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 from public procurement in Slovakia. We develop a collusion marker reflecting the optimal cartel strategy and identify bidders suspected of collusion. After a selective auction procedure was abandoned, these collusive bidders adjusted their strategy and the savings gap between auctions with and without collusion decreased by almost 60%.

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 the provision of public goods 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. The economic 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 were awarded using restricted procedures in the UK, but also more than 20% in Denmark and the Netherlands (Chong, Klien and Saussier, 2016). In a restrictive procedure, only a limited number of firms is preselected for participation in the main tender. Preselection criteria usually involve technical specifications and the quality of the product, but may also include the requirement of 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 only willing to participate if their chance of winning the contract is sufficiently high.[4] But 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

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

[2] For instance, Athey, Levin and Seira (2011) or Chassang and Ortner (2019). Moreover, a a number of papers covers detection of bid rigging 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).

compared to single-stage auctions.[5] First, we develop a theoretical model to derive the optimal behavior of a bid-rigging cartel and the effect of such collusion on procurement costs. Second, we use the theoretical insights to develop a collusion marker in order 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 beyond what has already been used for developing the marker. 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 find that preselection by opening bids allows collusive bidders to crowd out competitive rivals and thereby reduce the competition they present, in addition to reducing competition among colluders as is also possible without preselection. This leads to a larger gap between 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 which is common to all bidders. Bidders know their own cost realization, but not the realization of others. In a 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 *preselection stage* and to the second stage as *main auction*.[7] We show how a partial bid-rigging cartel, i.e., a cartel which does not involve all firms in a market, may exploit preselection by opening bids. With preselection, a sufficiently large cartel has the ability to profitably exclude cartel outsiders from participating in the main auction with a strictly positive probability, thereby eliminating competition in the main auction. Specifically, the optimal cartel strategy, which we refer to as *close bidding*, involves ensuring sufficiently many cartel members participate to fill all slots in the main auction and coordinate on a single cartel bid in the preselection stage. Only rival bidders who undercut the cartel bid can then

[5] Note that there may also be a concern about corruption if preselection criteria are discretionary (see Decarolis, Fisman, Pinotti and Vannutelli, 2020; Szucs, 2020). Our goal is to show that even if procurement agencies are not corrupted, restrictive procedures can be exploited by the bidders (without help by the agency).

[6] In the usual representation of the English descending auction, the prices decrease continuously and bidders indicate their interest to procure 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 such as to closely mirror the actual rules on the procurement platform in Slovakia.

proceed to the main auction. Building on this result, we consider the effect of removing preselection by comparing outcomes to an otherwise identical auction format, where all interested bidder are allowed to proceed irrespective of their opening bid. Such an auction format is equivalent to a standard English descending auction. Removing preselection eliminates the possibility to exclude rivals and thus the gains from joint participation in the auction process. This decreases cartel profits but increases overall procurement savings, which stands in contrast to the case where no cartel exists and removing 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 (non-pecuniary) 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 effect under collusion to be more beneficial for the procurement agency than under competition. 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 is not beneficial for the cartel without preselection, we expect it to be less prevalent compared to 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 where they don't.

We use data from the electronic contracting system (EKS) for public procurement in Slovakia to develop a collusion marker and verify our predictions. A reform in February 2017 allows us to observe outcomes for both the auction format 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 value between EUR 5.000 and EUR 135.000. Importantly, agencies cannot choose the auction design but are bound to the rules of the platforms. The latter makes the data particularly attractive from a research perspective, since outcomes are not confounded by the endogenous auction choice of the procurement agency.

The theoretical model suggests a simple marker for identifying potential collud-

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

ers: We consider firms which are frequently involved in bidding close to their rivals in the preselection stage as potentially collusive. Any auction such bidders participate in may thus be potentially affected by collusion. For brevity we may use the terms collusive and potentially collusive, as well as colluder and potential colluder interchangeably.[9] To confirm that our marker is indeed indicative of cartel membership and anti-competitive 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 public procurement auctions pre-reform. Despite the fact that we developed our marker before knowing the identities of the firms and our marker is such that we mark only 4% of bidders active before the reform, we mark 5 out of the 6 convicted cartel members.[10] 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 pre-reform auction format with preselection, when collusive bidders participate, bidding in the main auction is less aggressive in general, but particularly so if they managed to eliminate competitive bidders. These findings give us confidence that our marker is indeed identifying bidders which 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 savings in auctions which are affected by collusion are roughly 3.2 percentage points lower than savings in competitive auctions, after preselection is abandoned this savings gap reduces to roughly 1.9 percentage points, i.e., by almost 60 %. However, we do not find larger savings overall after the reform, as savings in competitive auctions, constituting a large majority of auctions at the platform, slightly decreased. Consequently, our results underline our theoretical result that a two-stage auction design is a double edged sword: While it may be 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.

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

[10] The first version of the paper was made publicly available on February 2021.

Auctions with bidder preselection have been analyzed theoretically in the literature on two-stage auctions, starting with Ye (2007). In private-value settings with entry costs, it has been shown that two-stage auctions eliminate miscoordination in the entry decision between bidders and thus may increase efficiency and decrease procurement cost compared to standard one-stage auctions (Bhattacharya et al., 2014; Lu and Ye, 2014; Sweeting and Bhattacharya, 2015). There is also a second, somewhat parallel, theoretical literature stream on a specific form of two-stage auctions which 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 two worlds (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 compared to one-stage auctions, which is the focus of our formal analysis.[11] 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.[12] 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 Ortner (2022) describe a novel bidding pattern which is inconsistent with competition irrespective of the cost distribution.[13] 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

[11] The literature on premium or Amsterdam auctions extends the simple hybrid setting by 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) have shown that cartel profits may be lower in such auctions compared to 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.

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

[13] More recently, Huber and Imhof (2019) use machine-learning techniques to identify cartel, which, similar to Chassang et al. (2022) relies on the identification of peculiar bidding patterns.

differences in outcomes to bid rigging. Similar to our methodology, Chassang and Ortner (2019) develop theoretical predictions and observe effects of an auction-rule reform which reveals the existence of cartels. They show that the introduction of a minimum price makes it more difficult to enforce a cartel 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.[14] Our contribution lies in providing a novel analysis of a different auction design element, preselection by opening bid, frequently used in practice and deriving a theory-based collusion marker. In addition, observing two different auction formats allows us to quantify the losses which arise due to exploitation of preselection.

The remainder of the paper proceeds as follows. Section 2 presents the theoretical model and forms predictions which help to identify collusive bidding patterns and understand the effects of preselection. Section 3 introduces the institutional background and describes the reform we analyze as well as the data. 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 discusses alternative explanations and assumptions and section 7 concludes.

2 Theoretical Framework

The goal of this section is to motivate the marker 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 auctions. To this end we start by introducing a simple model in Section 2.1, which still captures the most important components of the auction formats we are interested in. 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 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 are privately known i.i.d. draws from a cumulative distribution

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

function $F(c)$. $F(c)$ allows a density $f(c)$ which is strictly positive on the support $[\underline{c}, \overline{c}]$. Before the auction takes place, the procurer has to determine a reserve price r, which we assume will be above $\overline{c} < r$. Moreover, the procurer announces a preselection rule $n \in \{2, ..., N\}$ before any bidding occurs. Preselection is based on a sealed opening bid $b_i \leq r$ which 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 $P_n \subseteq A$.[15] We refer to the first stage where opening bids are submitted for preselection as *preselection stage*. Subsequently, the second stage, to which we refer 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 to procure the good, e.g. by pushing a button (see Milgrom and Weber, 1982). Bidders with their button pushed are coined "active" and releasing it 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 which 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 his 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 $q_i \leq b_i$.[16]

In summary the timeline of the model is as follows:

(0) *Auction preparation*: The procurer announces preselection rule $n > 1$ and reserve price $r > \overline{c}$.

(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 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 spending of government agencies. To this end, we define the procurement savings as the differ-

[15] 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. Note that this is a boundary case which does not happen in equilibrium if $n < N$, as we will see later.

[16] 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 which is no higher than its opening bid.

ence 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 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 which do not comprise all firms participating in an auction. Therefore, to capture groups of firms which form a cartel and to 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, cost realizations of all members are known within the cartel and, if any cartel member wins, the good will ultimately be procured by the cartel member with the lowest cost. As such, a cartel acts like a single entity which controls multiple bidder accounts. 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 joint profits of cartel members in expectation.[17] 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 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 get the following result for the main auction:

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

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 will win. 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 it receives is either the cost of the second-lowest-cost firm or the 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 as to not decrease the final price.[18] Avoiding competition within the cartel clearly maximizes cartel profits. Whether a cartel faces a competitive rival and thus

[17] This can be achieved by a pre-auction knock-out, for instance, as described by Asker (2010) or Graham and Marshall (1987). See Section 6.1 for further discussion

[18] This is also true, in case all cartel members placed the same opening bid and one is selected randomly to be active at his opening bid in the main auction. As it is irrelevant which cartel member wins, all other cartel members should stay out and the active cartel member should immediately drop out.

can avoid competition from outside the cartel depends on its bidding strategy in the preselection stage, which we will 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.[19] 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. In Section 2.3, we consider a setting where all firms are bidding competitively, i.e., firms bid to maximize individual profits. Then in Section 2.4 we turn to describe our results for the case when a single partial cartel exists. Section 2.5 extends our model to allow for cost updating.

2.3 Removing Preselection under Competition

We refer to an auction as being 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 $\beta : [\underline{c}, \overline{c}] \to [\underline{c}, r]$. 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 $\overline{c} \le \beta(c) \le r\ \forall c \in [\underline{c}, \overline{c}]$.*

Lemma 2 implies that there are infinitely many symmetric equilibrium bid functions. Any equilibrium bid function has to be increasing.[20] To understand that it has to be strictly so, note that if the bid function were such that a set of firm types $S \subset [\underline{c}, \overline{c}]$ with positive measure places the same bid, preselection would be randomized with some strictly positive probability. Hence, a firm with 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 which follow a strictly increasing bidding function β, the maximization problem of a bidder with cost

[19] 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.

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

c choosing opening bid b is given by:

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

In order to be preselected, a bidder has to place an opening bid which is 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, expected profits will be determined by either the own opening bid or the cost of the lowest-cost rival among other entrants, whichever is lower.[21] Now, for β to be a symmetric equilibrium bid function, it has to be optimal for the bidder to follow the same bidding function as his rivals, i.e. to submit $b = \beta(c)$ and thus perfectly reveal his type with his opening bid. Consider a marginal downward deviation from $b = \beta(c)$. This only pushes the firm into the set of preselected firms 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 which 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, neither affects 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 private values, risk-neutrality, symmetry and perfect competition between bidders.[22] Bidders have full knowledge of their cost already 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.

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

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

However, Proposition 1 does not imply that the reform had no effect on bidding behavior, but simply that any change in bidding is such that it does not affect 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 just increases accordingly such that overall savings s remain unaffected.

The above result is closely related to the result on indicative bidding by Ye (2007), Proposition 2 and Corollary 1. Similar to our model, he considers two-stage auctions, where the first stage is used to preselect bidders. While he considers various auction formats in the preselection stage, our format is different as bids form an upper bound on further bidding and are not prices paid by preselected firms for entry into the main auction. Still some analogies can be drawn to our setting: Since bidding in the selection stage does not affect final prices in equilibrium, it can be seen as "indicative" so the price for entry is simply zero. With that interpretation we come to the same conclusion as Ye (2007): there exist infinitely many equilibria when firms know their cost type at the beginning of the first stage. There is also a close connection to the two-stage auction literature when firm can update their cost, which we will elaborate on 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 other firms which are 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 have now two groups of bidders, cartel insiders and cartel outsiders, who differ with respect to their objective functions. Hence, a symmetric bid function which 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 $\beta : [\underline{c}, \overline{c}] \to [\underline{c}, r]$ with $\beta(c) > c \; \forall c$. In contrast, bids of cartel members may generally depend on the cost realization of all cartel members, not only the own one.

Proposition 2 (Collusive Exclusion)**.** *Under preselection rule $n < N$, suppose there 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 $\beta_k : [\underline{c}, \overline{c}] \to [\beta(\underline{c}), \beta(\overline{c}))$ 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 analsyis: 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. 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 avoids price competition in the main auction. Therefore, matching the lowest-cost bid among cartel members with other cartel bids strictly increase cartel profits and is a feature of the cartel bid strategy in any equilibrium. This is true irrespective of the exact shape of the bidding function which competitive rivals follow, as long as it is strictly increasing. For instance, it could be a competitive equilibrium bidding function according to Lemma 2, or one where competitive bidders know that they compete against a cartel. In turn, the exact value of the optimal cartel bid, thus whether the cartel will bid more or less aggressively than a competitive cartel outsider, will depend 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 for sure, while the cartel strictly benefits from it.[23]

The above result captures the most interesting case where the cartel has the ability to kick out competitive rivals from 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 of matching the lowest cartel bid.

When turning to the effect of the reform under presence of a cartel, we assume competitive rivals are not aware of the fact that they bid against a cartel.[24] Consequently, with preselection rule $n < N$, they follow a bid function β which is supported in a competitive equilibrium (see Lemma 2). Cartel members, on the other hand, know that all firms outside the cartel are competitive.

[23] 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.

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

Proposition 3. *Suppose there exists a cartel of size $|I_k|$ and competitive firms follow a bidding strategy which satisfies 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 compared to no preselection. The result in part (i) directly follows.

Also if $|I_k| \in \{n, ..., N-1\}$, the cartel can always reach the same profits as without preselection: It could follow a passive strategy, where all non-lowest-cost cartel members just bid the reserve price or don't bid at all, thus, as is also possible without preselection, eliminate competition from firms *within* the cartel. But 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 that removing preselection, which removes the possibility to exclude rivals for large enough partial cartels, to strictly reduce profits.

On the flipside, also government savings are only strictly affected if $|I_k| \in \{n, ..., N-1\}$, i.e., if a large enough partial cartel exists which could 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 which wins the contract. If the cartel uses a more aggressive bidding strategy than competitive rivals, it sometimes excludes a firm which would otherwise 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 the lowest-cost firm winning, collusive exclusion increases the price by elimination of competition. Thus, removing preselection leads to a transfer of rents from firms to government agencies.

2.5 Allowing for Cost Updating

While the previous model is useful to illustrate how cartels may exploit preselection rules, 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. The main modelling difference in this literature, beyond considering a different auction format for the first stage, is the assumption that firms do not fully know their cost in the preselection stage, but only observe a signal. Moreover, there may be an entry cost for proceeding to the main auction. Under these model assumption bidder entry into the main auction is endogenous and thus preselection helps the procurement agency to resolve miscoordination of the potential bidder's entry decisions. In order to make the collusion mechanism, which is the contribution of this paper, as clear as possible, we chose not to allow for these two model elements in our main model.[25] In our empirical application there is likely to be little cost updating and entry cost because products considered are standardized and commonly available on the market. Hence, benefits of preselection are likely to be small.

Still, in this section we show that our core insight of close bidding as a collusive marker remains valid also when allowing for cost updating. Thus, while preselection may be beneficial for procurement agencies under competition, a cartel exploiting the rules limits the surplus generated by preselecting bidders. Given that this mainly supports our previous findings but requires a more technical analysis, the quick reader may jump to Section 2.6 for the main take-away. Section 2.5.1 describes the model set-up with cost updating. Section 2.5.2 establishes that, under competition, our specific auction format with opening bids is outcome-equivalent to the two-stage auctions considered in the literature, despite the different auction formats. Finally, in Section 2.5.3 we show that close bidding is still optimal for a partial cartel under cost updating.

2.5.1 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 modelled 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 explicitly considering partial cartels.[26] 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 con-

[25] Allowing for these two elements prevents a closed form solution for the effect of removing preselection. This is also true for auction formats considered in the two-stage auction literature, which 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).

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

trols 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, 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 her cost C_m to provide the good.[27] Based on this signal, entities decide how many of the bidders in its control submit an opening bid as well as the value of these bids, i.e., $b_i \in [0, r] \cup \emptyset$. This set-up reflects that, in case of a cartel, decisions are made at the entity level, not at the bidder level. Moreover, in a world where cartels are perfectly enforceable, it is without loss of generality.

We denote the set of bidders who end up submitting an opening bid by A, where $|A| = a$.[28] 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 will only be excluded from participating in the main auction, if more bidders decide to submit 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 $|P_n|$ and $P_n \subseteq A$.[29] 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 opening bids as a starting value, as in the baseline model.

Moreover, we will make the following distributional assumptions:

Assumption 1. *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 $F_m(s)$ which is continuous on the bounded support $[\underline{s}, \bar{s}]$*
- *Conditional on signal realization s, cost C_m are drawn from a conditional cumulative distribution function $G_m(c|s)$, which is continuous on the support $[\underline{c}, \bar{c}]$ $\forall s$.*

[27] Note that this assumption differs from the baseline model, where we assumed that cost 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 is no precedence on such assumptions. Therefore, we opted for a more general

[28] Note that this is another difference to the baseline model, where all bidders submitted an opening bid, hence $A = N$, as there was no entry cost.

[29] 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 which does not happen in equilibrium if $n < N$, as we will see later.

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

2.5.2 Competition

In the case of competition, we assume that $|I_m| = 1 \ \forall m$, such that each bidder acts independently and maximizes own profit. Moreover, 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 $\beta : [\underline{s}, \bar{s}] \to [\underline{c}, r]$. 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 lowest cost among preselected bidders by $H(\cdot|\tilde{s})$.[30]

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

$$\max_b \int_{\beta^{-1}(b)}^{\bar{s}} \left\{ \int_{\underline{c}}^{\bar{c}} \left[\int_c^{\bar{c}} (\min\{b, x\} - c) dH(x|\tilde{s}) \right] dG(c|s) - K \right\} dF_{n:N-1}(\tilde{s}) \tag{2}$$

Equation (2) 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 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:

$$\max_b \int_{\beta^{-1}(b)}^{\bar{s}} \left\{ \int_{\underline{c}}^{\bar{c}} G(c|s)(1 - H(c|\tilde{s}))dc - \int_b^{\bar{c}} \int_c^{\bar{c}} G(x|s)h(x|\tilde{s})dxdc - K \right\} dF_{n:N-1}(\tilde{s}) \tag{3}$$

Equation (3) 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 were not binding. The second part represents the effective reduction in the value of winning due to the opening bid, hence can be viewed as price for entry into the main auction.

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

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

[30] Effectively, the equivalent equations in the simple model result when assuming $S_i = C_i$.

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

Assumption 2(a) implies that the expected value of participation in the main auction when having the n-th lowest signal is decreasing in own signal. While it is not guaranteed to be satisfied for arbitrary distributions, Ye (2007) established that it is necessary for some first-stage auction formats he considered, thus common in the literature. Assumption 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 still all bidders prefer to participate in the auction.[31] We prefer to not make such an assumption as it is rarely seen in practice and does not match our empirical application.

The maximization problem as stated in Equation (3) makes the parallels between the two-stage auction we consider and the auction formats previously considered by the literature particularly salient. In particular, the most popular specification for the first-stage is an all-pay auction, where each bidder pays what he bids, but only the n bidders with the highest bids are allowed to proceed.[32] 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 represent the price for entry. Hence, in our setting the price for entry is not paid directly but *implied by the opening bid*.

Proposition 4. *Consider the competitive setting under preselection rule $n < N$:*

(i) When the first stage involves opening bids and Assumption 2 is satisfied, there exists a unique and strictly increasing equilibrium bidding 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.

The revenue equivalence with previously considered two-stage auctions implies that results from this literature translate to our setting as well. Bhattacharya et al. (2014) and Sweeting and Bhattacharya (2015) have shown that two-stage auctions may increase expected revenues compared to 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 these assumption are rarely met. As entry costs are

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

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

not necessarily pecuniary, bidders are rarely reimbursed for the time and effort it takes to prepare bids are participate in the bidding process. Moreover, even abstracting 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 non-optimal preselection rules, which will limit 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, comparing preselection rule $n < N$ to no preselection is equivalent to the comparison already done in the literature, if n is chosen optimally.

2.5.3 Collusion

We now allow for the existence of cartel and assume it has exactly the crucial size to exploit the preselection rule, hence $k : |I_k| = n$. 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 5. *Under preselection rule $n < N$, suppose 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. $b_j = \beta_k(s_k)$, $j \in I_k$.*

The logic of the argument is very similar to the one in 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 n cartel members participate in the preselection stage and submit bids which are close to each other. Note that, depending on the interpretation of the entry cost, it may be doubtful in reality whether all proceeding cartel bidders have to incur it. If we believe that entry costs reflect the (non-pecuniary) cost of bid preparation and active participation in the main auction, it may well be reasonable to assume that cartel bidders which are not "serious" do not incur those costs, which makes close bidding even more profitable. Again, as before, without preselection there is no benefit of joint participation of cartel members anymore.

2.6 Empirical Predictions

The theoretical analysis abstracts from some real-world complexities, even when allowing for cost updating. In practice, expecting cartel members to engage in close bidding every single time they participate in an auction may be too strict. There is a variety of reasons for why a cartel may not always choose the short-run optimal bid strategy. For instance, it may be too suspicious and a cartel risks detection, in particular when auctions are held by the same auctioneer. But a cartel may also fear the response of competitive rivals once they realize that they may compete against a cartel. It is also conceivable that some cartels are "weak", 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 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 be too restrictive, an empirical collusion marker should allow for the possibility that collusive firms participate in close bidding frequently, but not necessarily always, in order 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 of joint participation of cartel members when removing preselection. Finally, without cost updating removing preselection is beneficial when a cartel is present, but does not matter otherwise. When allowing for cost updating, the effect of removing preselection is generally not clear anymore, both under competition as well as collusion. 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 removing preselection is more beneficial for procurement savings when a cartel is present, which we will estimate empirically.

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

1. With preselection, 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 compared to with preselection.

3. Removing preselection is likely to be more beneficial for the procurement agency when a cartel is present.

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 ground for our analysis, not only because authorities where mandated to use selective auctions with very transparent and objective preselection criteria for specific types of products, but also because a reform which initiated a platform-wide change of the mandatory auction format allows for a quasi-experimental analysis of the effect of removing preselection on procurement savings. We will base our collusion marker on Prediction 1(a) and use Prediction 1(b) as well as supplemental evidence to verify it. Finally, we will 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 post- communist, OECD high-income economy in Central Europe with 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 GDP and almost 38% of total government expenditures. These are among the highest shares in OECD countries (OECD, 2019).

As an EU member state, the country's procurement law is shaped by the European Union's directives on public procurement. This is particularly relevant for high-value contracts, where the EU rules apply directly. For lower-value contracts the national rules apply.[33] These can vary substantially across the EU member states, however national rules are still required to be in line with the general EU principles of transparency and equal treatment. The EU has developed initiatives for a transition to electronic procurement, which aim 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).

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

[33] The threshold for lower-value contract in our main period of analysis was EUR 135,000, 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.

and by whom. For example, at the time of the reform we study, the value threshold was set to EUR 135,000 for most goods that are typically purchased by the government and to EUR 5,350,000 for construction contracts. These thresholds are regularly revised, though the differences between revisions are usually negligible. For contracts with 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 at 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 public procurement process. Its key component, the Electronic 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 its full introduction on February 1, 2015 the use of EKS in public procurement is required for all goods, construction works and services that are "commonly available on the market" and have 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 level, as well as organizations falling under their administration such as public schools and hospitals.

The main method to initiate a tender in 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 it can be 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 characteristics are required from the EKS platform, most importantly CPV categorization[34], 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 CPV codes that they specified in their profiles on the platform.

[34] Common procurement vocabulary (CPV) is a unified classification system for standardized description of procurement in the European Union. 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 equipments, 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).

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 have at least 72 hours to place an opening bid for the good or service. This first stage serves to preselect bidders for the main procurement auction, which starts 15 minutes after the deadline of the first stage and lasts at least 20 minutes. As such, the pre-reform rules described below represent a practical implementation of the theoretical setting from Section 2 with the specific preselection rule $n = 3$.

The bidding in the preselection stage is constrained by the reserve price which is specified by the procurer; bidders are not able to bid above this reserve price. Before submitting an own bid, a potential bidder is able to see the latest bid placed for this tender as well as the current number of bids, however the identity of other bidders remains hidden during the entire auction process.[35] The first stage terminates sharply at a publicly known, pre-specified deadline.[36] Only bidders whose opening bids are among the three lowest are allowed to proceed to the main auction. Thus auctions with fewer than 4 bidders are not directly affected by this preselection rule.

At the beginning of the main auction, the preselected bidders observe their ranking and the lowest opening bid from the preselection stage. The main auction takes the form of a reverse English auction with the opening bid as binding upper bound for further bids. Although the main auction regularly lasts 20 minutes, it can be extended by 2 minutes if there is a new bid in the last 2 remaining minutes; this process repeats until there are no new bids. The winning bid is the lowest bid no one is willing to undercut. Once the main auction concludes, the platform automatically generates a contract agreement, which is published in the central register of contracts. A de-anonymized record of the entire auction is simultaneously published on the EKS website.

3.2.2 The Reform

Since February 1, 2017 the bidding process follows new auction rules that were announced one week prior to the date of the implementation. The key change involves 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

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

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

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 for bidding in the main auction. Hence, post-reform rules are a practical implementation of a setting without preselection as described in Section 2.

Figure 1: Auction rules and the reform

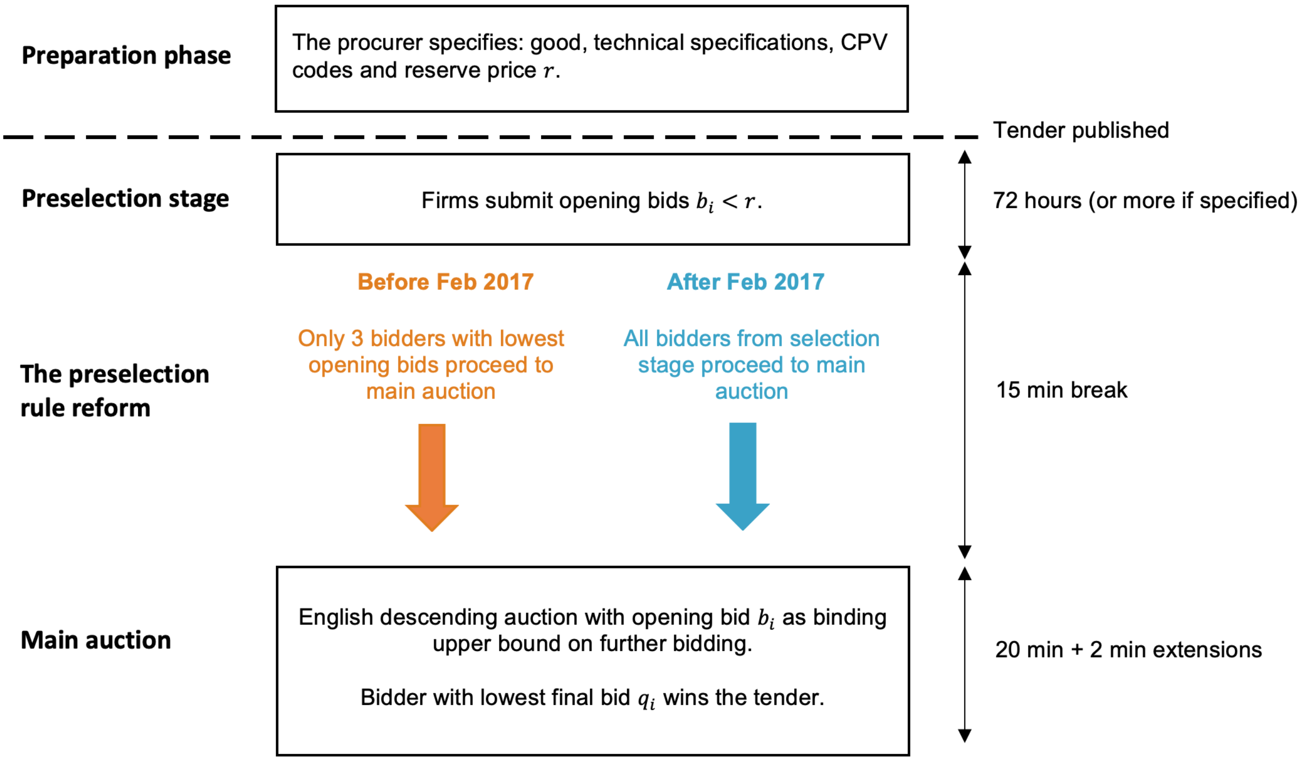


Figure 1 depicts a schematic representation of the auction rules and the reform. Further changes involved making electronic auctions at the EKS platform available not only for commonly available goods, but extending them also to services and construction works. As we do not observe these types of auctions before the reform, we exclude them from our analysis. The process of placing the bid on the platform was also slightly modified: to prevent erroneous entries, the price needs to be confirmed twice if it differs by more than 10%. At the same time the retraction of offers by a procurer has been disabled by the reform. We exclude all pre-reform auctions that featured retractions from our empirical analysis for the sake of consistency with the post-reform period, however our results are robust to this choice.

3.3 Data

Our dataset comprise 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 of a large variety of products, such as office equipment, medical devices or agricultural machinery. Moreover, we can identify bidders as well as 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 (expected value of the contract between EUR 5,000 and EUR 135,000), had to be procured through the EKS platform. In addition, its use has been available, though only optional, also for low value contracts falling below the go-to-tender threshold. The EKS auctions account for the majority of under-the-threshold contracts, though not in contract value. For example, in 2019 the EKS recorded 16,186 auctions worth of 274 millions EUR corresponding to 88% of under-the-threshold contracts, but only to 28% of contracts in terms of their value. Furthermore, the under-the-threshold contracts represented 20% of total procurement spending as under-the-threshold contracts are typically much smaller than major bespoke projects such as highway infrastructure.[37]

We restrict our sample to auctions taking place between February 2016 and January 2020, corresponding exactly to a period of 1 year before the reform and 3 years after the reform. We set the length of the pre-treatment period to 1 year, which is long enough to detect potential pre-trends, while avoiding confounding by other auction rule changes shortly after the launch of the EKS platform. At the same time, using the 3-year long post-treatment period allows us to capture the long-term impact of the reform.[38] We processed the raw data to maintain a consistent dataset before and after the reform, which results in a sample size of 77,646 auctions.[39] We normalize all bids by dividing them through the reserve price set by the agencies. This allows us to compare auctions which are used to procure very different goods and quantities. Since we are ultimately interested in the cost of public procurement, we consider savings for the procurement agency relative to the reserve price it determined.

Table 1 provides summary statistics of the main auction characteristics. In the first

[37] These computations are based on the EKS data and annual public procurement reports prepared for the government (UVO, 2020).

[38] Our results are robust to including a longer period pre-reform. However, in the initial auctions savings and bid patterns where much less stable over time which suggests that firms and agencies where in a learning phase of how to use the platform. As we don't want to make inference from this learning phase, we drop the initial six months.

[39] We drop auctions of construction work and services that were not auctioned before February 2017. We also drop 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 auctions).

four columns, we present basic statistics for our entire sample. The means and standard deviations are reported also separately for periods before and after the reform in February 2017. The reported raw differences present an interesting pattern for the two periods both in terms of savings and competition. Overall savings in the post-reform period are lower by 2 percentage points and savings based on the lowest opening bid in the preselection stage are even lower by 7 percentage points. This suggests that final bids partly compensate the lower aggressiveness of opening bids after the reform. A similar pattern emerges when considering the number of bidders and bids. While, after the reforms 0.39 fewer bidders participate in the preselection stage 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 reforms. This suggests that contracts tend to have higher value after the reform, which can be explained by changes in the lower threshold as well as general time trends. In all our empirical specifications, we control for year and month fixed effects in addition to the normalization mentioned above such that our results should not be affected.

We enrich our auction dataset from the EKS platform with the data from the Register of Financial Statements (RFS), that 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 are publicly accessible and searchable on the 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 profits and profits) from the RFS to the auction data using a firm identifier that is common across the datasets.

4 Collusion marker

Before the reform, collusive exclusion can only be effective if at least three cartel members participate in this scheme. Therefore, 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, we refer to those bids as close bids. In turn, in auctions in which we observe close bids in the preselection stage of an auction, we estimate the main auction to be substantially less competitive, with a significantly larger probability of no further bidding and lower savings (see Table C.1 in Appendix C). However, we are not interested in the auctions in which close bidding occurred per se, but in identifying firms which may be members of a bid-rigging cartel. Motivated by Prediction 1(a) in Sec-

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	-0.02***
Preselection Savings	0.05	0.11	0.00	1.00	0.10	0.15	0.03	0.08	-0.07***
Reserve price (k EUR)	15.47	37.32	0.00	18600	10.80	30.27	17.52	39.85	6.72***
Winning bid (k EUR)	14.30	35.19	0.00	1855	9.93	28.71	16.22	37.53	6.30***
# preselection bidders	3.11	2.09	1.00	24.00	3.37	2.44	2.99	1.91	-0.39***
# main auction bidders	1.57	1.46	0.00	11.00	1.20	1.16	1.73	1.55	0.52***
# main auction bids	26.12	55.81	0.00	2185	17.94	42.67	29.71	60.34	11.76***
Observations	77646				23701		53945		

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 2020. Savings are expressed relative to the reserve price. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

tion 2.6, we consider firms suspicious if they are involved in close bidding relatively frequently.

The distance of bids as an indicator for cartels has also been used in some other empirical papers on cartel detection. However, those studies have been exclusively on 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). When a cartel has only limited control over cartel bids in a first-price auction, Marshall and Marx (2007) show that 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 (2020) 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 which Chassang et al. (2022) dub "missing bids". In contrast, in 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.

In our main specification, we thus mark firms as being potential colluders if they are involved in close bidding in a group of three more frequently than 90% of firms which participate in more than ten auctions in our pre-reform sample. This results in 171 out of 4121 bidders being marked as collusive. Clearly this is an arbitrary percentile and our collusion marker will necessarily include false positives and miss false negatives. However, our results don't change qualitatively if we consider different bid value ranges (0.5%, 0.05%) or different firm percentiles (85th, 95th percentile). We report results from these robustness checks in Appendix D. We do believe that our method strikes the right balance, as will be supported by three pieces of evidence.

4.1 Overlap with convicted cartel members

First, we compare firms 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 which are known to be affected by collusion. Luckily, several months after the first version of this paper was made public, the Anti-monopoly Office of the Slovak Republic (AMO) convicted 6 companies in May 2021 of bid rigging in public procurement auctions published on EKS in the years 2015 to 2017.[40] While our study was not pre-registered, the publishing of the cartel case details after our collusion markers were defined allows us to convincingly validate our measure. We can directly compare collusive behavior implied by the theory to confirmed cartel behavior and check whether we detected the convicted cartel.

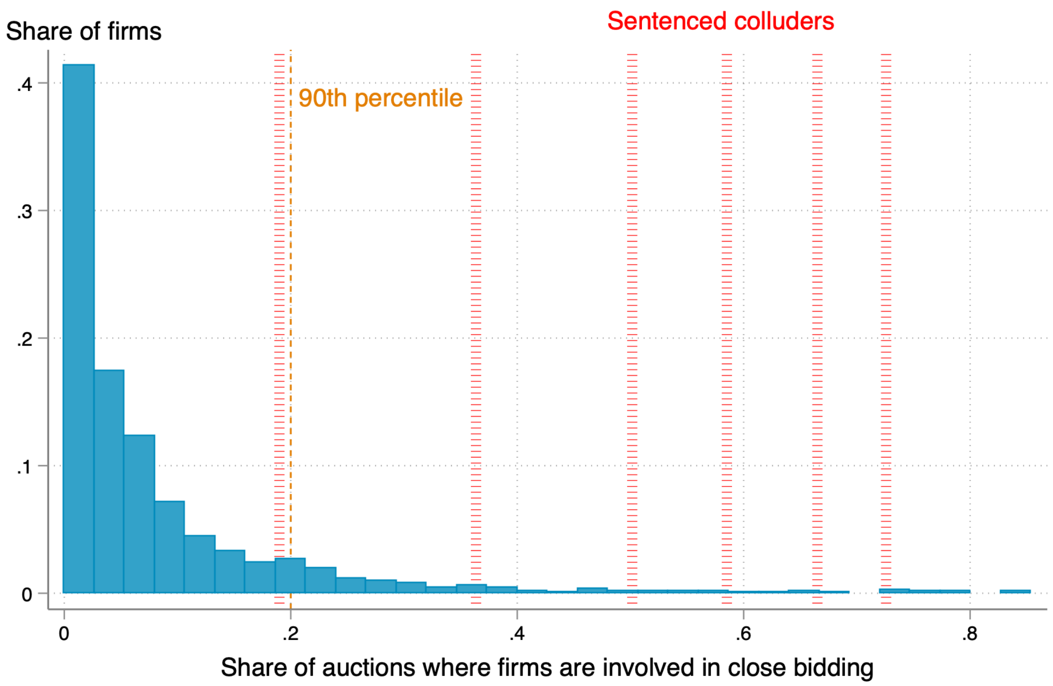
The cartel case concerned a coordination of bids in a way which exploits the preselection rule and was based on 276 auctions run on the EKS. More specifically, the evidence consisted of a combination of suspicious observations, for instance that those companies repeatedly participated in tenders in a group of three and simultaneously submitted their opening bid in the first stage. Moreover, they did not bid against each other in the main stage when jointly preselected, but as soon as a non-cartel participant was preselected they strikingly changed their behavior. The final, and legally most important piece of evidence was the fact that the submitted their bids from the exact same IP address. With the exception of the last point, these are all allegations which are in line 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

[40] 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.

on the cartel case see Appendix B.

Our collusion markers successfully identify 5 out of 6 convicted cartel members. Figure 2 shows the distribution of involvement in close bidding relative to the number of auctions a firm participated in, for firms engaged in more than 10 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 90-th percentile. In addition we indicated the location of the convicted cartel members in this distribution. Five convicted cartel members are to the right of the 90-th percentile, but we marked one out of the six firms as non-collusive even though it is. 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 only once, a contract worth only EUR 5'900. For comparison, the most active cartel member won contracts worth more than EUR 900'000.

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 auctions pre-reform. 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 sentenced colluders is indicated by red long-dashed lines.

4.2 Stable cartel rings

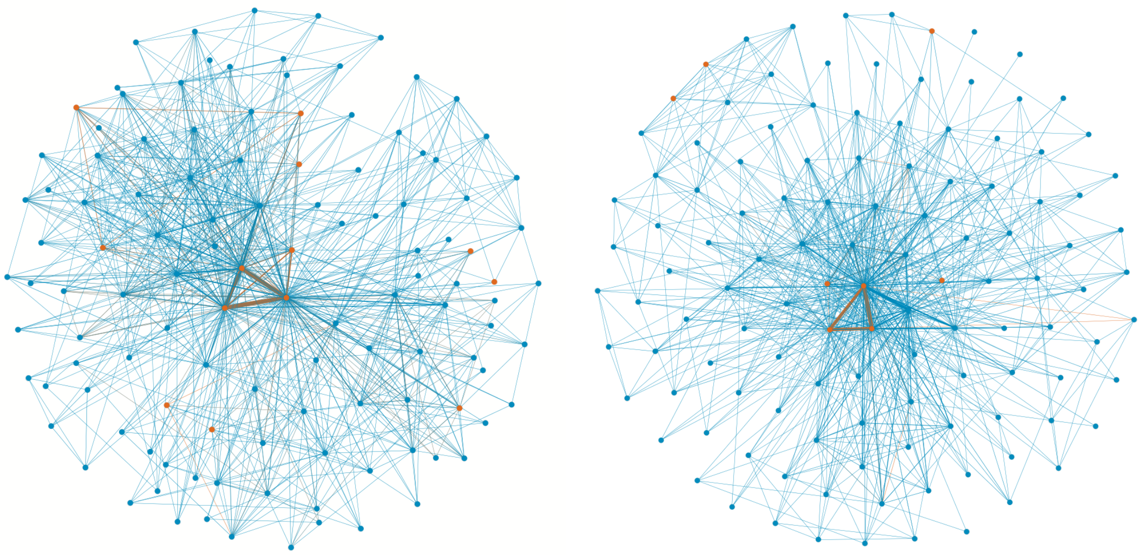
Second, we dig deeper into the idea that a cartel is a stable group of firms and and as such, we should expect suspicious interaction between the same firms repeatedly. While our collusion measure identifies single firms which we believe are likely members of a cartel, it does not explicitly rely on repeated interaction 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 frequent does pairwise close bidding have to be to be considered "stable"? How should we take into account varying sizes of cartels, where members of large ones may take turns in joint participation, like in the case of the convicted cartel? To circumvent these and similar related questions, we decided to refrain from further refining our collusion measure in our baseline specification.[41] Nonetheless, we show that our fairly simple 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 stable group structures which are a strong indication for a cartel. Visually detecting all potential cartels in the unwieldy full auction network would be difficult, however. Figure 3 shows two example sub-networks, where we focus on two collusive bidders and the network of other bidders they interacted with. On the left, we depicted the network of a convicted cartel member, while on the right we can see a network of a bidder we marked as potentially collusive but who was not convicted. 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 did not mark as collusive are blue. The connection between two bidders is shaded in a stronger orange the larger the share of auctions in which the two bidders were bidding close to each other in the preselection stage.

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 a collusive bidder frequently participates in auctions with at least two other collusive bidders and bids close to them. Connections to non-collusive bidders are largely blue, however, so it does appear that close bidding is happening in stable groups and not indiscriminately. We interpret these orange triangles as 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.

[41] We did incorporate a refinement as a robustness exercise, though. Appendix Section D includes results for a marker, which, in addition to our baseline specification, requires firms to be part of a stable close bidding group more often than 50% of potential colluders. Results are similar.

Figure 3: Convicted (l.) and non-convicted (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 edges represent the frequency of joint participation and the color represents the share of close bidding which happened between the bidders, where 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 we marked as collusive but was not convicted. We used the algorithm of Fruchterman and Reingold (1991) for the network layout.

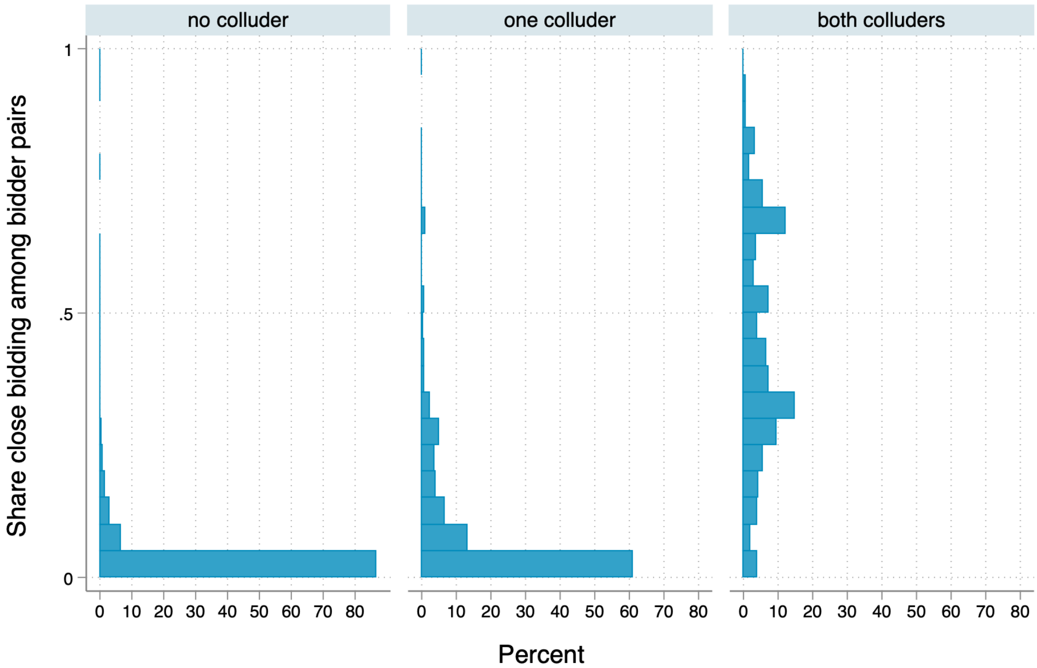
It depicts the distribution of the share of close bidding among bidder pair connections, weighted by the number of auctions bidder pairs participate in jointly.[42] Connections between two potential colluders rarely exhibit a low share of close bidding. In contrast, the distribution of interactions between 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.

4.3 Limited competition in the main auction

Finally, we analyze competition in the main auction when potential colluders participate. Out of the 23701 auctions taking place in the year before the reform, collusive bidders participate in 4685, representing 28% 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

[42] The unweighted graph looks very similar, see Figure C.1 in Appendix C.

Figure 4: Distribution of 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 auctions a bidder pair participated in pre-reform, weighted by the total number of these auctions.

auction, bidding in the main auction should be very different when collusive exclusion is achieved compared 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 in 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	19.14	46.32	21.09	50.24	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	4685		3256		821		608	

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:

$$\begin{aligned} Y_{apct} = {} & \alpha_0 + \alpha_1 \mathbb{1}(\geq 1Colluder)_a + \alpha_2 \mathbb{1}(\geq 3Colluders)_a + \alpha_3 \mathbb{1}(RivalExcluded) \\ & + \beta_1 \mathbb{1}(\geq 2Bidders)_a + \beta_2 \mathbb{1}(\geq 3Bidders)_a + \beta_3 \mathbb{1}(\geq 4Bidders)_a + \beta_4 \mathbb{1}(\geq 5Bidders)_a \\ & + \gamma_t + \delta_p + \theta_c + \epsilon_{apct}, \end{aligned} \tag{4}$$

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. $\mathbb{1}(\geq 1Colluder)$ and $\mathbb{1}(\geq 3Colluder)$ are dummy variables which indicate whether at least one and three potential colluders participate in the preselection stage of an auction respectively. Similary, $\mathbb{1}(\geq 2Bidders)$, $\mathbb{1}(\geq 3Bidders)$, $\mathbb{1}(\geq 4Bidders)$ and $\mathbb{1}(\geq 5Bidders)$ are dummy variables which indicate whether at least two, three, four and five bidders in total participate in the preselection stage of an auction, hence an auction with one single bidder is the baseline.[43] When at least three potential colluders participate, we want to differentiate between auctions where those could take up all slots in the main auction or not, which is captured by $\mathbb{1}(RivalsExcluded)$, an indicator which is one if no competitive rival proceeds to the main auction. The term γ_t refers to year and month fixed effects,

[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 $\mathbb{1}(\geq 5Bidders)$ term, which equals one if the auction has five or more bidders and zero otherwise.

δ_p to procurer fixed effects and θ_c 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 level of the 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 as well as 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 considered a second specification, where we control for the full code, but drop contracts where multiple codes were indicated. This substantially reduces the sample size but may arguably more accurate.

The first three columns in Table 3 show the specification where we control for CPV categories on the 2-digit level, while the columns four to six show the same specification but with full CPV category fixed effects. 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 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 deserves some discussion. Adding a fourth bidder to the auction barely affects competition in the main auction, which is due to the specific auction design which only allows three bidders to proceed.

[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”.

Table 3: Bidding in the main auction with preselection

	Competition in the Main Auction Stage:					
	#Bidders	#Bids	Pr(any bids)	#Bidders	#Bids	Pr(any bids)
≥1 colluder	-0.26***	-5.80***	-0.08***	-0.24***	-5.96***	-0.07***
	(0.03)	(1.18)	(0.01)	(0.04)	(1.55)	(0.02)
≥3 colluders	0.05	3.41	0.01	-0.10	-0.99	-0.06*
	(0.05)	(1.90)	(0.02)	(0.07)	(2.62)	(0.03)
Rivals excl.	-1.15***	-21.35***	-0.49***	-0.95***	-15.57***	-0.38***
	(0.07)	(1.86)	(0.03)	(0.10)	(2.74)	(0.04)
≥2 bidders	1.11***	16.61***	0.58***	1.07***	13.21***	0.57***
	(0.02)	(0.65)	(0.01)	(0.02)	(0.91)	(0.01)
≥3 bidders	0.66***	11.02***	0.18***	0.65***	11.81***	0.17***
	(0.02)	(1.10)	(0.01)	(0.03)	(1.37)	(0.01)
≥4 bidders	0.05	1.36	0.01	0.10*	4.07*	0.03
	(0.03)	(1.46)	(0.01)	(0.04)	(1.87)	(0.02)
≥5 bidders	0.09**	-0.03	0.02*	0.08*	-0.03	0.03
	(0.03)	(1.37)	(0.01)	(0.04)	(1.93)	(0.02)
Constant	0.12***	-0.04	0.07***	0.18***	1.39	0.10***
	(0.03)	(1.08)	(0.01)	(0.04)	(1.51)	(0.02)
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	0.40	0.44	0.19	0.43
Avg. Outcome	1.20	17.94	0.56	1.20	17.94	0.56
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 the probability of any bid submission (Pr(any bids)) in the main auction stage. Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Looking at main-auction outcomes in 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

[45] Already exactly one colluder is correlated with significantly lower competition in the main auction. This may be simply due 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

coefficients on the number of active bidders and no-bid probability in the main auction for the third colluder captures both cases where all slots in the main auction are taken by potential colluders and where some slots are taken by competitive bidders. It turns out that competition in the main auction is only lower when all slots are taken by potential colluders, as the coefficients for *RivalsExcluded* are large and highly significant across all specifications. 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

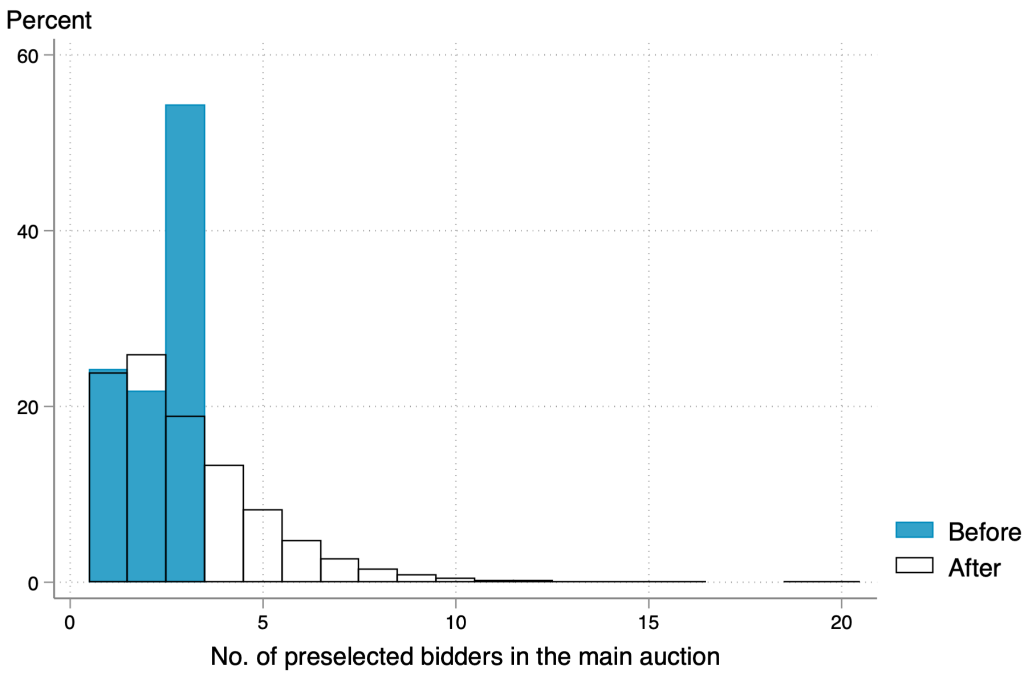
While there may generally be competitive reasons why bidders place bids which are close to each other, our previous results help to rule those out. First, close bids in the preselection stage could be competitive in our modelling framework if it is the result of the firms having similar costs or signals, which should happen very rarely. Moreover, in the main auction, as they bid each other down to their costs, such firms should compete harshly which would lead to almost zero profits. However, if close bids are collusive, no such harsh competition is expected and further bids, if any, should be close to opening bids in the preselection stage. This provides the reasoning for a first test of whether our marker indeed picks up a collusive pattern: when firms bid close in the preselection stage, additional savings generated by the main auction should be low, which is what we find in Table C.1 in Appendix C. Moreover, it is particularly hard to rationalize that collusive bidders only stop competing once they managed to exclude competitive rivals after close bidding. A second competitive explanation for close bids requires 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 should 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 which 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 place the same bid and, across auctions, this set of firms appears to be stable. Consequently, explanations relying on competitive bidding cannot mimic the collusive patterns we observe.

against many competitors. Another reason may be that our collusion measure simply does not capture all cartel members and, in fact, often there are other cartel members active in those auctions as well.

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 which likely form a cartel.[46] Thus, we can move to an analysis of the reform. Remember that the reform lifted preselection for participating in the main auction, such that all bidders who participate in the preselection stage are allowed to proceed to the main auction, not only three. Hence, if preselection was binding, mechanically, we should observe more than three bidders participating in the main auction after the reform. Note that participants are not necessarily actively bidding in the main auction, but they are able to bid. Figure 5 confirms that there is no bunching at three bidders after the reform. However, it should be recognized that 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.

[46] One may wonder whether, instead of being part of a real cartel, collusive bidders are actually 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 6.2.

5.1 The effect on cartel strategy

After the reform cartels lose the ability to exclude competitive rivals from the main auction. As a result, they should adapt their cartel strategy. According to Prediction 2 in Section 2.6, we expect cartel firms to participate jointly less frequently, as the reform eliminates the gain from doing so. One should note that this reasoning assumes that the cartel continues to exist after the reform. There is also the possibility that under the new auction rules, a cartel is not worthwhile to uphold. If a cartel breaks down in response to the reform, previous cartel members become genuine competitors. Then, we should only expect a decrease in joint participation, if, previously, cartel members were aiding each other to win contracts they would not have competed for as independent bidders. This could be either due to imperfect product portfolio overlap, or due to capacity constraints. Either way, a decrease in joint participation of firms we tagged 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:

$$\begin{aligned} CollusiveOpponent_{iapct} = {} & \alpha_0 + \alpha_1 Post + \alpha_2 Colluder_i \times Post \\ & + \beta_1 \mathbb{1}(\geq 3Bidders)_a + \beta_2 \mathbb{1}(\geq 3Bidders)_a \times Post \\ & + \beta_3 \mathbb{1}(\geq 4Bidders)_a + \beta_4 \mathbb{1}(\geq 4Bidders)_a \times Post \\ & + \beta_5 \mathbb{1}(\geq 5Bidders)_a + \beta_6 \mathbb{1}(\geq 5Bidders)_a \times Post \\ & + \gamma_t + \delta_p + \theta_c + \omega_i + \epsilon_{iapct}, \end{aligned} \tag{5}$$

where the outcome variable is equal to one if bidder i faces a collusive bidder as rival in the preselection stage of the auction a. $Colluder_i$ indicates whether bidder i is himself a potential colluder and $Post$ is a dummy variable indicating whether the auction takes place after the reform. While we again control for year and month fixed effects, as well as procurer and CPV category, note that the regression is on a bidder-auction level, such that we can also control for bidder identity. Moreover, as the sample is 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	0.045***	0.062***	0.076***	0.101***
	(0.010)	(0.011)	(0.013)	(0.013)
Colluder × post		-0.218***		-0.209***
		(0.036)		(0.038)
≥3 bidders	0.062***	0.053***	0.069***	0.057***
	(0.006)	(0.006)	(0.007)	(0.007)
≥4 bidders	0.061***	0.065***	0.057***	0.065***
	(0.006)	(0.006)	(0.006)	(0.007)
≥5 bidders	0.195***	0.196***	0.184***	0.186***
	(0.007)	(0.007)	(0.008)	(0.008)
≥3 bidders × post	-0.021**	-0.009	-0.028***	-0.012
	(0.008)	(0.008)	(0.009)	(0.010)
≥4 bidders × post	-0.023***	-0.027***	-0.018**	-0.025**
	(0.007)	(0.007)	(0.007)	(0.008)
≥5 bidders × post	-0.080***	-0.084***	-0.067***	-0.074***
	(0.009)	(0.009)	(0.010)	(0.011)
Constant	0.074***	0.076***	0.077***	0.079***
	(0.007)	(0.007)	(0.008)	(0.008)
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	0.39	0.39	0.48	0.48
Avg. Outcome	0.21	0.21	0.21	0.21
N	168264	168264	103425	103425

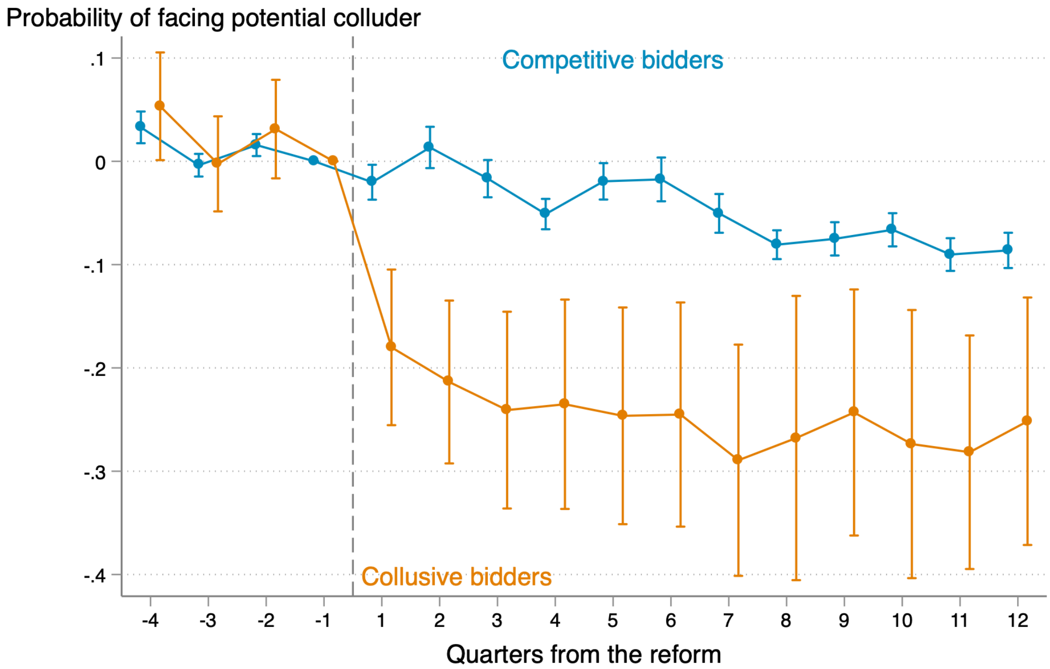
Notes: Fixed effects included in the specifications are indicated at the bottom of the table. Standard errors in parentheses are clustered at the bidder level * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4 shows that, indeed, colluders are less likely to face an opponent who is also a potential colluder in the preselection stage. This reduction in probability is not only significant, but also sizeable. The probability of a colluder to participate jointly with other colluders before the reform is 74.2%, while the corresponding probability of a competitor is only 21.9%. Based on column (4) where we control for the full CPV category, this probability does not change substantially for competitive bidders.[47] Compared to the change for competitive bidders, the probability for collusive bidders drops by additional 20.9 percentage points. To see the overall effect more clearly, Figure 6 illustrates the finding in the form of an event study-style graph. Note that there seemingly is a negative time trend in the probability of facing a colluder. To some extent, this is a mechanical result due to exit and entry. As we define colluders only based on pre-reform data, the set of potential colluders will decrease over time while new firms enter, which are competitive by default. We control for time trends in the regression specification with year and month dummies.

All-in-all this finding strongly supports the idea that, with preselection, cartel members participate jointly in order exclude competitive rivals. One should note 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 all-together. However, the fact that we don't 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 C.2 in Appendix C).

[47] Note that the coefficient of *Post* only contains the effect for auctions with two bidders.

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

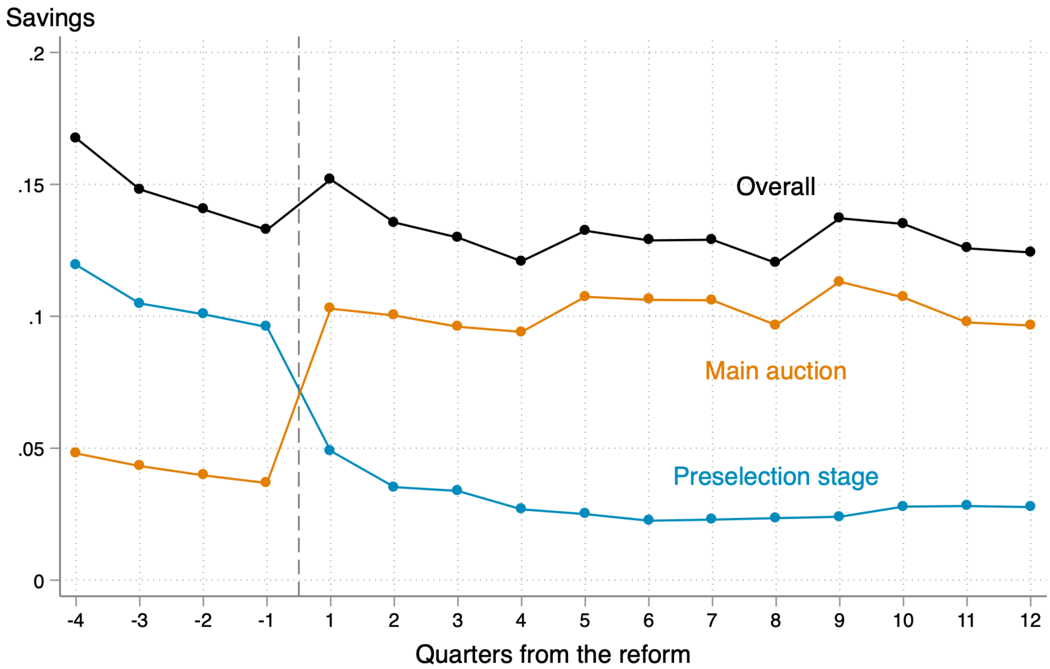


Notes: The graph plots event study coefficients from a regression of an indicator, which is one if a bidder faces a potential colluder in the preselection stage, on the full set of quarter indicators, bidder as well as procurer fixed effects and CPV-category fixed effects. The omitted category is one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

5.2 The effect on savings

Before moving to the overall effect on savings, it is instructive to describe how the reform affected bidding in the two stages respectively. Even without an overall effect on savings, the reform may still change 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 action. The reform decreased the distance between reserve price and opening bid, but increased the distance between opening bid and final 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 2/3 of overall savings, the reform led to a swap in the share of savings attributed to the preselection stage and the main auction. Overall, however, the reform did not seem to have an immediate effect. This is generally in line with Proposition 1, where we predicted no effect in a model without cost updating.

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



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

In order 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 in a consistent manner before and after the reform. We have seen in the previous section that joint participation happens 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 as well as after the reform. Moreover, as we consider the overall savings that realize in an auction, our unit of observation is an individual auction. This leads us to the following regression specification.

$$\begin{aligned} Savings_{apct} = {} & \alpha_0 + \alpha_1 Collusive_a + \alpha_2 Post + \alpha_3 Collusive_a \times Post \\ & + \beta_1 \mathbb{1}(\geq 2Bidders)_a + \beta_2 \mathbb{1}(\geq 2Bidders)_a \times Post \\ & + \beta_3 \mathbb{1}(\geq 3Bidders)_a + \beta_4 \mathbb{1}(\geq 3Bidders)_a \times Post \\ & + \beta_5 \mathbb{1}(\geq 4Bidders)_a + \beta_6 \mathbb{1}(\geq 4Bidders)_a \times Post \\ & + \beta_7 \mathbb{1}(\geq 5Bidders)_a + \beta_8 \mathbb{1}(\geq 5Bidders)_a \times Post + \gamma_t + \delta_p + \theta_c + \epsilon_{apct}, \end{aligned} \tag{6}$$

where *Collusive* is a dummy variable indicating whether at least one potential colluder participates and *Post* is a dummy variable indicating whether the auction takes place after the reform. As before, γ_t refers to year and month fixed effects and δ_p refers to fixed effects for the procurer setting up the auction and θ_c 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.

We consider column (4) of Table 5 our main specification. It shows that the overall effect of the reform on savings is slightly negative. While adding more bidders to the preselection stage has a significantly positive, though decreasing, effect on savings, the reform dampened this effect for the second but increased it for the third bidder.[48] This suggests that, in our data, preselection is associated with higher savings for auctions for which the rule is not binding. The explanation is that, in the preselection stage, bidders don't exactly know how many other bidders are going to join. Even though the number of previously submitted opening bids at the time of own submission is indicated, there is uncertainty about the number of future opening bids submitted just before the deadline. To ensure against a large number of future opening bids, bidders seem to submit a more aggressive opening bid than would be ex-post required given the number of actual bidders.

Our primary interest, however, lies in the effect of collusion. In column (4), auctions which are affected by collusion have 3.2 percentage points lower savings before the reform. This corresponds to about 23 percent lower savings relative to average savings of 14 percent. After the reform abolished preselection, savings were still lower for collusive auctions, but the difference to average savings decreased by about 1.9 percentage points, almost 60 percent of the pre-reform 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 was not possible anymore 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 of which collusive bidders seems 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 hybrid auctions due to the ability to eliminate competitive rivals from the main auction.

[48] 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	-0.018**	-0.018**	-0.007	-0.007
	(0.006)	(0.006)	(0.008)	(0.008)
Collusive		-0.053***		-0.032***
		(0.003)		(0.004)
Collusive × Post		0.018***		0.019***
		(0.004)		(0.005)
≥2 bidders	0.087***	0.090***	0.090***	0.092***
	(0.002)	(0.003)	(0.003)	(0.003)
≥3 bidders	0.067***	0.072***	0.064***	0.067***
	(0.004)	(0.004)	(0.004)	(0.004)
≥4 bidders	0.044***	0.046***	0.037***	0.039***
	(0.005)	(0.004)	(0.005)	(0.005)
≥5 bidders	0.067***	0.075***	0.061***	0.067***
	(0.004)	(0.004)	(0.005)	(0.005)
≥2 bidders × post	-0.006*	-0.007**	-0.012**	-0.013***
	(0.003)	(0.003)	(0.004)	(0.004)
≥3 bidders × post	0.011**	0.008	0.015**	0.012*
	(0.004)	(0.004)	(0.005)	(0.005)
≥4 bidders × post	0.001	0.000	0.006	0.005
	(0.005)	(0.005)	(0.006)	(0.006)
≥5 bidders × post	0.019***	0.013*	0.015*	0.012
	(0.005)	(0.005)	(0.006)	(0.006)
Constant	0.022***	0.024***	0.021***	0.023***
	(0.002)	(0.002)	(0.003)	(0.003)
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	0.46
Avg. Outcome	0.14	0.14	0.14	0.14
N	59101	59101	37046	37046

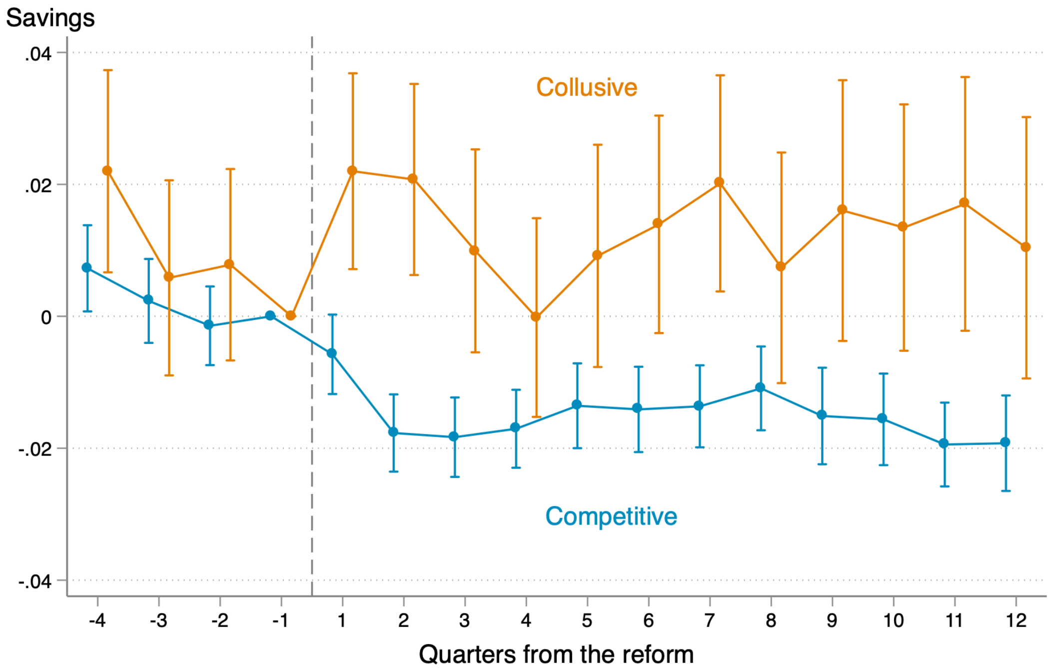
Notes: Fixed effects included in the specifications are indicated at the bottom of the table. Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

To put these numbers into perspective, consider a scenario where the reform would have been implemented one year earlier. In the year before the reform, contracts of 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. Taking the estimates at face value, had the reform been implemented one year earlier, then savings on these contracts would have been higher by 13.5 % (or EUR 1.28 million).[49] However, in the majority of auctions, only competitive bidders participated. For these auctions, implementing the reform one year early would lead a decrease in savings by 6.7 % (or EUR 1.43 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 are 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.

[49] Note that this number reflects the net effect, taking into account the increase in savings due to limiting collusion as well as the overall slightly negative effect of the reform. As the number of bidders participating in collusive auctions is above average this baseline negative effect is smaller in size compared to the average competitive auction.

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 pre-reform quarter. The model is estimated separately for potentially collusive and not 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 were not able to exploit competitive rivals anymore, savings in auctions where potential colluders participated increased. Still, this finding does not refute 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 improve 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. Agencies should keep track of previous suspicious behavior and avoid selective procedures if they suspect coordination among bidders. This can be done even before clear evidence for conviction is available and thus prevent large losses due to cartel activity.

6 Discussion

6.1 Partial cartels and endogenous cartel formation

Several empirical (e.g., Athey et al., 2011; Bajari and Ye, 2003; Wallimann et al., 2020) 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, appears in an auction. To the contrary, 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.[50] Rigorously answering this question in our setting is beyond the scope of this paper because it requires to take a stance on the internal organization of the cartels, be it side payments or a rotation scheme which minimizes deviation incentives. For instance, consider the case of a cartel which is enforced by side payments. Whether admitting an outside firm is profitable for the cartel will depend on the competitive threat that firm poses relative to the payment it receives 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 have posed a relatively little competitive threat but the frequency of receiving side payments was as high as for other cartel members.[51] This suggests that cartel outsiders should be weaker than insiders, but it is, of course, specific to the compensation scheme analysed. For this reason we take cartel membership as given in the theoretical analysis.

6.2 Competitors versus Colluders

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

[50] While the activity of multiple cartels in a single market has rarely been observed and we are not aware of a paper describing it, it might theoretically happen.

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

not observe similar exit rates after the reform, for instance. Also the reform should eliminate the savings gap entirely, and 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 firm name and location, which presents some hurdles for registering a fake firm. Moreover, comparing the distribution of revenues generated on the platform before the reform, if anything, non-collusive firms have lower revenues and a larger probability of not generating any sales at all. This also applies to the revenue distributions after the reform, see Figure C.4. To get a full picture of firms participating on the EKS, we also analyze their overall economic activity based on data from the Register of Financial Statements (RFS). First, one should note that the RFS provides annual financial information onyl on Slovak firms. Foreign and international firms are not obliged to provide their financial information in this Register. Thus missing information could either indicate that the company is foreign-based or non-existent. For the set of firms which are active before the reform, we fail to match 41% of firms 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 is not only real but also registered in Slovakia. Conditional on finding firms in the Register we provide summary statistics in Table C.2. Sales and asset distribution 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 though. Hence, we do not see any indication that collusive firms are likely to be "fake".

6.3 Heterogeneity of bid rigging by sector

The literature has identified and analyzed cartels in many different sectors, for instance timber, school milk, stamps or, most notably, construction. This suggests that cartels are relevant across the board and as such, we also find collusive firms in most sectors (CPV categories on the 2-digit level) in our dataset. The two exceptions are repair/maintenance services and business services. However, we do see a large variation in the savings gaps collusive bidders are able to generate in different sectors, which we interpret as their effectiveness, see Figure C.5. Sectors where collusive bidders have been most successful before the reform are producing chemical products, food and beverages and are active in construction and the textile sector, such as the convicted cartel. Are 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* and *Collusive* $\times$ *Post* from Equation (6) across sectors, which is significant at the one percent level. This suggests that the procurement agency could reclaim most of their savings in sectors where collusive bidders led to the largest distortions before the reform.

7 Conclusion

In this paper, we analyze bid rigging in public procurement auctions with bidder preselection and compare outcomes to auctions without bidder preselection. We develop a theoretical model to show that the optimal strategy of a partial bid-rigging cartels 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 rival in the main auction stage. Hence, in contrast to standard auctions without preselection, bid rigging causes additional harm to procurement agencies as it not only reduces competition between cartel members, but also from competitive rivals. This counteracts potential benefits from using auctions with preselection. We then take the model to the data and derive a collusion marker which closely mirrors the optimal cartel behavior, based on administrative data from public procurement in Slovakia. This data is quite attractive for our analysis as we observe a reform which abandons preselection. Bidders are then marked as potentially collusive if they frequently participate in close bidding groups in the preselection stage before the reform. We show that our collusion marker captures anti-competitive behavior well by showing that we identify a majority of convicted cartel members, that collusive bidders are selective in who they bid close to, and that competition in the main auction is much lower when collusive bidders participate. The exclusive strategy of cartels is specific to auctions with preselection, hence after the reform we observe a significant drop in joint participation of collusive bidders. Finally the savings gap between collusive and competitive auctions is significantly lower by 60% after the reform. At the same time, 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 in fact 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. When costs of participating in the main auction are low, preselecting bidders should be avoided at all cost. When costs are high, the evaluation becomes more difficult, but agencies should not wait for a cartel to be prosecuted to switch the auctions design. As soon as they observe suspicious bidding behavior they should reconsider their auction design choice and experiment with abandoning preselection.

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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 cost 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 $c_m \geq b_j$, by assumption $b_j < \min_{i \in P_n} b_i$, hence firm j has to procure the good at his 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 $c_m < b_j$, bidder m will be 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 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.[52] 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 which 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 $c_m \geq min_{i \in I_k} b_i$ or $c_m < min_{i \in I_k} b_i$ (instead of $c_m \geq b_j$ or $c_m < b_j$). $\square$

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 then, the expected payoff is negative). We will now derive the set of equilibrium bid functions in two steps.

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. Otherwise a firm on the downward-sloping part of the bid function has an incentive to decrease its bid since it might undercut firms with higher costs which would be preselected. Moreover, any

[52] 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.

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 of being preselected, while the probability is strictly lower than P. Firm i could profitably deviate by bidding $x - \epsilon$ for ϵ arbitrarily small and thereby increase its probability to proceed 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 with $\beta(c) \in [\bar{c}, r]$ can be supported in equilibrium. 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 rival firms follow the same bidding function β, their opening bid is revealing 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 always holds as long as $\beta(c) \geq \bar{c}$. Hence any strictly increasing bid function which satisfies this condition for all c in addition to being strictly increasing can be supported in equilibrium. $\square$

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 to proceed but strictly increases 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. 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[53]

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

With selection rule $n < N$, expected profit of firm i when all firms including 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.

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 expected savings, when firms follow an optimal bid function 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 $\mathbb{E}(s^S) = \mathbb{E}(s^F)$. $\square$

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

A.4 Proof of Lemma 2

Proof. A cartel has to coordinate multiple bids, which makes the decision problem generally more complicated compared to 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 his profits are equivalent to cartel profits. We refer to this cartel member as cartel winner. Consequently, by definition, 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 $b_k = \beta_k(c_k)$ which 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:

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

While 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 cost larger than b_k, hence would 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 which 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 are 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 as well as profits are bounded, and expected cartel profits do not depend on the cost of cartel members other than the one 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 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 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 which has to hold for an interior solution is then:

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

Note that whether the cartel bids more or less aggressive 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 as well as the distribution of cost $F(c)$. However, the cartel always bids strictly below the highest bid on the competitive rival's bid support $\beta(\bar{c})$:

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

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 i 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 just bid r and achieve the maximum possible final price.

With preselection rule N and $|I_k| < N$, similar to the analysis in the competitive case, any bidding 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 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 cartel profits when reporting to be of the lowest type. If $n \leq N - |I_k|$ reporting $c' = \underline{c}$ will lead to the following cartel profits

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

Also if $n > N - |I_k|$ reporting $c' = \underline{c}$ will lead to an increase in cartel profits by exploiting the selection rule, even though the cartel profit does not require to bid 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.

Analysing 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 $F_{i,j:n}(x_i, x_j)$. 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 non-cartel bids) is given by:

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

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 the lowest-cost firm among competitive rivals (represented by the last part in the equation).

When considering selection rule $n < N$ and $|I_k| < n$, it is trivial to see 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 $\gamma : C \to C$. 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'_k. If a cartel bids more aggressive than a competitive firm, it may exclude rivals which could otherwise have won. If a cartel bids less aggressive, 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 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 savings in the hypothetical case:

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

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 increases savings strictly. □

A.6 Proof of Proposition 4

(i) Consider the the maximization problem as stated in 3 and suppose rivals following a symmetric bidding function β. For β to be an equilibrium bidding function, the following condition has to hold:

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

Rearranging to get at $\beta'(s)$:

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

It is easy to see that the sign of the bidding function's slope is 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 bidding 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 if 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 $\beta(\bar{s}) = \tilde{\beta}(\bar{s})$.

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:

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

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 2(b), $\Omega(\bar{s}) - K = 0$, hence $\tilde{\beta}(\bar{s}) = \bar{c}$ and $\frac{\partial P(\beta(s),s)}{\partial s}_{|s=\bar{s}} = 0$. As $\Omega'(s) < 0$ (by Assumption 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 preselection stage, the equilibrium bidding function π has to solve for all s:

$$
\pi(s) = \arg\max_{p} \int_{\pi^{-1}(p)}^{\bar{s}} \left\{\int_{\underline{c}}^{\bar{c}} G(c|s)(1 - H(c|\tilde{s}))dc - K\right\} dF_{n:N-1}(\tilde{s}) - p \tag{7}
$$

There, bids are simply the price paid for entry. Note that in contrast to our setting, price paid for entry is increasing in the first-stage bid. From the first order conditions to Equations (3) and (7), we get:

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

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, 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. ∎

A.7 Proof of Proposition 5

First, suppose $n = 2$. 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:

$$\begin{aligned}\max_{b_j, j\in I_k} \int_{\beta^{-1}(b_k)}^{\bar{s}} \Bigg\{ \int_{\underline{c}}^{\bar{c}} \Bigg[\int_{\underline{c}}^{\beta^{-1}(b_I)} \int_{c}^{\bar{c}} (\min\{b_k, x\} - c) dG(x|s_1) - K dF(s_1|\tilde{s})\\ + \int_{\beta^{-1}(b_I)}^{\tilde{s}} (b_k - c - 2)K dF(s_1|\tilde{s}) \Bigg] dG_k(c|s_k) \Bigg\} dF_{n:N-n}(\tilde{s})\end{aligned}$$

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

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

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. ∎

B Cartel Conviction by the Antimonopoly Office of the Slovak Republic

While the lion's share of these cases of cartel behavior originate in public procurement, only recently a cartel was convicted for bid rigging in public procurement auctions on the EKS. On June 6, 2017 a case was opened against 6 firms that are 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 identity of bidders was unknown. Finally, in May 2021, the case was concluded with a confirmation of the verdict and the authorities released the firm names and auctions affected.

Out of 276 auctions analyzed by the antitrust authority, we can locate 274 in our dataset. Table B.1 summarizes those 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 as compared to the main auction can be observed. However, the number of auctions investigated after the reform is very low, so any comparison should be made with caution. Interestingly, in all investigated auctions post-reform, a cartel member won the contract and the number of cartel members participating substantially decreased.

Table B.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 which were investigated by the anti-monopoly authority.

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

Table B.2 sheds also light on how outcomes change when the cartel is successful at excluding rivals. Clearly when less 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 big enough to exclude rivals, but it is only successful in column (2). Most strikingly, when a cartel successfully excluded rivals, none of the three cartel members submitted any further bids in the main auction. Moreover, the cartel seemed to be more likely successful when the contract value was rather high.

Table B.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 pre-reform period.

Shortly after the reform which abolished 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 a coordination of bids in a way which exploits the preselection rule. The evidence was based on a detailed investigation of 276 electronic auctions.[54] Bid rigging affected various procurement categories, namely furniture, medical equipment, clothing, footwear and textile products.[55]

An interesting observation is that cartel members were highly asymmetric in size, with ARTRA as the biggest in revenues 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 only participated in 14 and only won a single auction. On the other hand, the strong core of the cartel appears to be 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 only won 17. This suggests that it was largely helping the others, while getting compensated through side payments instead of a rotation scheme. JASTA played a similar role, but participated less frequently, only in 53 auctions and PMB only played a minor role.[56]

Since the fines imposed by the anti-monopoly authority were designed to be proportional to annual revenues, they stood in stark contrast to the gains from bid rigging, at least when focusing on the 250 contracts in our dataset. While ARTRA only won contracts with a total value of 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, while being fined EUR 162’247 and EUR 8’621, respectively.[57]

[54] 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.

[55] In fact, these are also the categories where are results suggest the biggest effects see XX

[56] 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 had competition by non-cartel rivals in the main auction. Unfortunately we cannot observe all firms which participate in the preselection stage since they only appear in the documentation if they proceed to the main auction.

[57] In the 274 auctions contained in our data and investigated by the anti-monopoly authorities, 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, fines in the same order amounted to EUR 12’455, EUR 10’807 and EUR 50’236.

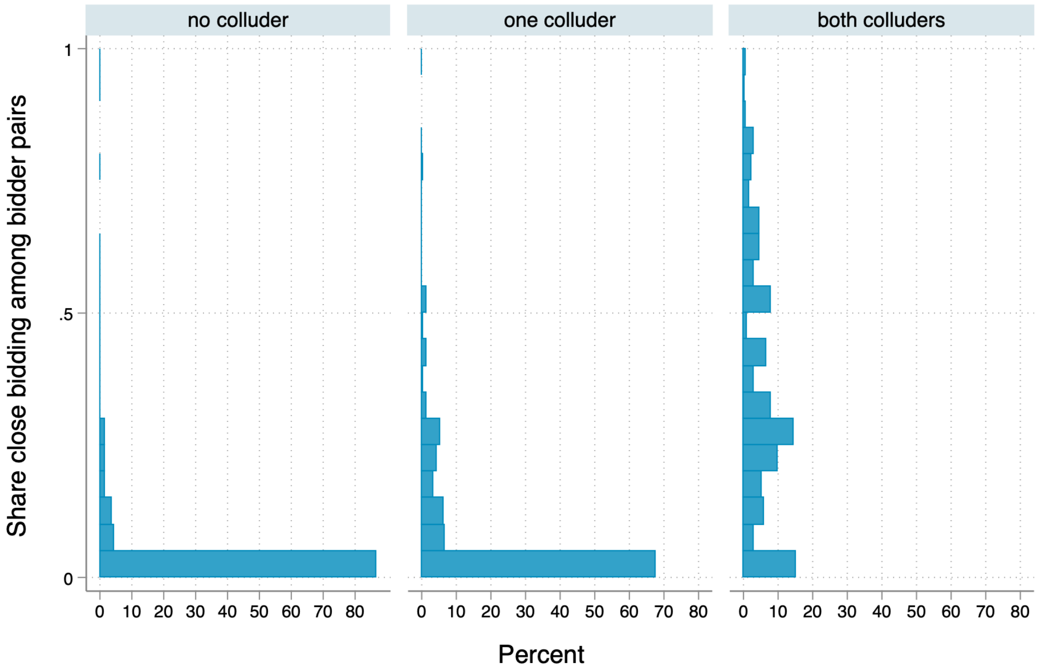
C Supplementary Figures and Tables

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

	Competition in Stage 2:			Savings:		
	Bidders	Bids	Any bids	Stage 1	Stage 2	Total
Close Bidding	-0.29***	-3.60**	-0.11***	-0.06***	-0.02***	-0.08***
	(0.03)	(1.36)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #2	1.10***	16.33***	0.58***	0.03***	0.06***	0.09***
	(0.02)	(0.65)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #3	0.67***	11.05***	0.18***	0.05***	0.02***	0.08***
	(0.02)	(1.10)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #4	0.00	0.47	-0.01	0.05***	-0.01*	0.04***
	(0.03)	(1.45)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #5	0.05	-0.82	0.01	0.09***	-0.02***	0.07***
	(0.03)	(1.40)	(0.01)	(0.00)	(0.00)	(0.00)
Constant	0.10***	-0.28	0.07***	0.03***	-0.00	0.03***
	(0.03)	(1.08)	(0.01)	(0.00)	(0.00)	(0.00)
Month FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
CPV Category FE	yes	yes	yes	yes	yes	yes
Procurer FE	yes	yes	yes	yes	yes	yes
Adj. R2	0.40	0.12	0.39	0.39	0.14	0.37
Avg. Outcome	1.20	17.94	0.56	0.10	0.04	0.15
N	18055	18055	18055	18055	18055	18055

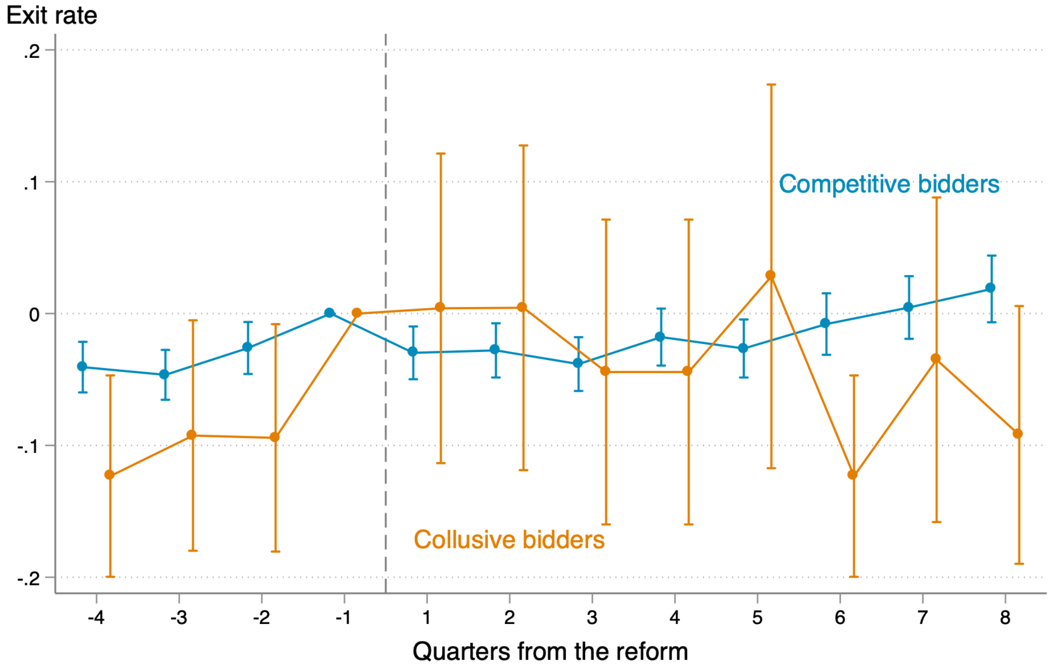
Notes: All specifications include fixed effects indicated at the bottom of the table. Stage 1 and Stage 2 refer to the preselection stage and the main auction, respectively. Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure C.1: Distribution of share of close bidding among bidder pairs (unweighted)



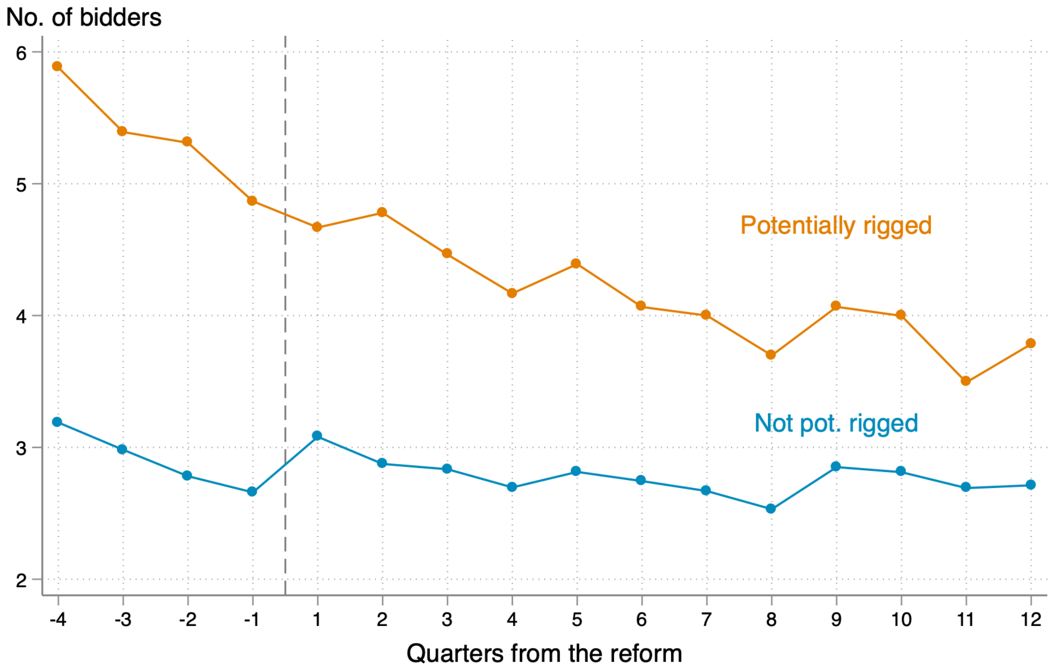
Notes: Close bidding is defined as the occurrence of three opening bids within a value range of 0.1% of each other relative to the reserve price. We consider the share of close bidding among pre-reform auctions a bidder pair participated in.

Figure C.2: The effect of the reform on the exit rate



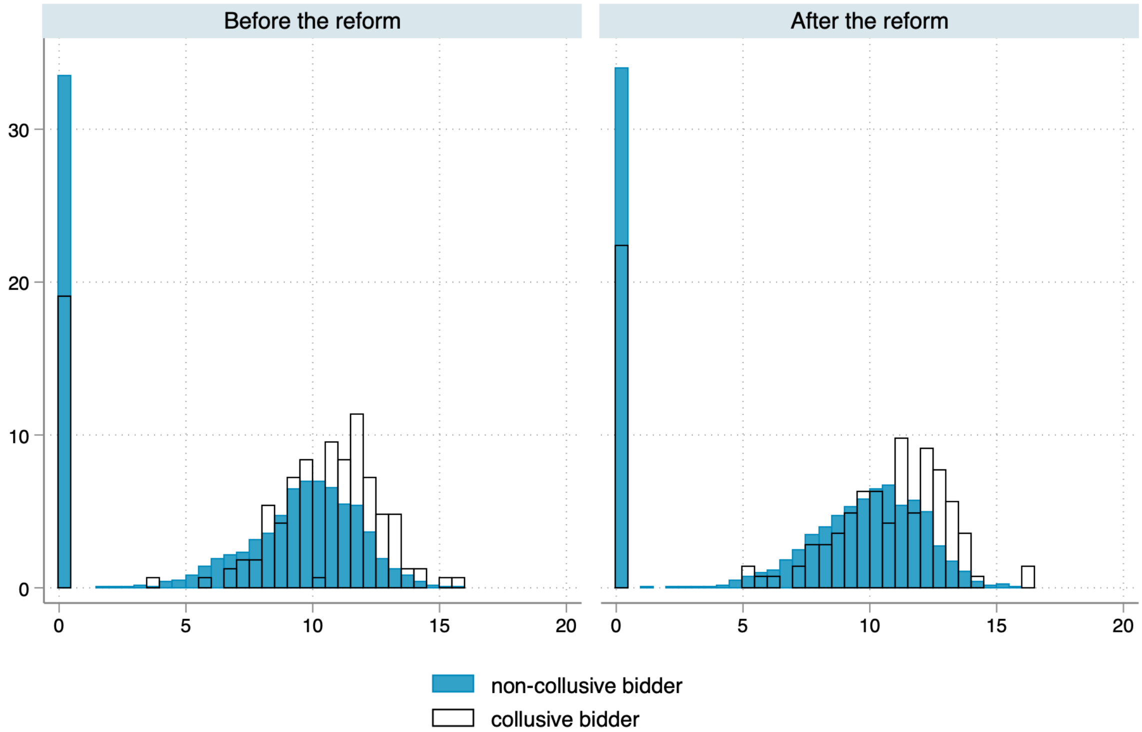
Notes: The graph plots event study coefficients from a regression of exit rates on the full set of quarter indicators. The omitted category is one quarter before the reform to show changes in the exit rate relative to the last pre-reform quarter. The model is estimated separately for collusive and competitive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

Figure C.3: The effect of the reform on the number of bidders



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

Figure C.4: Log Revenue distribution on the EKS platform



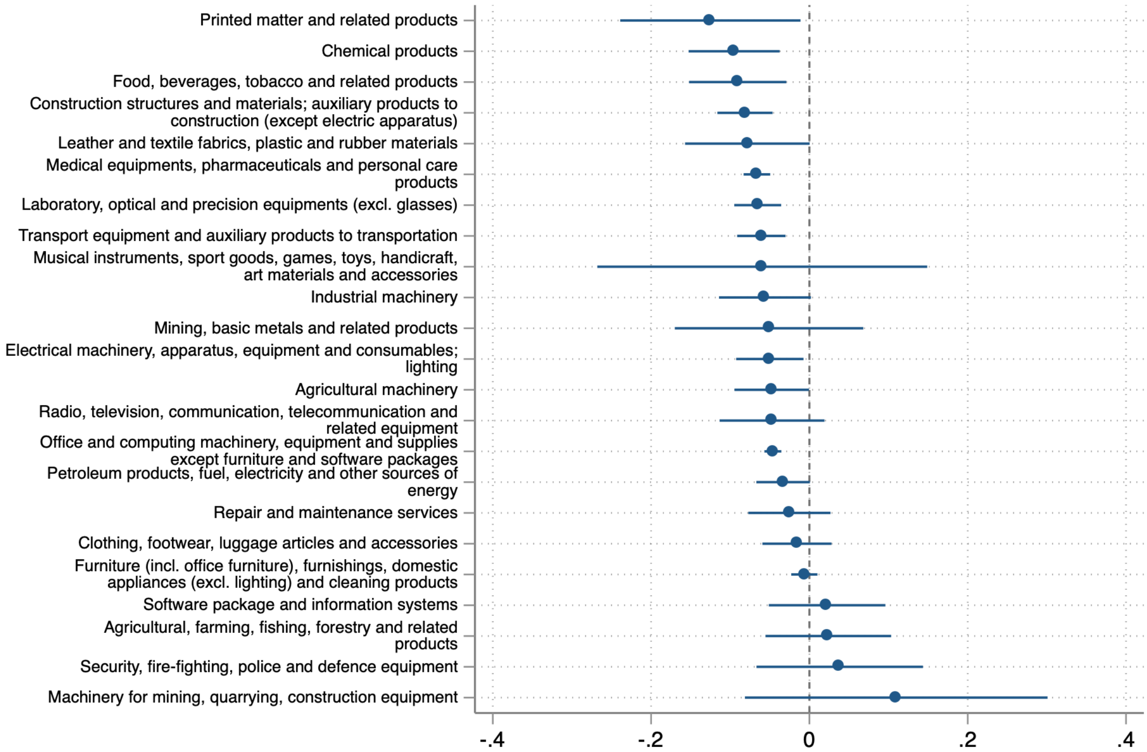
Notes: The graph plots the distribution of log revenues generated on the EKS platform for collusive and competitive bidders one year before (l.) and one year after the reform (r.).

Table C.2: Overall economic activity of bidders registered at 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		

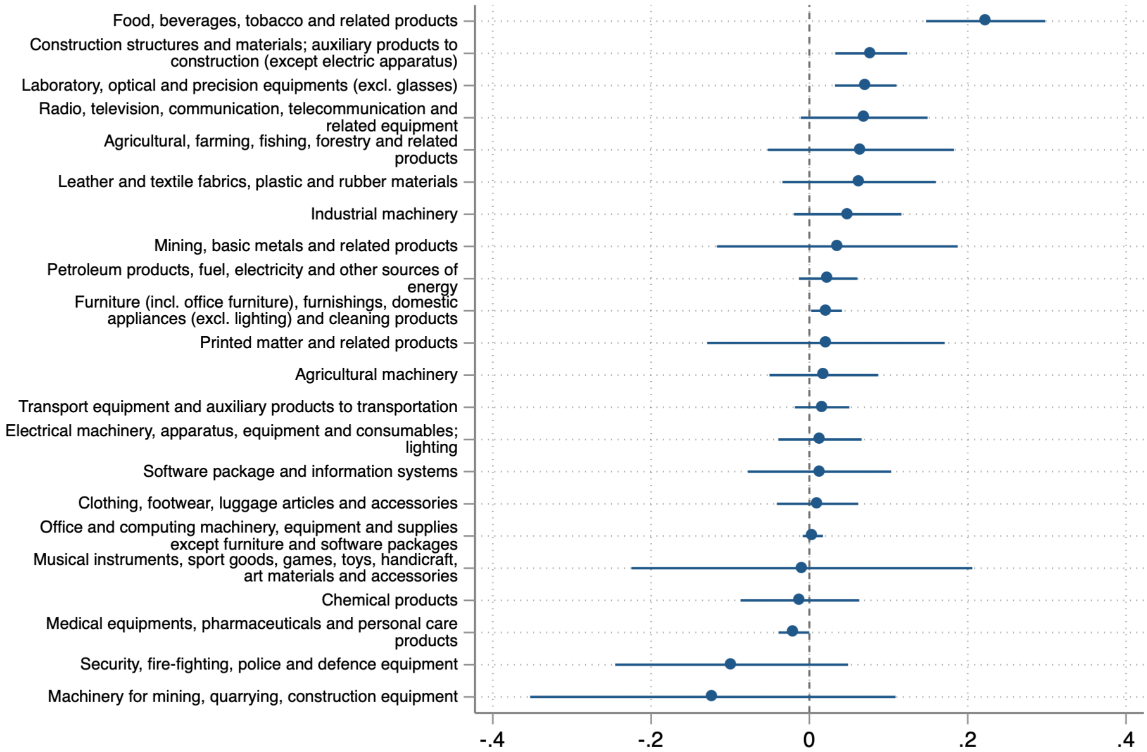
Notes: The table summarizes firm-level variables for firms in our sample which were registered at the RFS in Slovakia. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure C.5: Savings gap before the reform by CPV category



Notes: The graph plots the coefficent as well as the 95% confidence interval of *Collusive* in regression specification (6) run separately for each CPV category on the 2-digit level.

Figure C.6: Effect of the reform on collusive auctions by CPV category

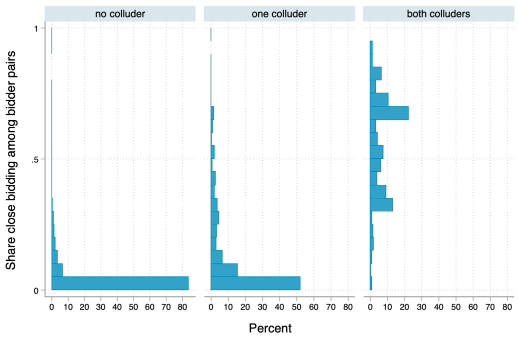


Notes: The graph plots the coefficent as well as the 95% confidence interval of $Collusive \times Post$ in regression specification (6) run separately for each CPV category on the 2-digit level.

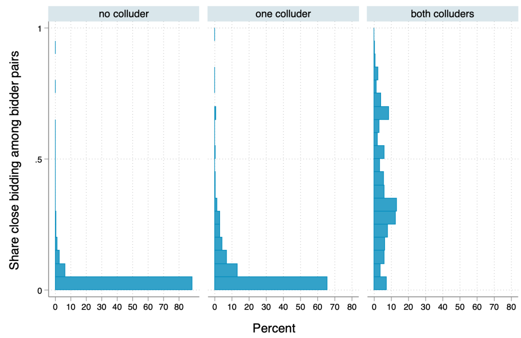
D Robustness

D.1 Close bidding among bidder pairs

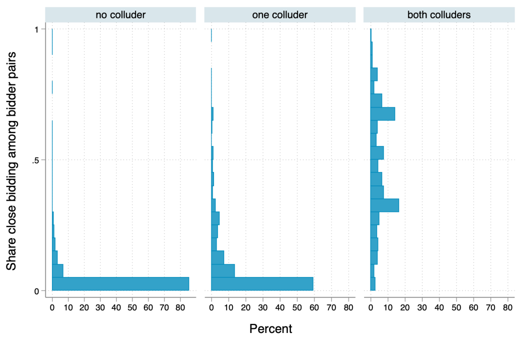
Figure D.1: Distribution of share of close bidding among bidder pairs (weighted)



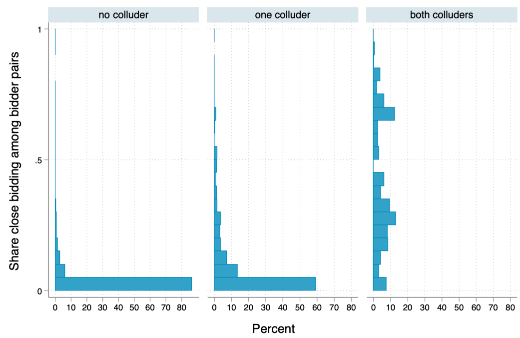
(a) 95th firm percentile



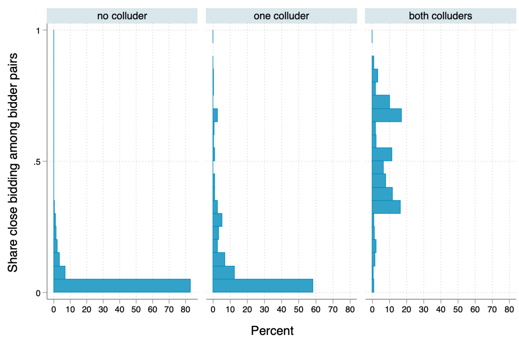
(b) 85th firm percentile



(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 among pre-reform auctions a bidder pair participated in and weigh by the number of these auctions.

D.2 Effect on cartel strategy

Table D.1: Effect of the reform on the probability of facing a cartel member in the pres-election stage

	Add. criterion	Firm percentile		Bid range	
	(1)	(2)	(3)	(4)	(5)
	stable group	95th	85th	0.05 %	0.5 %
Post	0.042***	0.067***	0.082***	0.083***	0.122***
	(0.013)	(0.012)	(0.014)	(0.014)	(0.020)
Colluder × Post	-0.145**	-0.216***	-0.181***	-0.192***	-0.250***
	(0.050)	(0.059)	(0.030)	(0.038)	(0.070)
Bidder #3	0.028***	0.020***	0.111***	0.060***	0.075***
	(0.005)	(0.005)	(0.016)	(0.007)	(0.021)
Bidder #4	0.030***	0.037***	0.068***	0.052***	0.077***
	(0.005)	(0.006)	(0.010)	(0.006)	(0.019)
Bidder #5	0.132***	0.140***	0.209***	0.162***	0.200***
	(0.007)	(0.008)	(0.008)	(0.007)	(0.008)
Bidder #3 × Post	-0.006	0.001	-0.034**	-0.013	-0.030
	(0.008)	(0.008)	(0.013)	(0.010)	(0.019)
Bidder #4 × Post	-0.013*	-0.019**	-0.018	-0.016*	-0.017
	(0.006)	(0.006)	(0.011)	(0.007)	(0.012)
Bidder #5 × Post	-0.048***	-0.045***	-0.078***	-0.055***	-0.089***
	(0.008)	(0.009)	(0.012)	(0.010)	(0.014)
Constant	0.074***	0.063***	0.086***	0.071***	0.035*
	(0.007)	(0.007)	(0.009)	(0.008)	(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	0.50	0.48	0.49	0.48	0.42
Avg. Outcome	0.13	0.13	0.25	0.18	0.20
N	103425	103425	103425	103425	103425

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 * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

D.3 Effect on savings

Table D.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	-0.008	-0.007	-0.008	-0.007	-0.008
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Collusive	-0.019***	-0.024***	-0.036***	-0.028***	-0.041***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)
Collusive × Post	0.015**	0.016**	0.024***	0.015***	0.030***
	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)
Bidder #2	0.091***	0.091***	0.093***	0.092***	0.092***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Bidder #3	0.065***	0.065***	0.069***	0.066***	0.069***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Bidder #4	0.037***	0.038***	0.039***	0.038***	0.039***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Bidder #5	0.063***	0.064***	0.067***	0.065***	0.069***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Bidder #2 × Post	-0.012**	-0.012**	-0.014***	-0.012***	-0.013***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Bidder #3 × Post	0.014**	0.014**	0.010*	0.013*	0.010*
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Bidder #4 × Post	0.006	0.005	0.005	0.005	0.004
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Bidder #5 × Post	0.014*	0.013*	0.011	0.013*	0.009
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Constant	0.022***	0.022***	0.023***	0.023***	0.022***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
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	0.46	0.46	0.46	0.46	0.46
Avg. Outcome	0.14	0.14	0.14	0.14	0.14
N	37046	37046	37046	37046	37046

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

E Supplementary Information

E.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 the dominant market position or formation of cartels.

The practice of bid-rigging in public procurement is considered by the AMO SR as one of the hardest 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 up to 10% of a firm's turnover. A taxonomy of collusion practices in procurement, together with an explanation of 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 for a reduction of the fine for the first cartel member that would provide decisive evidence on the existence of the cartel and thus implicating other cartel members. Alternative instruments available to AMO SR instead of fines are "commitments" that bind an infringing entity to remove the identified anti-competitive element and "settlements" that can reduce fines in exchange for acknowledging participation in the breach and bearing related liabilities.

However, the existing legal framework to prevent formation and sustainment of cartels is applied relatively rarely as cartels are difficult to detect. Since 2010, there were only 32 cases of suspected cartel behavior initiated by the AMO SR.[58] Out of these, 22 (69%) resulted in a punishment (fines and in several cases also bans on participation in public procurement), while the remaining case were either dismissed or overturned by second degree decisions. The average fine amount was EUR 920,014. In total the AMO SR imposed fines worth more than 20.2 million EUR 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, the remaining cases involved 96 distinct companies or entrepreneurs.

In 2016, the AMO SR started analysing behavior of bidders in auctions on the EKS

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

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 a 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.

Supplementary References

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

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