the national competition authority in Slovakia. Analogously to similar authorities in other EU member states, its role is to oversee mergers and prevent prohibited practices such as abuses of a dominant market position or formation of cartels.

The practice of bid-rigging in public procurement is considered by the AMO SR to be one of the most serious forms of cartel agreements, being explicitly prohibited by Act No. 136/2001 Coll. on Protection of Competition. The AMO SR can punish such a breach by imposing a fine of up to 10% of a firm's turnover. A taxonomy of collusion practices in procurement, together with an explanation of the harmful effects of bid-rigging, is available on the website of the competition authority (AMO SR, n.d.), highlighting that the national competition authority is well aware of potential bid-rigging in procurement markets. Moreover, there is a reward scheme in place, offering 1% of the imposed fine as a reward (capped at EUR 100,000) for cartel-relevant information and evidence such as e-mails, written documents or other information that would lead to a raid. In addition, the reward scheme is supported by a leniency program that allows a reduction in the fine for the first cartel member that provides decisive evidence on the existence of the cartel and thus implicates other cartel members. Alternative instruments available to the AMO SR instead of fines are "commitments," which obligate an infringing entity to remove the identified anticompetitive element, and "settlements," under which fines can be reduced in exchange for acknowledgment of participation in the breach and acceptance of related liabilities.

However, the existing legal framework to prevent the formation and maintenance of cartels is applied relatively rarely, as cartels are difficult to detect. Since 2010, there have been only 32 cases against suspected cartel behavior initiated by the AMO SR.[66] Out of these, 22 (69%) resulted in a punishment (fines and, in several cases, also bans on participation in public procurement), while the remaining cases were either dismissed or overturned by second instance decisions. The average fine amount was EUR 920,014. In total, the AMO SR has imposed fines worth more than EUR 20.2 million since 2010. The most frequently investigated sector is construction, with 9 separate cases (28% of all cases). Other common sectors are IT services, machines and engineering, and office supplies, each with 3 cases. The AMO SR opened 4 cases against professional associations, and the remaining cases involved 96 distinct companies or entrepreneurs.

In 2016, the AMO SR started analyzing the behavior of bidders in auctions on the EKS platform after receiving multiple complaints and later published its findings, consisting primarily of anecdotal evidence, in a short policy document (AMO SR, 2017). In response to the increased interest and complaints, the EKS modified its auction rules on February 2017 without giving longer notice, giving rise to the discontinuity that we study. The reform occurred more than 3 months before the findings of the AMO SR were published.

[66] These calculations are based on decisions published on the website of the AMO SR, processed by the authors.

Supplementary References

AMO SR, "Elektronické trhovisko (EKS) – podlimitné zákazky," https://www.antimon.gov.sk/data/att/1879.pdf 2017.

_, "Indications of anticompetitive conduct of entrepreneurs within public procurement," https://www.antimon.gov.sk/data/files/170_indications-of-anticompetitive-conduct-of-entrepreneurs-within-public-procurement.pdf. Retrieved on February 5, 2020.