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 bid-rigging cartel and show how 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 rivals and thereby increase procurement costs. To test our predictions, we use administrative data from public procurement in Slovakia. By leveraging a unique auction format reform we show that after a preselection procedure was abandoned, the savings gap between potentially rigged and non-rigged auctions decreased by 48%. In contrast to the conventional motivation for two-stage auctions, our analysis suggests that two-stage auctions might facilitate bid rigging and increase procurement costs.

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

JEL: D43, D44, H57, L12, L13

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1 Introduction

Bid rigging in public procurement auctions is perceived as a major threat to an efficient and competitive procurement process. Because public procurement represents 29% of government expenditures in OECD countries (OECD, 2019), bid rigging can impose additional strains on government budgets, seriously harm the delivery of public goods and ultimately the credibility of public institutions. The design of procurement auctions is crucial for prevention of bid rigging: for instance, open auctions are considered to be more prone to collusion than sealed-bid auctions (Athey, Levin and Seira, 2011), and bidding constraints such as minimum price requirements can weaken collusion (Chassang and Ortner, 2019). While collusive behavior has been studied in standard, single-stage auctions, in practice bidders often have to complete a preceding step where they are required to submit an opening bid. How does this practice affect the ability of cartels to rig auctions?

To answer this question we analyze auctions, where bidders are preselected according to an opening bid submitted in a first stage and only preselected bidders are allowed to continue bidding in the second stage. Such auctions are common in private and public procurement: if an "invitation to quote" precedes the actual procurement auction and opening bids are used for bidder preselection, this effectively constitutes a first stage of the procurement process.[1] A specific two-stage auction format is the *hybrid auction*. It entails one first-price sealed-bid auction stage and one descending English auction stage.[2] For instance, a World Bank study by Maurer and Barroso (2011) describes the use of such formats in Latin America (e.g., for electricity procurement in Brazil). The reasoning behind the use of hybrid auctions is as follows: sealed-bid auctions make collusion more difficult, while open descending auctions are conducive to aggressive price competition, so hybrid auctions combine the best of two worlds (see Klemperer, 1998 and Maurer and Barroso, 2011). In particular for collusion argument, however, there exists neither theoretical support nor empirical evidence, so whether two-stage auctions indeed hamper bid rigging is an open question.

In this paper, we compare outcomes in two-stage auction to standard one-stage auctions with a focus on how bid-rigging cartels affect this comparison. We develop a theoretical model to analyze the optimal behavior of a bid-rigging cartel and its consequences for procurement costs in a two-stage auction. We test the model's predic-

[1] Procedures with some form of bidder preselection are called selective tendering procedures. Next to product and firm characteristics, it is common to also request an opening bid in the application for participation in the procurement auction, see for instance the guidance on the use of electronic auctions in the UK (`https://www.gov.uk/guidance/eauctions`).

[2] Hybrid auctions were first described in the academic literature by Klemperer (1998) who conversely considers a two-step auction design which consists of, first, a descending English auction and then a first-price sealed-bid auction.

tions using administrative data from electronic public procurement in Slovakia. We use a sudden reform that changed the auction design to test whether two-stage auctions outperform standard auctions. Specifically, before the reform a hybrid auction was mandated where, in the first stage, a sealed-bid first-price auction serves to preselect bidders for an English descending auction in the second stage. To reflect their purpose, we generally refer to the first stage as *preselection stage* and to the second stage as *main auction*. We compare outcomes under pre-reform rules to outcomes under post-reform rules that eliminated preselection: all interested firms were able to participate in the main auction, therefore the auction format reduced to a simple descending English auction. In this quasi-experimental setting we find that hybrid auctions do not hamper bid rigging compared to the standard English auction. In contrast, bid rigging cartels may exploit the preselection rule and thereby increase potential cartel gains. When considering auctions where there is no indication for cartel participation, our empirical results are in line with previous theoretical papers. In competitive auctions, removing preselection slightly decreases procurement savings and increases procurement costs.

In our theoretical analysis, we first establish that preselection increases the gains from forming a partial bid-rigging cartel, i.e., a cartel which does not involve all firms in a market, compared to no preselection. With preselection, the cartel can sometimes profitably exclude cartel outsiders from participating in the main auction by coordinating on a "cartel bid" in the preselection stage, which helps cartel members to jointly proceed to the main auction. When their exclusion strategy is successful, the cartel faces no competition in the main auction. The existence of a cartel leads to lower overall procurement savings in the auction with preselection compared to the standard English descending auction. This stands in contrast to the case where no cartel exists. Our theoretical analysis also suggests a marker for identifying potential colluders: 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 rigged.

To apply the marker and verify our predictions, we use data from the electronic contracting system (EKS) for public procurement in Slovakia. A reform in February 2017 allows us to observe outcomes for both the auction format with and without preselection. 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.

Our results show that in the pre-reform auction format with preselection, when collusive bidders participate, bidding in the main auction is less aggressive, with less active bidders and a larger probability that there is no further bidding. This finding suggests that our marker is indeed correlated with bid rigging. Moreover, auctions which are potentially rigged have 31 % lower savings compared to non-rigged auctions before the reform. After the reform, when preselection is abandoned and the auction format reduces to a simple English descending auction, potential bid rigging still decreases savings, but only by around 16 %, implying that abandoning preselection reduces the savings gap between potentially rigged and non-rigged auctions by 48 %. Consequently, in contrast to the general perception, our analysis suggests that two-stage auctions may end up combining the worst and not the best of two worlds: they may increase the profitability of bid rigging and eliminate price competition compared to standard auctions.

Auctions with bidder preselection have been analyzed theoretically in the literature on two-stage auctions, starting with Ye (2007).[3] 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. In contrast, we study bid-rigging of cartels 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.[4] 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 (2020) describe a novel bidding pattern which is inconsistent with competition irrespective of the cost distribution.[5] 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

[3] When comparing two-stage auctions to standard auctions, the common finding in this stream of literature is that two-stage auctions usually create more revenue for the seller (or generate lower costs for the procurer) because with perfect competition, endogenous entry and value updating using a preselection mechanism increases efficiency (Bhattacharya, Roberts and Sweeting, 2014; Lu and Ye, 2014; Sweeting and Bhattacharya, 2015).

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

[5] More recently, Huber and Imhof (2019) use machine-learning techniques to identify cartel, which, similar to Chassang et al. (2020) 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.[6] Our contribution lies in analyzing a different auction design element frequently used in practice and deriving a theory-based collusion marker which allows to test differential predictions depending on cartel participation.

The remainder of the paper proceeds as follows. Section 2 introduces the institutional background and describes the reform we analyze. Section 3 presents the theoretical model and forms predictions which help to identify collusive bidding patterns and understand the effects of the reform. Section 4 describes the data as well as our empirical design and results. Section 5 discusses alternative explanations and assumptions. Section 6 concludes.

2 Institutional Background & Reform

2.1 E-procurement in Slovakia

Our analysis uses 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. 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).

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

The thresholds for contract values, which determine whether national or EU rules apply, are set at the EU level and depend on what product or service is being procured and by whom. For example, at the time of the reform 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 at the time of the reform set at EUR 5,000 for most goods and services.

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[7], 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

[7] 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).

notifications when a newly published tender matches CPV codes that they specified in their profiles on the platform.

2.2 Pre-reform Auction Rules

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.

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.[8] The first stage terminates sharply at a publicly known, pre-specified deadline.[9] 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.

2.3 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

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

[9] 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.

Figure 1: Auction rules and the reform

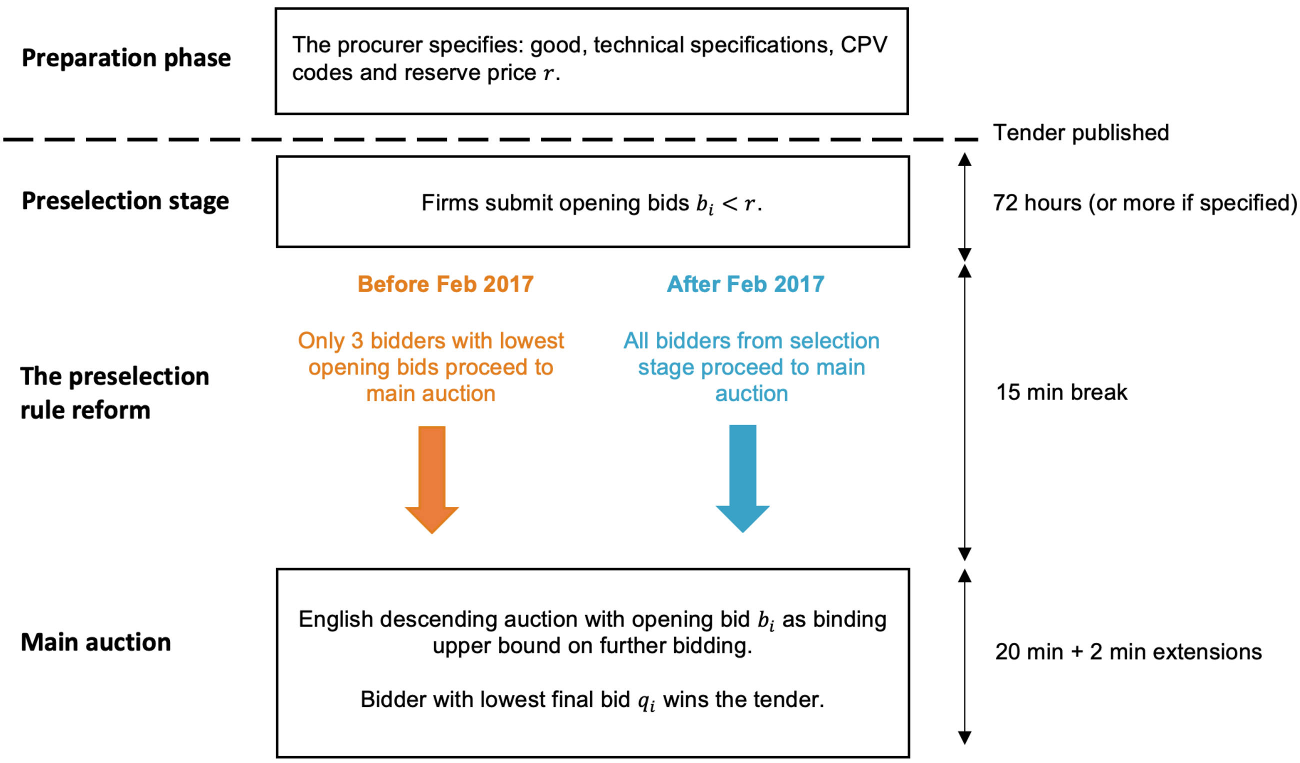


Figure 1 depicts a schematic representation of the auction rules and the reform. Further changes involved making electronic auctions at the EKS platform available not only for commonly available goods, but extending them also to services and construction works. As we do not observe these types of auctions 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 analysis for the sake of consistency with the post-reform period, however our results are robust to this choice.

3 Theoretical Framework

We set up a model to closely mirror the actual rules both before and after the reform. This model will motivate the marker we use to identify potentially collusive practices in the data, and allows us to form differential predictions for rigged vs. non-rigged auctions. The theoretical analysis will answer three major questions. First, which effect of the reform should we expect if there exists no cartel, i.e., all firms are competitive? Second, if there exists a cartel, which bid pattern would we expect to see with preselection? And finally, how do we expect the effect of the reform to be different if there exists a cartel? All proofs can be found in the Appendix A.

3.1 Model Setup

Consider N risk-neutral firms $i \in \{1, ..., N\}$. We refer to the set of all firms as A, hence $|A| = N$. Each firm i draws its cost of providing a good to the procurer from an i.i.d. cumulative distribution function $G(c)$. $G(c)$ allows a density $g(c)$ which is strictly positive on the support $[\underline{c}, \bar{c}]$. Before the auction takes place, the procurer has to determine a reserve price r, which we assume will be above $\bar{c} < r$. Moreover, the procurer announces a preselection rule $n \in \{1, ..., N\}$ before any bidding occurs. Preselection is based on a sealed opening bid $b_i \in [\underline{c}, r]$ 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 $P_n \subseteq A$.[10] We refer to the stage where opening bids are submitted for preselection as *preselection stage*. Subsequently, the *main auction* takes place in the form of an English descending auction where the final price will be determined. In the main auction opening bids from the preselection stage constitute a binding upper bound on further bids. We denote the lowest final bid of firm i with $q_i \in [\underline{c}, r]$. The firm with the lowest final bid wins the contract.[11]

In summary the timeline of the model is as follows:

(0) Procurer announces preselection rule n and reserve price $r > \bar{c}$.

(1) *Preselection stage:* Each firm i submits a sealed bid b_i.

(2) *Main auction:* Firms $i \in P_n$ are allowed to participate in a modified English auction with opening bid b_i as binding first bid. The firm with the lowest final bid q_i wins.

Ultimately, we are interested in the effect of the reform on spending of government agencies, which frequently indicate the efficiency of public procurement in terms of

[10] 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.

[11] Again, ties are broken randomly.

savings. In the above setup, savings for the procurer based on the lowest opening bids are given by $s_1 = r - \min_{i \in P_n} b_i$. Overall savings for the procurer are given by $s = r - \min_{i \in P_n} q_i$, and hence the savings increment through bidding in the main auction is given by $s_2 = s - s_1 = \min_{i \in P_n} b_i - \min_{i \in P_n} q_i$.

3.2 Main Auction

The outcome of the main auction depends on whether and which firms are competitive or part of a bid-rigging cartel. We are explicitly interested in partial cartels, i.e., cartels which do not comprise all firms active in an auction. Therefore, to capture groups of firms which form a cartel and distinguish them from competitive firms, we define partitions of the set of firms $I_k \subseteq A$ such that firms within a partition coordinate their bids. Hence, if firm $i \in I_k$ is part of a cartel, $|I_k| > 1$. This notation also covers competitive firms: if firm $i \in I_{k'}$ is a competitive firm, then $|I_{k'}| = 1$. 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 expected profits of cartel members.[12] Denoting minimal rival cost as $c_{-I_k} = \min_{i \in P_n \setminus I_k} c_i$ and minimal opening bid within the own partition with $b_{I_k} = \min_{i \in I_k} b_i$, 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 win the auction with its final bid $q_j = \min\{c_{-I_k}, b_{I_k}\}$, where I_k is such that $j \in I_k$.*

Hence, as long as every firm's opening bid from the preselection stage is larger 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 continue undercutting the current lowest bid as long as it is above its marginal cost, but not below. 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 member of a cartel and jointly preselected with other cartel members, they should not undercut their opening bid and thereby decrease the final price received by the winning cartel member. Avoiding competition within the cartel maximizes cartel profits and is a common result in the literature on bid-rigging. Whether a cartel faces a competitive rival and thus can avoid competition from outside the cartel depends on its bid policy in the preselection stage.

In the remainder of this section, we consider a reform, which changes the preselection rule from $n_0 < N$ to $n_1 = N$.[13] Using backwards induction, we study the effect of the reform on bidding behavior in the preselection stage and the resulting procurement

[12] For a discussion of internal cartel organization and formation, see Section 5.2

[13] We implicitly assume that the reform has no effect on the number of firms participating in an auction. We discuss the validity and consequences of this assumption in Section 5.3

cost (or savings) of government agencies. In Section 3.3., we consider a setting where all firms are bidding competitively, i.e., firms bid to maximize individual profits. Then in Section 3.4. we turn to describe our results for the case when a single partial cartel exists. Our data represents the special case of a reform where $n_0 = 3$.

3.3 The Effect of the Reform on Competitive Auctions

We refer to an auction as being competitive if $|I_k| = 1\ \forall k$, 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 $n_0 < N$, firms anticipate that they will only have a chance of winning the auction if they are among the n_0 lowest bidders in the preselection stage. We focus on symmetric equilibria of the preselection-stage game, where firms follow a symmetric bid function $\beta : [\underline{c}, \overline{c}] \to [\underline{c}, r]$.

Lemma 2. *In competitive auctions with preselection rule $n_0 < N$, a bid function β_S constitutes a symmetric equilibrium if and only if it is strictly increasing with $\overline{c} \leq \beta_S(c_i) \leq r\ \forall c_i \in [\underline{c}, \overline{c}]$.*

Lemma 2 implies that there are infinitely many symmetric equilibrium bid functions. Any equilibrium bid function has to be increasing.[14] To understand that it has to be strictly so, note that if the bid function is such that a set of firm types $S \subset [\underline{c}, \overline{c}]$ with positive measure place the same bid, preselection may be randomized with some strictly positive probability. Hence, a firm with type $c_i \in S$ could profitably deviate by decreasing its bid by an arbitrarily small amount.

Given that equilibrium bid functions have to be strictly increasing, we consider the direct revelation mechanism where firms are required to report their types. We denote the n_0-lowest cost among $N-1$ rivals with c_0 and the distribution of the cost of the lowest-cost rival conditional on being lower than c_0 as $G_{C|C<c_0}(\cdot)$. Consider the expected profit of firm i with cost c_i when it reports to be of type c_i' and faces rivals who bid according to a strictly increasing bid function β_S, thus report their type truthfully:

$$\Pi^S(c_i', c_i; \beta_S) = \mathbb{E}1_{c_i' < c_0}\left[\int_{c_i}^{c_0} (\min\{\beta_S(c_i'), x\} - c_i)\, dG_{C|C<c_0}(x)\right]$$

Firm i has to report to be of lower cost type than the rival with the n_0-lowest cost c_0 to be preselected. Conditional on being preselected and if firm i has the lowest cost, expected profits will be determined by either own opening bid or the cost of the lowest-cost rival, whichever is lower.[15] Now, for β_S to be an equilibrium bid function, it has

[14] 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.

[15] Hence, the difference to expected profits in a second-price auction are the binding upper bound $\beta_S(c_i')$ and the updated belief about minimum rival cost.

to be optimal for firm i to report $c_i' = c_i$. Consider a marginal downward deviation from $c_i' = c_i$. This only pushes the firm into the set of preselected firms if $c_0 = c_i$, but then firm i makes zero profit 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 firm i 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 $\beta_S(c_i) \geq \bar{c}$. 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.

The above result is closely related to the result on indicative bidding by Ye (2007), Proposition 2. 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.

When the preselection rule is changed to $n_1 = N$, 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 $n_0 < N$ to $n_1 = N$ 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: With preselection rule $n_1 = N$ the auction is equivalent to a second-price open auction. Also with preselection rule $n_0 < N$, we modelled an auction with independent private values where a single unit of a good is procured, bidders are risk-neutral, symmetric and competitive.[16] 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 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

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

overall savings s remain unaffected. Consequently, given this result, we do not expect huge changes in overall savings due to the reform when all firms bid competitively.

3.4 The Effect of the Reform on Rigged Auctions

In this section, we refer to an auction as being rigged if there is one cartel (i.e., there is one partition I_k with $|I_k| > 1$), but other firms which are not part of this cartel are competitive (i.e., $|I_{k'}| = 1$ for $k' \neq k$). As above, we first focus on the case when the preselection rule is $n_0 < N$. Remember that in the main auction any competitive firm is willing to bid down to its marginal costs, while firms which are part of a cartel should only continue to bid if they are the lowest-cost firm among cartel members. Considering the preselection stage, we have now two groups of bidders, cartel insiders and cartel outsiders, who differ with respect to their profit 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 $\beta_O : [\underline{c}, \overline{c}] \to [\underline{c}, r]$ with $\beta_O(c) > c \ \forall c$. Note that the set of such bid functions is a strict superset of the set of functions which can arise in a competitive equilibrium according to Lemma 2. In contrast, bids of cartel members may generally depend on the cost realization of all cartel members, not only the own one.[17]

Lemma 3 (Collusive Exclusion)**.** *Under preselection rule $n_0 < N$, suppose there exists a cartel of size $|I_k|$ with cost $\hat{c} = \min_{j \in I_k} c_j$. In any equilibrium where competitive bidders follow a strictly increasing bid function β_O, the cartel bid policy (b_j): $j \in I_k$ satisfies the following properties:*

- *(i) There exists a bid function $\beta_C : [\underline{c}, \overline{c}] \to [\beta_O(\underline{c}), r]$ such that at least n_0 cartel members submit the same opening bid $b_j = \beta_C(\hat{c})$ while remaining cartel members are recommended $b_j \geq \beta_C(\hat{c})$.*
- *(ii) If $n_0 \leq |I_k| < N$, in addition $\beta_C(\hat{c}) < \beta_O(\overline{c}) \ \forall \hat{c}$.*

Hence, in contrast to the the main auction, it is not always optimal for the cartel if all but one cartel member avoids competing and places 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. If the cartel consists of less than n_0 bidders, there is also no gain of bidding close since the

[17] The fact that the bid of some auction participants not only depends on own characteristics has problematic implications for equilibrium existence. While equilibrium existence has been shown for asymmetric first-price auctions (see Lebrun, 1999; Maskin and Riley, 2000), to our knowledge, no such result has been found for partial cartels where competition within the cartel cannot be suppressed completely.

cartel will have to compete against the lowest-cost competitive rival in the main auction irrespective of whether all or one cartel member are preselected. Given that it is weakly optimal for both cartel members to bid the same, the exact shape of the cartel bid function β_C will generally depend on the outsider bid function β_O and the number of competitive rivals $N - |I_k|$. However, it can never be optimal to bid below the lowest competitive bid $\beta_O(\underline{c})$ because it does not increase the likelihood to be preselected, while reducing the expected final price. On the other hand, if the cartel is complete, therefore faces no competitive rival whatsoever, it is trivial to see that there is no reason to compete and all cartel members should just bid the highest possible value r.

The no-gain result changes when the cartel is of size $n_0 \leq |I_k| < N$ (part (ii) of Lemma 3). Then, matching the lowest-cost bid among cartel members with other cartel bids strictly increase cartel profits because the cartel is large enough to fill all open slots in the main auction. Conditional on some cartel bid value, placing the same opening bid minimizes the chance for the cartel to be jointly preselected with competitive rivals. This is profitable because the exclusion of competitive rivals avoids price competition in the main auction. When $n_0 \leq |I_k| < N$, the cartel is large enough for exclusion to be possible but small enough that competitive rivals exists. An optimal cartel bid function $\beta_C(\hat{c})$ will take this into account. In particular, whether the cartel will bid more or less aggressive than a competitive cartel outsider will depend on the outsider bid function β_O, the number of rivals $N - |I_k|$ and the cost distribution $G(c)$. However, an important finding is that, irrespective of cartel cost realization $\hat{c}$, it is never optimal to bid the highest competitive bid $\beta_O(\bar{c})$ or more.[18] This is because, at the highest competitive bid, the cartel does not exclude any competitive rival, but has a strictly positive gain from doing so since $\beta_O(\bar{c}) > \bar{c}$.

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.[19] Consequently, with preselection rule $n_0 < N$, they follow a bid function β_S 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.

Proposition 2. *Suppose there exists a cartel of size $|I_k|$ and competitive firms follow a bidding strategy which satisfies Lemma 2 under preselection rule n_0. Changing the preselection rule*

[18] Note that this holds even if $N - |I_k| < n_0$ and thus at least one cartel member would be preselected even when the cartel bid is r.

[19] With preselection rule $n_1 = N$, this assumption does neither affect firm profits nor savings. More generally, it simplifies our analysis, but we also think it is reasonable given that we think of competitive rivals in a partial cartel setting as entrants or firms which are mostly active in adjacent markets. Such a firm likely 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.

from $n_0 < N$ to $n_1 = N$

(i) leaves cartel profits and savings unchanged if $|I_k| < n_0$ or $|I_k| = N$.

(ii) strictly decreases cartel profits and strictly increases savings if $n_0 \leq |I_k| < N$.

From the discussion of Lemma 3, we know that in case $|I_k| < n_0$ 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_0 and cannot do better compared to no preselection ($n_1 = N$). The result in part (i) directly follows.

Also in case $n_0 \leq |I_k| < N$, the cartel can always reach the same profits as with preselection rule $n_1 = N$: It could follow a passive strategy, where all non-lowest-cost cartel members just bid the reserve price, thus, as is also possible with preselection rule $n_1 = N$, eliminate competition from firms *within* the cartel. But we have seen before that the cartel has a strict incentive to engage in collusive exclusion, see Lemma 3 (*ii*). 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 $n_0 < N$. Consequently we expect the reform, 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 a large enough partial cartel exists which could exploit the preselection rule pre-reform. The increase in savings due to the reform 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, changing the preselection rule form $n_0 < N$ to $n_1 = N$ 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, changing the preselection rule also leads to a transfer of rents from firms to government agencies.

In sum, the theoretical analysis suggests that the reform only strictly increases savings in auction where there exists a partial but not complete cartel. Such cartels use a conspicuous strategy pre-reform to exclude competitive rivals: they bid very close in the preselection stage and then remain inactive in the main auction.

4 Empirical Analysis

4.1 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.[20]

Our data prepared for the analysis contain 76,969 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.[21] We processed the raw data to maintain a consistent dataset before and after the reform.[22] 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

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

[21] 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.

[22] 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).

the reserve price it determined.

Table 1 provides summary statistics of the main auction characteristics. In the first four columns, we present basic statistics for our entire sample. The means and standard deviations are 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.

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)	15.48	37.40	0.00	1860	10.80	30.27	17.56	39.98	6.76***
Winning bid (k EUR)	14.33	35.29	0.00	1855	9.93	28.71	16.28	37.69	6.35***
Preselection bidders	3.10	2.09	1	24	3.37	2.44	2.98	1.91	-0.39***
Main auction bidders	1.56	1.46	0	11	1.20	1.16	1.71	1.54	0.51***
Main auction bids	25.88	55.67	0	2185	17.94	42.67	29.42	60.23	11.47***
Observations	76969				23701		53268		

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

4.2 Collusive marker

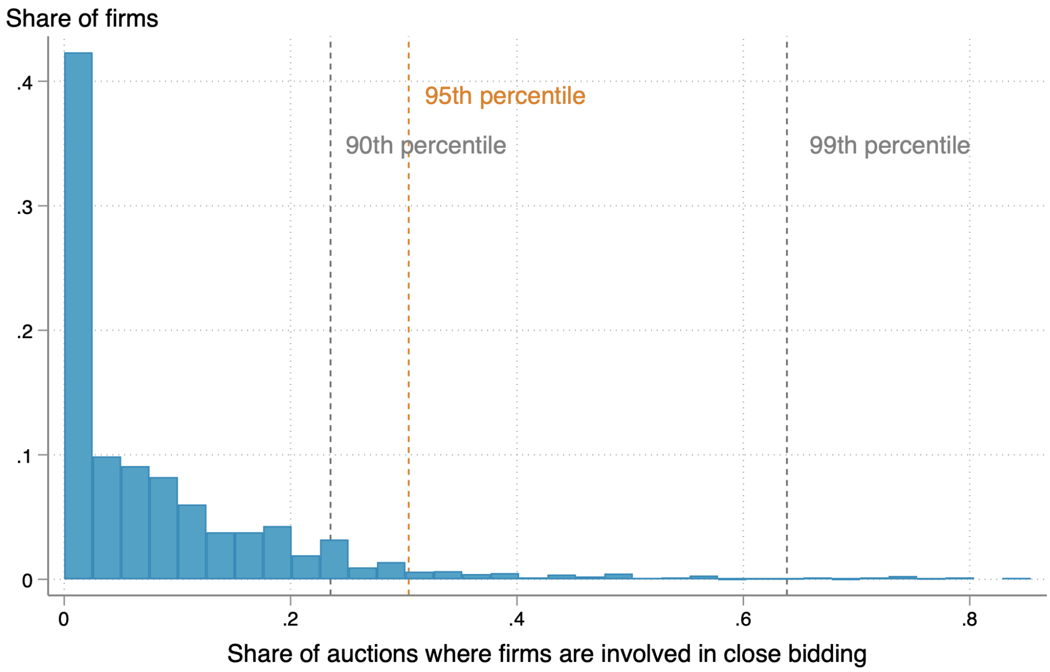
Our theory shows the profitability of a very specific collusive bidding strategy which is aimed at excluding competitive rivals. According to Lemma 3, partial cartels can exploit the preselection rule pre-reform to exclude non-cartel rivals by bidding very close to each other in the preselection stage. We use this theoretical insight to mark such a suspicious bid pattern in the preselection stage irrespective of bid patterns in the main auction. While close bidding in the preselection stage is aimed at reducing competition and activity in the main auction, it only achieves that goal if exclusion of competitive rivals was successful. Hence, including low activity in the main auction into the collusive marker would only capture auctions where collusive exclusion was successful which is only a subset of rigged auctions. Second, restrict the marker to bid patterns in the preselection stage allows us test the prediction of lower competition in the main auction and give credibility to our approach.

Collusive exclusion pre-reform can only be effective if at least three cartel members participate in this scheme. In this light, if in the preselection stage of an auction, at least three opening bids are within a value range of 0.01% of each other, we refer to those bids as close bids. However, we are not generally interested in the auctions in which close bidding occurred, but in identifying firms which may be members of a bid-rigging cartels. To rule out that a firm was involved in close bidding by chance, we want to mark firms who bid close to other firms relatively frequently. Figure 2 shows the distribution of involvement in close bidding relative to the number of auctions a firm participated in, for firms engaged in at least 4 auctions before the reform. While the majority of firms never submitted a close bid, the distribution has a long right tail. If close bidding happened by chance, we would not expect some firms being involved in a large fraction of auctions they participate in. This argument becomes even stronger the more frequent those firms participate in auctions overall.

In our main specification, we thus mark firms as being potential colluders if they are involved in close bidding more frequently than 95% of firms in our sample. Note that a potential cartel member does not necessarily bid close to other cartel members in all auctions he participates in. One reason may be that for some time period the cartel may in fact be complete, such that there is no competitive entrant to exclude. 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. Therefore, it is natural to allow for imperfect compliance with the cartel-optimal bid policy. Setting a large percentile threshold for the collusive marker therefore comes at the cost of potentially missing some colluders of weak cartels, while a low threshold may identify competitive bidders as collusive. This should be kept in mind, even though our results don't change qualitatively if we consider different bid value ranges (0.05%, 0.005%) or different firm percentiles (90th, 99th percentile). We report results from these robustness checks in Appendix C.

If the collusive marker we created is indeed predictive for cartel membership, we expect little competition between cartel members in the main auction and hence additional participation of cartel members should not increase the number of active bidders and bids submitted in the main auction. Moreover, if cartels engage in the described

Figure 2: Distribution of relative participation in close bidding across firms



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 all auctions pre-reform a firm participated in.

collusive exclusion strategy pre-reform at least occasionally, we should observe that adding a third cartel member to the auction should be substantially worse for main auction competition than adding a second member. To test these hypotheses we run the following regression:

$$\begin{aligned} Y_i = {} & \alpha_0 + \alpha_1 Colluder\#1_i + \alpha_2 Colluder\#2_i + \alpha_3 Colluder\#3_i + \alpha_4 Colluder\#4_i \\ & + \beta_1 Bidder\#2_i + \beta_2 Bidder\#3_i + \beta_3 Bidder\#4_i + \beta_4 Bidder\#5_i + \gamma_t + \delta_p + \theta_c + \epsilon_i, \end{aligned} \tag{1}$$

where an auction i is the unit of observation. Y is either the number of active bidders, number of bids or probability of no further bid in the main auction. We also consider savings in the preselection stage and additional savings generated in the main auction as well as total savings. *Colluder#1*, *Colluder#2*, *Colluder#3* and *Colluder#4* are dummy variables which indicate whether at least one, two, three and four potential colluders participate in the preselection stage of an auction. Similary, *Bidder#2*, *Bidder#3*, *Bidder#4* and *Bidder#5* 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.[23] The term γ_t refers to year and month fixed

[23] About one tenth of auctions in our dataset have six or more bidders in the preselection stage. These

effects, δ_p to procurer fixed effects and θ_c captures CPV-category fixed effects.

Table 2: Bidding in the main auction with preselection

	Competition in Stage 2:			Savings:		
	Bidders	Bids	Without bids	Stage 1	Stage 2	Total
Bidder #2	1.10***	16.44***	-0.58***	0.03***	0.06***	0.09***
	(0.02)	(0.64)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #3	0.66***	10.91***	-0.18***	0.05***	0.02***	0.07***
	(0.02)	(1.08)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #4	0.02	0.77	0.00	0.05***	-0.01*	0.04***
	(0.03)	(1.44)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #5	0.07*	-0.74	-0.02	0.09***	-0.02***	0.07***
	(0.03)	(1.36)	(0.01)	(0.00)	(0.00)	(0.00)
Colluder #1	-0.24***	-6.05***	0.06***	-0.01**	-0.02***	-0.03***
	(0.03)	(1.69)	(0.01)	(0.00)	(0.00)	(0.01)
Colluder #2	-0.14*	3.93	0.08**	-0.02**	-0.02***	-0.04***
	(0.06)	(2.44)	(0.03)	(0.01)	(0.00)	(0.01)
Colluder #3	-0.30***	-4.31	0.12***	0.00	0.00	0.01
	(0.08)	(3.12)	(0.03)	(0.01)	(0.00)	(0.01)
Colluder #4	0.12	-2.44	-0.04	0.06*	0.00	0.06*
	(0.16)	(4.95)	(0.07)	(0.02)	(0.01)	(0.02)
Constant	0.11***	-0.23	0.93***	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	0.38	0.14	0.36
Avg. Outcome	1.20	17.94	0.44	0.10	0.04	0.15
N	18253	18253	18253	18253	18253	18253

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

The results in Table 2 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. Even though we are not specifically interested in savings at this stage, it is reassuring that more participation also leads to

auctions are also captured by the *Bidder*#5 term, which equals one if the auction has five or more bidders and zero otherwise.

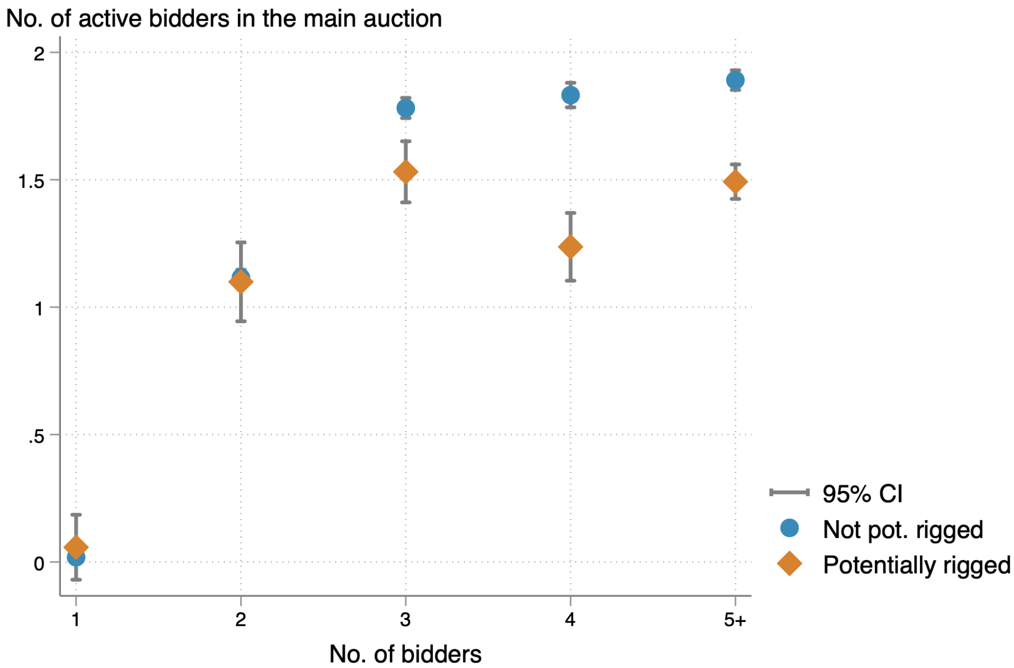
more savings based on both the preselection stage and the main auction. While the coefficients for the second and third bidder confirm the general insight that a larger numbers of participants in an auction has positive but decreasing returns for procurement agencies, the coefficients for the fourth 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. However, the fourth bidder does affect savings nontheless. While savings generated in the first stage increase substantially due to harsher competition for preselection, the increase in competition is partly compensated by lower aggressiveness of bids and thus lower additional savings generated in the second stage. The same is true for the fifth bidder. This illustrates that a substantial part of competition takes place in the preselection stage.

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. Again, even though it is not our main interest for this exercise, it is reassuring that the reduced competition in the main auction also translates to lower savings. It is worth noting that the coefficients on the number of active bidders and no-bid probability in the main auction for the third colluder is significantly larger in size than for the second colluder. This confirms the idea that three colluders are necessary to exclude competitive rivals from the main auction. However, this result should be interpreted with caution due to two reasons. First, as mentioned, even though our marker captures some collusive bidders we may miss some others, so the exact count of collusive bidders may be noisy. Second, the coefficients are average effects over auctions with different number of bidders but exclusion is only possible if at least one potential rival participates.

Figure 3 visualizes the heterogeneity of the collusive effect with respect to the total number of bidders. We refer to auctions as being *potentially rigged* if at least one potential cartel member participates and plot the number of active bidders in the main auction for different number of bidders in the preselection stage, controlling for the same fixed effects as in the regression above. While with at least four bidders, potentially rigged auctions have significantly less competition in the main auction compared to non-rigged auctions, this effect is smaller or vanishes for when less than four bidders participate. This suggests that the cartel members we detect have large collusive gains if the preselection rule is binding.[24]

[24] Remember that we also refer to auctions as being potentially rigged if only a single potential colluder participates. In such a setting we would not expect that competitive activity is lower compared to auctions where two competitive firms participate. In both cases both firms wish to win the auction.

Figure 3: Heterogeneity of the collusion effect



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

Using the other two alternative measures, namely the number of bids in the main auction and the probability of no bids in the main auction (see Figure B.1 and Figure B.2), generates patterns highly consistent with Figure 3.

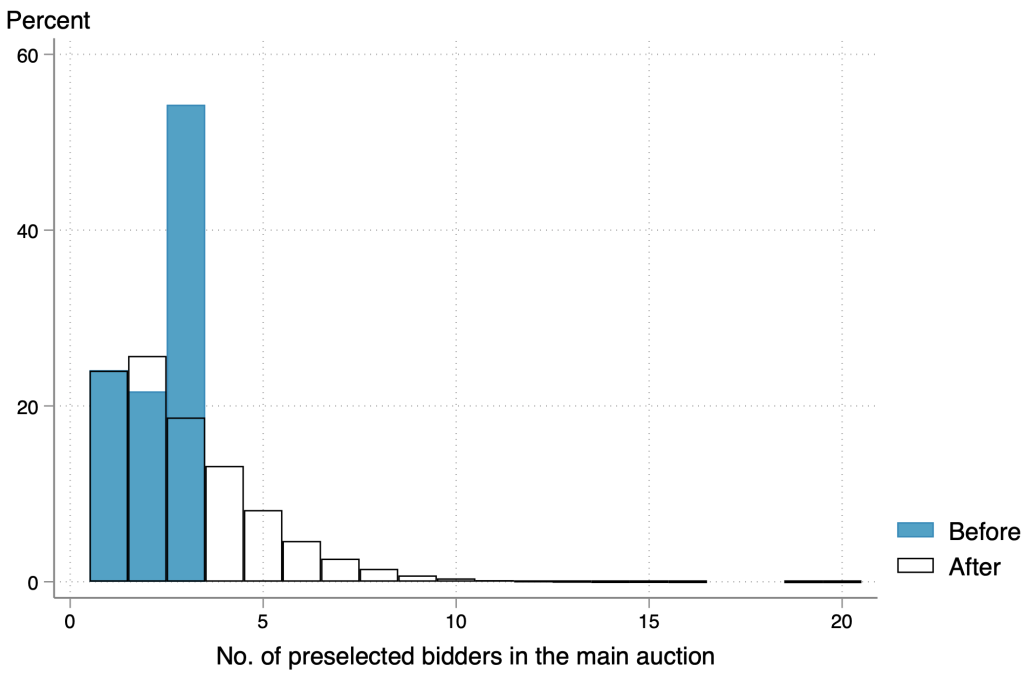
Finally, we find a significant positive correlation between firms we tag as potentially collusive and firms which have been prosecuted due to cartel activity (corr = 0.06, p=0.0022). 23 firms in our dataset have been involved in cartel cases in the last ten years. Note that the information on prosecution need not be for bid-rigging in public procurement and often concerns full cartels. Hence any correlation is unlikely to be large and the fact that we still find it is quite reassuring. Interestingly, there is only one case which specifically deals with a cartel rigging bids on the EKS platform, but since it is still in process the identity of the firms involved is not yet revealed. Appendix D.1 gives some background information of the Slovak competition authority's activity.

4.3 The Effect of the Reform

To illustrate the direct impact of the reform, we start with examining the distribution of number of preselected bidders in the main auction. These are not necessarily actively bidding in the main auction, they are just able to bid. Since the reform lifted preselection for participating in the main auction, we should observe more than three bidders participating in the main auction after the reform. Figure 4 confirms that the preselection rule was indeed binding as 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.

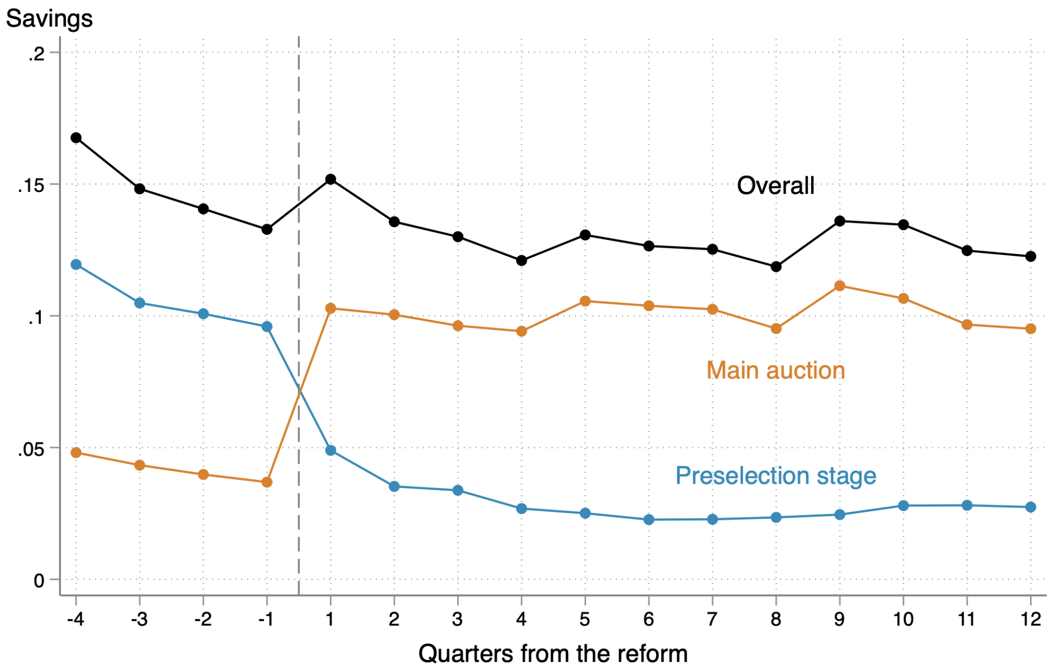
According to Proposition 1, we should not expect a large effect of the reform on savings overall if firms behave competitively. However, this does not mean that bidding behavior is not affected. While the theory does not make clear predictions about how the reform changes bidding in the preselection stage versus the main auction, Figure 5 draws a clear picture. Overall no strong effect is visible on total savings, but the reform shifted 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.

Figure 4: 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.

Figure 5: 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.

To evaluate differential effect of the reform on rigged versus non-rigged auctions, we make use of our behavioral collusion marker again. Collusive exclusion by the cartel is not possible after the reform because of the change in the preselection rule, thus it becomes no longer profitable for the cartel to appear in groups of three. Consequently, we would expect that participation of multiple cartel members in the same auction becomes less likely.[25] Still, those auctions involve a previous potential colluder and we want to identify them as such. Hence, we again mark auctions as *potentially rigged* if at least one potential colluder participates.

We use this definition of potentially rigged auctions in the following regression specification:

$$\begin{aligned} Savings_i = {} & \alpha_0 + \alpha_1 PotentiallyRigged_i + \alpha_2 PotentiallyRigged_i \times Post \\ & + \beta_1 Bidder\#2_i + \beta_2 Bidder\#2_i \times Post \\ & + \beta_3 Bidder\#3_i + \beta_4 Bidder\#3_i \times Post \\ & + \beta_5 Bidder\#4_i + \beta_6 Bidder\#4_i \times Post \end{aligned} \tag{2}$$

[25] In fact, a cartel with unlimited control over member's bids would want to eliminate participation of other cartel members except the predetermined winner, see the discussion in Section 5.1.

$$+ \beta_7 Bidder\#5_i + \beta_8 Bidder\#5_i \times Post + \gamma_t + \delta_p + \theta_c + \epsilon_i,$$

where *PotentiallyRigged* 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 2-digit level CPV-category of the procured good.

The main specification is column (3) in Table 3. Column (3) shows that the overall effect of the reform on savings is, if anything, 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.[26] Paradoxically, given the negative baseline effect of -1.7 percentage points, this suggests that, in our data, preselection is associated with higher savings for auctions for which the rule is not binding. A possible 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 than would be ex-post required given the number of actual bidders. Still, this result is in line with results in the two-stage auction literature showing that preselection increases returns, i.e savings.

[26] 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 3: Effect of the reform on overall savings

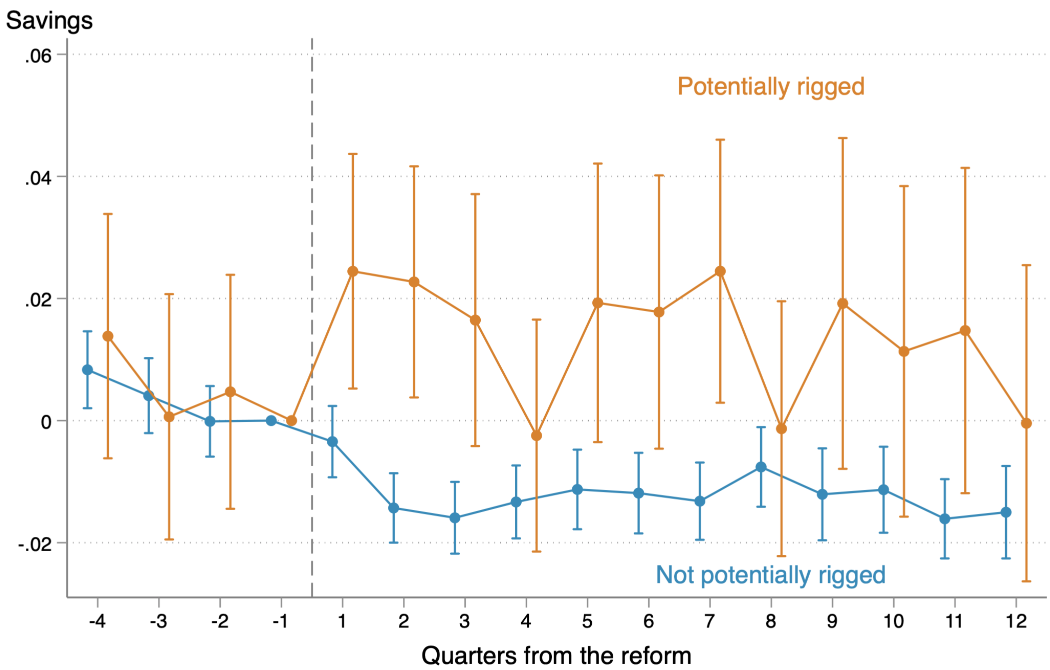
	(1) OLS	(2) OLS	(3) OLS
Post	-0.016**	-0.016**	-0.017**
	(0.006)	(0.006)	(0.006)
Potentially rigged	-0.059***	-0.050***	-0.044***
	(0.003)	(0.003)	(0.004)
Pot. rigged × Post	0.008	0.012**	0.020***
	(0.004)	(0.004)	(0.005)
Bidder #2	0.081***	0.085***	0.088***
	(0.002)	(0.002)	(0.002)
Bidder #3	0.066***	0.068***	0.070***
	(0.003)	(0.003)	(0.004)
Bidder #4	0.044***	0.042***	0.044***
	(0.004)	(0.004)	(0.004)
Bidder #5	0.079***	0.073***	0.072***
	(0.004)	(0.004)	(0.004)
Bidder #2 × Post	-0.008***	-0.007**	-0.008**
	(0.002)	(0.002)	(0.003)
Bidder #3 × Post	0.007*	0.007	0.008*
	(0.004)	(0.004)	(0.004)
Bidder #4 × Post	0.002	0.005	0.000
	(0.005)	(0.005)	(0.005)
Bidder #5 × Post	0.023***	0.021***	0.018**
	(0.005)	(0.005)	(0.005)
Constant	0.026***	0.027***	0.022***
	(0.002)	(0.002)	(0.002)
Month FE	yes	yes	yes
Year FE	yes	yes	yes
CPV Category FE	no	no	yes
Procurer FE	no	yes	yes
Adj. R2	0.33	0.37	0.39
Avg. Outcome	0.14	0.14	0.14
N	76969	76165	55654

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

Our primary interest, however, lies in the effect on potentially rigged auctions. Confirming our results from Section 4.2, auctions which we tagged as potentially rigged have 4.4 percentage points lower savings before the reform. This corresponds to about 31 percent lower savings relative to average savings of 14 percent. After the reform abolished preselection, savings were still lower for potentially rigged auctions, but the difference to average savings decreased by about 2.1 percentage points, more than 48 percent. 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.

Figure 6 depicts an illustration of this 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 non-rigged auctions and rigged auctions are trending similarly, but after the reform potentially rigged auctions have higher savings by about 2 percentage points, but with a seasonal pattern. This seasonal pattern seems to be driven by the time around the Christmas holidays where we generally observe fewer auctions, fewer bidders and lower savings.

Figure 6: Effect on the potentially rigged auctions



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 rigged and not rigged auctions.

Overall our results suggest that cartels were rigging auctions more successfully 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 non-rigged auctions we do find a slight negative effect of the reforms, which is concentrated in auctions with fewer bidders. However, our focus on bid rigging allowed us to uncover a weak point in the previous arguments in favor of two-stage auctions.

5 Discussion and Robustness

5.1 Alternative explanations for close bids

In standard 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. In this regard, our derived optimal strategy is not entirely new to the literature on bid-rigging cartels. Even so, in our model close bidding 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, it is important that three firms bid close to each other, not only two.

Furthermore, we are able to rule out alternative explanations in which competitive firms bid close to each other. First, close bids in the preselection stage could be competitive if it is the result of the firms having similar costs. 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 our data (see Section 4.2). 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. Consequently, explanations relying on competitive bidding cannot mimic the collusive pattern we observe.

5.2 Partial cartels and endogenous cartel formation

Several empirical (e.g., Athey et al., 2011; Bajari and Ye, 2003; Wallimann, Imhof and Huber, 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.[27] 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. 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.[28] 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.

5.3 Endogenous number of auction participants

One latent assumption in the theoretical and empirical analysis is that the number of auction participants does not respond to the reform. There are a few reasons why this assumption may not be as restrictive as it seems. First, note that there is no entry fee set by the procurer. Second, since the goods and services in our analysis are standardized and the auction takes place online, we do not expect high internal costs of preparing bids. It is more likely that participation is driven by free capacity, e.g., firms participate

[27] 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.

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

if they have a positive expected profit of doing so. But even if one believes that the cost of preparing a bid is sufficiently large to drive participation, Proposition 1 for the competitive case tells us that profits are not affected by the reform, so participation should not be affected either.

For illustration, suppose there is some positive entry cost which firms face upon participation to an auction. It has been shown in the literature that, when expected profit decreases in cost type, there is a threshold cost below which a firm participates and above which it does not participate (see Gentry, Li and Lu, 2017). This threshold cost is given by the marginal firm type for which expected profit equals entry cost. Since the reform does not affect profit for any firm cost type, this threshold should not be affected either. When a cartel exists, however, Proposition 2 implies that participation is less profitable for the cartel after the reform. This should dampen the positive effect of the reform on savings: With selection rule $n = N$, the cartel does not lead to inefficient outcomes, hence non-participation can only have a positive effect on the final price of the auction.

Consequently, if anything, endogenous entry is likely to dampen the effect of the reform when a cartel exists. The fact that we still find a positive effect in our data supports our claim that this increase is largely driven by removing the ability for collusive exclusion by a cartel. Further, notice that we can empirically observe the number of participants in the auctions and thus even test the exogenous entry assumption. In fact, in Figure B.3 in Appendix B the number of participants in competitive auctions is stable over time, while for potentially rigged auctions it decreases. The latter is consistent with the fact that after the reform, it is not profitable for multiple cartel members to participate anymore.

5.4 Common values and cost updating

While the theoretical literature on two-stage or hybrid auctions considers models with imperfect information about own type and/or a common value component, we chose to abstract from these issues for a number of reasons. First, the EKS platform is mandatory and therefore predominantly used for standardized goods and services, for which firms are likely to have a precise cost estimate. Second, the result on the optimal cartel bidding behavior is qualitatively not affected by our assumption (Lemma 3). Irrespective of the arrival of new information at the beginning of the main auction, since it is costless to match the lowest cartel opening bid, colluders should do so. Obviously, the exact shape of the bid function may differ in a model with value updating, but since also in such a model the shape would depend on model parameters and distribution assumptions, we chose an approach which does not require us to take a stance on what value a collusive bid should have. Close opening bids in and of themselves are a sufficient statistic for bid rigging, independent of the exact bid value. Finally, including the possibility of cost updates at the beginning of the main auction (via a common or private value component of the cost type) into our model should decrease the effect of the reform on profits and savings (Propositions 1 and 2). In principle, it is possible that it may even reverse the effect of the reform when a cartel exists. The fact that we observe a positive effect in our empirical analysis therefore suggests that exploitation of the preselection rule overcompensates any savings increasing effects of hybrid auctions.

6 Conclusion

In this paper, we analyse how a partial cartel may exploit preselection rules of two-stage or hybrid auctions. If the preselection stage is in form of a first-price sealed-bid auction and a fixed number of bidders is preselected according to their opening bids in the preselection stage, members of a cartel will place the same opening bid and thereby potentially exclude rivals from the main auction. Our theoretical model formalizes this intuition and makes predictions about the effect of abolishing the preselection rule to allow any interested firms to participate in the main auction. Without preselection a bid-rigging cartel cannot exploit preselection rules anymore and thus collusive gains decrease to what is possible by only avoiding competition within the cartel and not also from outsiders. This is reflected in higher savings for procurement agencies when bidders are not preselected. In contrast, if all firms are competitive, abandoning preselection should have no effect on profits and savings. Using the theoretically derived collusive practice as a collusive marker, we can confirm those predictions with quasi-experimental evidence. We study a reform on the electronic public procurement platform in Slovakia which removes bidder preselection. Results show that participation of firms, which we mark as collusive because they were frequently involved in close bidding, is associated with little competition in the main auction stage and lower savings for public procurement authorities overall. The reform increased savings in such auctions, but slightly decreased savings in auctions where only competitive firms participate.

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 bid rigging which may undo all those gains. Our theoretical result hinges on the assumption that the submission of opening bids has very low cost, which is realistic when standardized goods and services are procured. When submitting an opening bid is costly, participation by multiple cartel members may not be worth the gains of excluding competitive rivals. Then, previous results in the two-stage auction literature again prevail. Hence, the optimal auction format depends on the competitive as well as informational environment in which the firms operate. Taking this into account, procurement agencies need to carefully weigh the pros and cons to choose the auction format best suited for the good or service they demand. By adding an important dimension to the analysis of two-stage auctions, our results are informative for government agencies making that decision.

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A Theoretical Appendix

A.1 Proof of Lemma 1

Proof. First note that no firm would undercut the bid of any other firm with $q_i < c_i$, since not bidding leads to profits of zero and bidding leads to negative profits $q_i - c_i < 0$. Hence any final bid must satisfy $q_i \geq c_i$. W.l.o.g., suppose that firm j has the lowest cost, hence $c_j = \min_{i \in P_n} c_i$.

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 $c_m \geq b_j$, then, as established before, firm l will never undercut firm j's opening bid b_j and firm j wins at a final bid $q_j = b_j$. If $c_m < b_j$, for any final bid $q_m : b_j \geq q_m > c_m$ of firm m, firm j would profit from marginally undercutting m's final bid. But then firm m would again profit from undercutting as long as $q_j > c_m$. Hence, undercutting continues to happen until either $q_j = c_m$ or $q_m = c_m$. If $q_j = c_m$, firm j receives c_m. If $q_m = c_m$, firm j finds it profitable to marginally undercut firm m and receives $c_m - \epsilon$ for ϵ arbitrarily small.

Second, consider the case when j is part of a cartel, i.e., $j \in I_k$ with $|I_k| > 1$. Any other selected cartel member $l \neq j$, $l \in P_n \cap I_k$, should not bid further in the main auction, hence $q_l = b_l$: If $q_l < \min_{i \in P_n \setminus I_k} c_i$, a marginal increase in the final bid of cartel member l, q_l, would lead to a strict increase in the price received by the cartel, otherwise the price will remain unaffected. 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 that same logic as above in the competitive case with the exception that the case distinction has to consider whether $c_m \geq min_{l \in I_k} b_l$ or $c_m < min_{l \in I_k} b_l$ (instead of $c_m \geq b_j$ or $c_m < b_j$). □

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 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 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:

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

Note however that, if more than n_0 bidders place opening bid x, n_0 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:

$$\Delta P = \sum_{t=n_0}^{N-1} \binom{N-1}{t} \frac{t+1-n_0}{t+1} (G(b) - G(a))^t (1 - G(b))^{N-1-t} > 0.$$

The strict inequality follows from the fact that $n_0 \leq N-1$.

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_0-th lowest cost c_0 among $N-1$ rivals with $G_{n_0:N-1}(c_0)$, and the distribution of the lowest-cost rival conditional on its cost being lower than c_0 as $G_{C|C\leq c_0}(\cdot)$. Given a report profile $c = (c_i, c_{-i})$, a direct revelation mechanism describes a main-auction entry rule $\{x_i(c)\}_{i=1}^N$ and an entry payment rule $\{p_i(c)\}_{i=1}^N$. The entry rule is $x_i(c_i, c_{-i}) = 1$ if $c_i < c_0$, and $x_i(c_i, c_{-i}) = 0$ if $c_i > c_0$, where $\sum_{i=1}^N x_i(c) = n_0$. The expected entry payment when reporting c_i is then

$$\mathbb{E}\left[p_i(c_i, C_{-i})\right] = \int_{c_i}^{\bar{c}} \int_{\beta(c_i)}^{c_0} x - \beta(c_i) dG_{C|C<c_0}(x) dG_{n_0:N-1}(c_0).$$

Suppose firm i faces rivals which report their types truthfully. The expected profit of firm i when it indicates to be of type c_i' at the beginning of the selection stage is given by:

$$\Pi^S(c_i', c_i; \beta) = \int_{c_i'}^{\bar{c}} \int_{c_i}^{c_0} (\min\{\beta(c_i'), x\} - c_i) dG_{C|C<c_0}(x) dG_{n_0:N-1}(c_0)$$

The FOC evaluated at $c_i' = c_i$ is then given by:

$$\frac{\partial \Pi^S}{\partial c_i'}_{|c_i'=c_i} = \int_{c_i}^{\bar{c}} \int_{\min\{\beta(c_i),\bar{c}\}}^{c_0} \beta'(c_i) dG_{C|C<c_0}(x) dG_{n_0:N-1}(c_0)$$

In a symmetric equilibrium, the marginal profit of increasing the own bid at $c_i' = c_i$ has to equal 0. It is easy to see from the above equation that this always holds as long as $\beta(c_i) \geq \bar{c}$. Hence any strictly increasing bid function which satisfies this condition for all c_i in addition to being strictly increasing can be supported in equilibrium. □

A.3 Proof of Proposition 1

Proof. First note that with selection rule $n_1 = N$, 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 $b_i \in [\bar{c}, r]$ 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[29]

$$\Pi^{F*}(c_i) = \int_{c_i}^{\bar{c}} (x - c_i) dG_{1:N-1}(x)$$

With selection rule $n_0 < N$, expected profit of firm i when all firms including itself follow an optimal bid function β_S as described in Lemma 2 is given by

$$\begin{aligned}\Pi^{S*}(c_i) &= \int_{c_i}^{\bar{c}} \int_{c_i}^{c_0} (x - c_i) dG_{C|C<c_0}(x) dG_{n_0:N-1}(c_0) \\ &= \int_{c_i}^{\bar{c}} (x - c_i) dG_{1:N-1}(x) = \Pi^{F*}(c_i)\end{aligned}$$

where the second equality follows from the fact that $G_{C|C<c_0}(x) G_{n_0:N-1}(c_0) = G_{1:N-1}(x)$.

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:

$$\mathbb{E}(s^F) = r - \int_0^{\bar{c}} x dG_{2:N}(x)$$

With selection rule n expected savings, when firms follow an optimal bid function

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

β^S, can be written as:

$$\mathbb{E}(s^S) = r - \int_0^{\bar{c}} \int_0^x \min\{\beta^S(c), x\} dG_{C|C<x}(c) dG_{2:N}(x)$$

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

A.4 Proof of Lemma 3

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 $\hat{c}$ always submits the lowest final cartel bid b_C (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: $b_j \geq b_C$ $\forall j \in I_k$.

With this assumption in mind, the proof is structured as follows: We prove (i) in two steps: First, taking the lowest cartel bid b_C as given, step (ia) shows that it is optimal for at least n_0 cartel members to bid $b_j = b_C$, while remaining cartel members may bid more. Second, step (ib) shows that there exists a function such that $b_C = \beta_C(\hat{c})$ which lies in the interval $[\beta_O(\underline{c}), r]$. Finally, we prove part (ii) of the Lemma.

(ia) With $|I_k| < n_0$, let us denote the bidding recommendation of the non-winning cartel member with $b_I \geq b_C$. Independent of b_I, $|P_n \backslash I_k| \geq 1$ as $n_0 < N$. Moreover, since rival's bid function is strictly increasing, the rival firm with cost $\min_{i \in A \backslash I_k} c_i$ is always selected. Then, it is easy to see that any $b_I \in [b_C, r]$ (including $b_I = b_C$) leaves cartel profits unaffected, see Lemma 1. With $|I_k| = N$, it is clearly optimal to minimize competition in the selection stage and thus for everyone to bid $b_I = b_C = r$.

When $N > |I_k| \geq n_0$ the cartel has more than n_0 bids at its disposal and faces at least one competitive rival. Since the cartel does not care about the identity of bidders, we denote b_I to be the n_0-lowest cartel bid, i.e., there exist exactly $n_0 - 2$ cartel members j such that $b_C \leq b_j \leq b_I$.[30] Hence, the value of b_C 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 $\boldsymbol{b}_C$. If $n_0 \leq N - |I_k|$, cartel profits are

[30] Since competitive rivals bid according to a strictly increasing bid function, one could again rewrite the problem as one of revealing the cost type of cartel members. However, since it is one entity which in principle can choose multiple bids, it is easier to follow when considering the effective bidding scheme.

given by:[31]

$$\Pi_C^S(\boldsymbol{b}_C,\beta_O)=\int_{\beta_O^{-1}(b_C)}^{\bar{c}}\left[\int_{\hat{c}}^{\beta_O^{-1}(b_I)}(\min\{b_C,x\}-\hat{c})^+dG_{C|C<c_0}(x)\right.$$
$$\left.+\int_{\beta_O^{-1}(b_I)}^{c_0}b_C-\hat{c}dG_{C|C<c_0}(x)\right]dG_{n_0:N-|I_k|}(c_0)$$

While if $n_0>N-|I_k|$, cartel profits are given by:[32]

$$\Pi_C^S(\boldsymbol{b}_C,\beta_O)=\int_{\hat{c}}^{\beta_O^{-1}(b_I)}(\min\{b_C,x\}-\hat{c})^+dG_{1:N-|I_k|}(x)+\int_{\beta_O^{-1}(b_I)}^{\bar{c}}b_C-\hat{c}dG_{1:N-|I_k|}(x)$$

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

Moreover, reducing b_I as long as $\beta_O(b_C)>b_I\geq b_C$ 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, $\frac{\partial\Pi_C^S}{\partial b_I}$, can be rewritten as:

$$(\min\{b_C,\beta_O^{-1}(b_I)\}-\hat{c})^+-(b_C-\hat{c})<\min\{b_C,\beta_O^{-1}(b_I)\}-b_C<0$$

Consequently, it is always optimal for the cartel to set a bidding scheme where $b_I=b_C$, whether $n_0\leq N-|I_k|$ or $n_0>N-|I_k|$.

(ib) First note that except for the n_0 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_0 of its members b_C. Moreover, the bid support as well as profits are bounded, and expected cartel profits exclusively depend on the lowest cost among cartel bidders $\hat{c}$. Hence, a single optimal bid function for the cartel $b_C=\beta_C(\hat{c})$, where $\beta_C:C\to[\underline{c},r]$, always exists (though it may not be unique). Now we show that it cannot be smaller than the lower bound of the competitive bid image support. Suppose there exists some $\hat{c}$ such that $\beta_C(\hat{c})<\beta_O(\underline{c})$. Clearly, increasing the cartel bid by at most $\beta_O(\underline{c})-\beta_C(\hat{c})$ would increase the expected price received upon winning the main auction but not change the amount and identity of rivals selected. Hence $\beta_C(\hat{c})<\beta_O(\underline{c})$ cannot be optimal.

[31] In this case, there are enough cartel outsiders to allow for the possibility that not a single cartel member is selected for the main auction.

[32] In this case, at least one cartel member proceeds irrespective of the value of b_C with certainty.

(ii) We have established that the cartel's optimal scheme has to involve that at least n_0 members bid the same value $b_j = \beta_C(\hat{c})$, while all other bids have to be weakly larger but their exact value is irrelevant. Hence, since the cartel effectively chooses one bid, we use consider the associated problem where the cartel reports its type: For any bid $\beta_C(\hat{c})$ that the cartel makes, since β_O is strictly increasing, we can find a unique cost level c' associated with the cartel bid: $c' = \beta_O^{-1}(\beta_C(\hat{c}))$.

Then, if $n_0 > N - |I_k|$ and $N > |I_k| \geq n_0$ cartel profits can be rewritten as:

$$\Pi_C^S(c', \hat{c}; \beta_O) = \int_{\hat{c}}^{c'} (x - \hat{c})^+ dG_{1:N-|I_k|}(x) + \int_{c'}^{\bar{c}} (\beta_O(c') - \hat{c}) dG_{1:N-|I_k|}(x)$$

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

$$\begin{aligned}\frac{\partial \Pi_C^S(c', \hat{c}; \beta_O)}{\partial c'} &= \mathbb{1}_{c' > \hat{c}}(c' - \hat{c}) g_{1:N-|I_k|}(c') - (\beta_O(c') - \hat{c}) g_{1:N-|I_k|}(c') \\ &+ (1 - G_{1:N-|I_k|}(c'))\beta_O'(c') = 0\end{aligned}$$

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

$$\begin{aligned}\frac{\partial \Pi_C^S(c', \hat{c}; \beta_O)}{\partial c'}|_{c'=\bar{c}} &= (\bar{c} - \hat{c}) g_{1:N-|I_k|}(\bar{c}) - (\beta_O(\bar{c}) - \hat{c}) g_{1:N-|I_k|}(\bar{c}) + (1 - G_{1:N-|I_k|}(\bar{c}))\beta_O'(\bar{c}) \\ &= -(\beta_O(\bar{c}) - \bar{c}) g_{1:N-|I_k|}(\bar{c}) < 0\end{aligned}$$

In case of $n_0 \leq N - |I_k|$ and $N > |I_k| \geq n_0$ the analysis is similar. □

A.5 Proof of Proposition 2

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

Effect on cartel profits 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 $n_1 = N$ and $|I_k| < N$, similar to the analysis in the competitive case, any bidding scheme $\boldsymbol{b}_C^F \in [\bar{c}, r]^{|I_k|}$ is a weakly dominant strategy for the cartel and leads to optimal profits:

$$\Pi_C^{F*} = \int_{\hat{c}}^{\bar{c}} (x - \hat{c}) dG_{1:N-|I_k|}(x)$$

Remember from Lemma 3 that, with preselection rule $n_0 < N$, it is weakly optimal for the cartel to let all cartel members place the same opening bid, i.e., $b_j = \beta_C(\hat{c})$ for all $j \in I_k$ and we can denote the cartel profits with $\Pi_C^S(c', \hat{c}; \beta_S)$ assuming that rivals bid according to β_S as $c' = \beta_S^{-1}(\beta_C(\hat{c}))$. If $|I_k| < n_0$ and $n_0 \leq N - |I_k|$, cartel profits are given by:

$$\Pi_C^S(c', \hat{c}; \beta_S) = \int_{c'}^{\bar{c}} \int_{\hat{c}}^{c_0} (\min\{\beta_S(c'), x\} - \hat{c}) dG_{C|C<c_0}(x) dG_{n_0:N-|I_k|}(c_0)$$

Note that this is essentially the same problem as the one a competitive firm faces, with the exception that the relevant rival distribution is $G_{n_0:N-|I_k|}$ instead of $G_{n_0:N-1}$. Hence, it is optimal for the cartel to follow the same bid function as competitive firms and report $c' = \hat{c}\ \forall \hat{c} \in C$. If $n_0 > N - |I_k|$ 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 $\beta_C(\hat{c}) = \beta_S(c') \in [\bar{c}, r]$ can be supported in equilibrium. In both cases, cartel profits are the same as with selection rule N. Consequently, changing the selection rule does not affect the cartel's profits.

Now we come to the more interesting case, when $n_0 \leq |I_k| < N$. The optimal cartel bid $\beta_S(c^*)$ will depend on β_S and $G(c)$, however notice that $\Pi_C^{S*} = \Pi_C^S(c^*, \hat{c}; \beta_S) \geq \Pi_C^S(\underline{c}, \hat{c}; \beta_S)$, 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 $n_0 \leq N - |I_k|$ reporting $c' = \underline{c}$ will lead to the following cartel profits

$$\begin{aligned}
\Pi_C^S(\underline{c}, \hat{c}; \beta_S) &= \int_{\underline{c}}^{\bar{c}} \left[\int_{\underline{c}}^{c_0} (\beta_S(\underline{c}) - \hat{c}) dG_{C|C<c_0}(x) \right] dG_{n_0:N-|I_k|}(c_0) \\
&\geq \int_{\underline{c}}^{\bar{c}} \left[\int_{\underline{c}}^{c_0} (\bar{c} - \hat{c}) dG_{C|C<c_0}(x) \right] dG_{n_0:N-|I_k|}(c_0) \\
&= \bar{c} - \hat{c} > \int_{\hat{c}}^{\bar{c}} (x - \hat{c}) dG_{1:N-|I_k|}(x) = \Pi_C^{F*}
\end{aligned}$$

Also if $n_0 > N - |I_k|$ 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:

$$\begin{aligned}
\Pi_C^S(\underline{c}, \hat{c}; \beta_S) &= \int_{\underline{c}}^{c_0} (\beta_S(\underline{c}) - \hat{c}) dG_{1:N-|I_k|}(x) \\
&\geq \bar{c} - \hat{c} > \int_{\hat{c}}^{\bar{c}} (x - \hat{c}) dG_{1:N-|I_k|}(x) = \Pi_C^{F*}
\end{aligned}$$

Hence in either case $\Pi_C^{S*} > \Pi_C^{F*}$ if $n_0 \leq |I_k| < N$.

Effect on procurement savings 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 with $G_{i,j:n}(x_i, x_j)$. 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:

$$
\begin{aligned}
&\mathbb{E}(s_C^F) = \\
&r - \int_0^{\bar{c}} \left\{ \int_0^{\hat{c}} \frac{1}{G_{1:N-|I_k|}(x_1)} \left[\int_{x_1}^{\bar{c}} x_2 dG_{2,1:N-|I_k|}(x_2, x_1) + (1 - G_{2,1:N-|I_k|}(\hat{c}, x_1))\hat{c} \right] dG_{1:N-|I_k|}(x_1) \right. \\
&\left. + \int_{\hat{c}}^{\bar{c}} x_1 dG_{1:N-|I_k|}(x_1) \right\} dG_{1:|I_k|}(\hat{c})
\end{aligned}
$$

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 expression).

When considering selection rule $n_0 < N$ and $|I_k| < n_0$, 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_0 members participates in the auction.

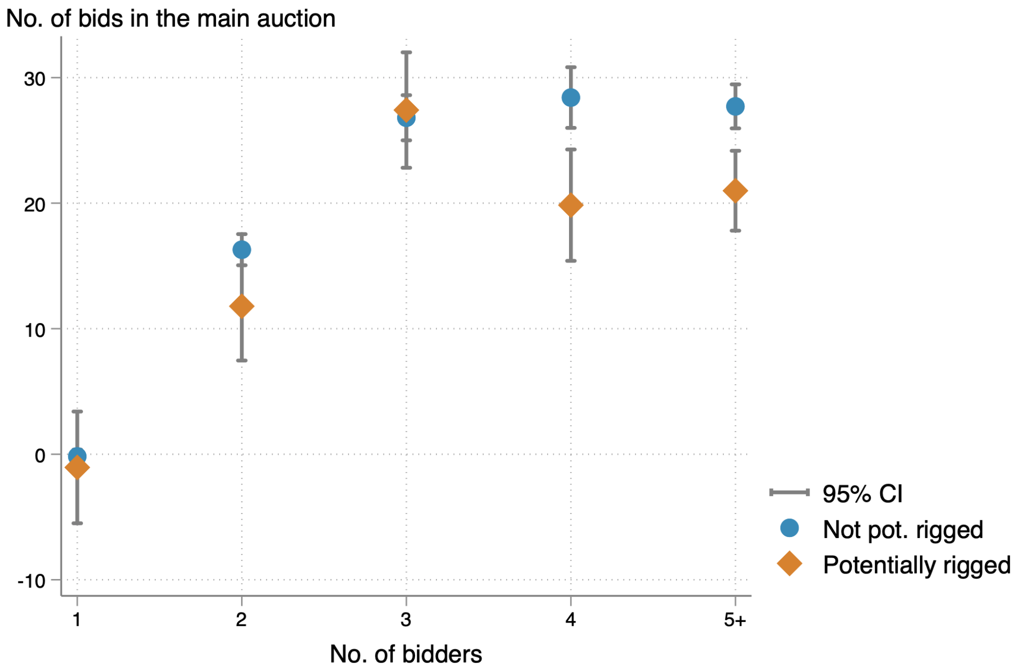
When $n_0 \leq |I_k| < N$, to show the effect on savings, we use the previously described fact that for each minimum cost level among cartel members $\hat{c}$ the cartel reports to be of type $c' = \beta_S^{-1}(\beta_C(\hat{c}))$ hence the cartel report can be written as a function $c' = \gamma(\hat{c})$ with $\gamma : C \to C$. Remember that it depends on the bidding strategy of competitive firms β_S and the distribution of costs $G(c)$ whether the cartel will locally choose to bid more or less aggressively than a competitive firm, i.e., whether $c' < \hat{c}$ or $c' \geq \hat{c}$. 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 $n_0 < N$. Abstracting from this inefficiency can be viewed as an upper bound on savings and simplifies the expressions: 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, $\mathbb{E}(s_C^H) \geq \mathbb{E}(s_C^S)$, where $\mathbb{E}(s_C^H)$ denote savings in the hypothetical case:

$$\mathbb{E}(s_H^C) =$$
$$r - \int_0^{\bar{c}} \left\{ \int_0^{\hat{c}} \frac{1}{G_{1:N-|I_k|}(x_1)} \left[\int_{x_1}^{\bar{c}} x_2 dG_{2,1:N-|I_k|}(x_2, x_1) + (1 - G_{2,1:N-|I_k|}(\hat{c}, x_1))\hat{c} \right] dG_{1:N-|I_k|}(x_1) \right.$$
$$\left. + \int_{\hat{c}}^{\max\{\hat{c},\gamma(\hat{c})\}} x_1 dG_{1:N-|I_k|}(x_1) + \int_{\max\{\hat{c},\gamma(\hat{c})\}}^{\bar{c}} \beta_C(\hat{c}) dG_{1:N-|I_k|}(x_1) \right\} dG_{1:|I_k|}(\hat{c})$$

By Lemma 3 *(ii)*, $\gamma(\hat{c}) \in [\underline{c}, \bar{c})$. Since $\beta_C(\hat{c}) \geq \beta_S(\underline{c}) \geq \bar{c}\ \forall \hat{c} \in C$, $\mathbb{E}(s_C^F) > \mathbb{E}(s_C^H)$, and changing the selection rule increases savings strictly. □

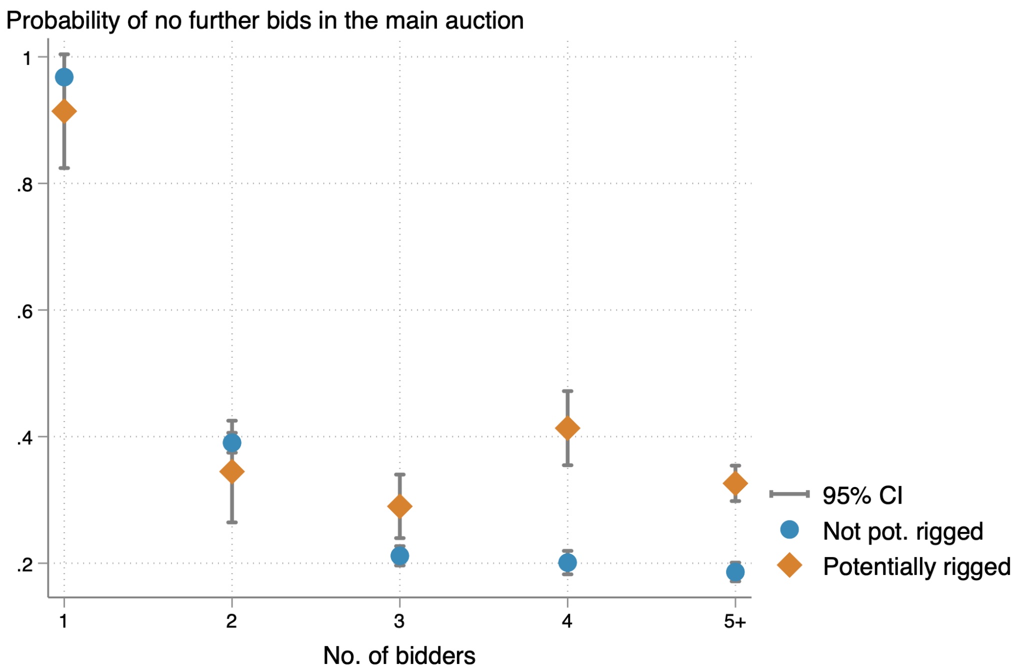
B Supplementary Figures

Figure B.1: Heterogeneity of the collusion effect: number of bids



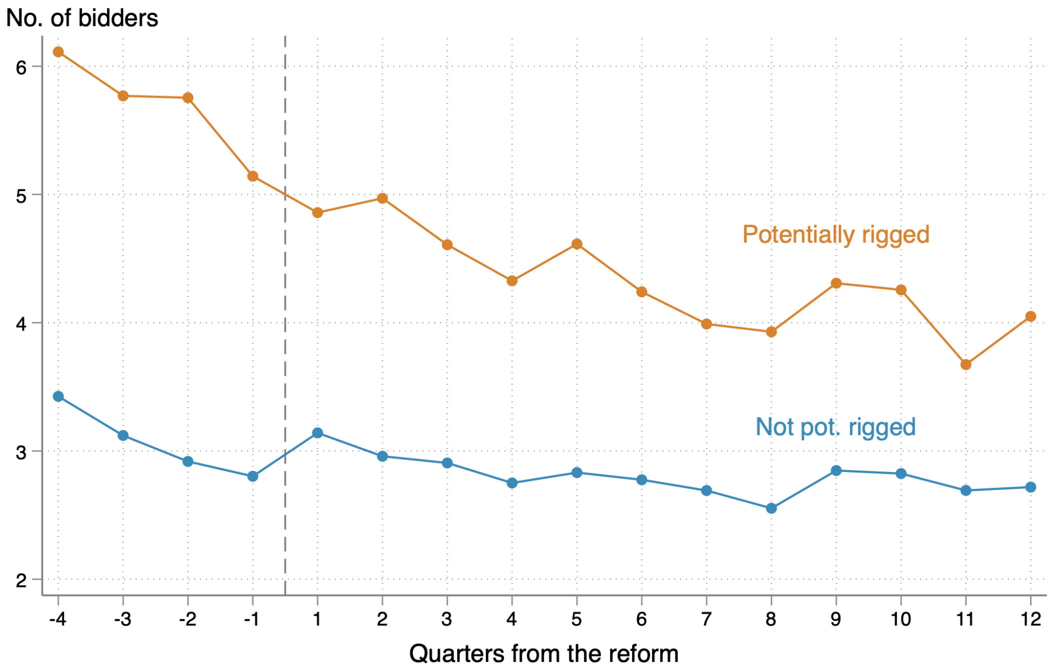
Notes: The graph plots estimates of number of bids in the main auction from a regression with full interactions between the number of bidders and an indicator for a potentially rigged auction, while controlling for a set of CPV-category, procurer, year and month fixed effects. The value 5+ on the x-axis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

Figure B.2: Heterogeneity of the collusion effect: no bids



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

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



Notes: The graph shows average number of bidders by quarter, separately for potentially rigged auctions and not rigged auctions.

C Supplementary Tables

C.1 Robustness: 99th percentile close bidding

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

	Competition in Stage 2:			Savings:		
	Bidders	Bids	Without bids	Stage 1	Stage 2	Total
Bidder #2	1.10***	16.34***	-0.58***	0.03***	0.06***	0.09***
	(0.02)	(0.64)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #3	0.64***	10.85***	-0.17***	0.04***	0.02***	0.07***
	(0.02)	(1.08)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #4	0.01	0.70	0.00	0.05***	-0.01*	0.04***
	(0.03)	(1.44)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #5	0.06	-0.80	-0.01	0.08***	-0.02***	0.07***
	(0.03)	(1.37)	(0.01)	(0.00)	(0.00)	(0.00)
Colluder #1	-0.56***	-9.41***	0.21***	-0.02*	-0.02***	-0.04***
	(0.06)	(2.00)	(0.03)	(0.01)	(0.00)	(0.01)
Colluder #2	-0.06	-4.91	0.03	-0.02	-0.00	-0.02
	(0.12)	(3.16)	(0.05)	(0.02)	(0.01)	(0.02)
Colluder #3	0.44*	5.96	-0.18	-0.00	0.02	0.02
	(0.22)	(4.88)	(0.10)	(0.04)	(0.01)	(0.04)
Colluder #4	-0.29	-3.09	0.09	0.02	0.01	0.02
	(0.82)	(9.09)	(0.39)	(0.07)	(0.03)	(0.10)
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	0.38	0.13	0.36
Avg. Outcome	1.20	17.94	0.44	0.10	0.04	0.15
N	18253	18253	18253	18253	18253	18253

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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

	(1) OLS	(2) OLS	(3) OLS
Post	-0.017**	-0.017**	-0.017**
	(0.006)	(0.006)	(0.006)
Potentially rigged	-0.049***	-0.047***	-0.050***
	(0.006)	(0.006)	(0.007)
Pot. rigged × Post	0.017*	0.031***	0.037***
	(0.008)	(0.008)	(0.010)
Bidder #2	0.079***	0.084***	0.087***
	(0.002)	(0.002)	(0.002)
Bidder #3	0.061***	0.065***	0.068***
	(0.003)	(0.003)	(0.004)
Bidder #4	0.045***	0.042***	0.044***
	(0.004)	(0.004)	(0.004)
Bidder #5	0.074***	0.069***	0.070***
	(0.004)	(0.004)	(0.004)
Bidder #2 × Post	-0.008**	-0.006*	-0.008**
	(0.002)	(0.002)	(0.003)
Bidder #3 × Post	0.008*	0.008*	0.010*
	(0.004)	(0.004)	(0.004)
Bidder #4 × Post	-0.001	0.004	-0.000
	(0.005)	(0.005)	(0.005)
Bidder #5 × Post	0.027***	0.024***	0.019***
	(0.005)	(0.005)	(0.005)
Month FE	yes	yes	yes
Year FE	yes	yes	yes
CPV Category FE	no	no	yes
Procurer FE	no	yes	yes
Adj. R2	0.32	0.36	0.38
Avg. Outcome	0.14	0.14	0.14
N	76969	76165	55654

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

C.2 Robustness: 90th percentile close bidding

Table C.3: Bidding in the main auction with preselection

	Competition in Stage 2:			Savings:		
	Bidders	Bids	Without bids	Stage 1	Stage 2	Total
Bidder #2	1.11***	16.57***	-0.58***	0.03***	0.06***	0.09***
	(0.02)	(0.64)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #3	0.68***	11.26***	-0.18***	0.05***	0.02***	0.07***
	(0.02)	(1.08)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #4	0.01	0.66	0.01	0.05***	-0.01	0.04***
	(0.03)	(1.44)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #5	0.09**	-0.47	-0.03*	0.09***	-0.01***	0.07***
	(0.03)	(1.36)	(0.01)	(0.00)	(0.00)	(0.00)
Colluder #1	-0.23***	-4.49**	0.07***	-0.02***	-0.02***	-0.03***
	(0.03)	(1.38)	(0.01)	(0.00)	(0.00)	(0.00)
Colluder #2	-0.14*	-3.91	0.05*	-0.02*	-0.01*	-0.02**
	(0.06)	(2.17)	(0.02)	(0.01)	(0.00)	(0.01)
Colluder #3	-0.25***	1.36	0.12***	-0.01	-0.01**	-0.02*
	(0.07)	(2.38)	(0.03)	(0.01)	(0.00)	(0.01)
Colluder #4	0.19	7.06	-0.09*	0.03*	0.00	0.03*
	(0.10)	(3.95)	(0.04)	(0.01)	(0.00)	(0.01)
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	0.41	0.12	0.39	0.38	0.14	0.37
Avg. Outcome	1.20	17.94	0.44	0.10	0.04	0.15
N	18253	18253	18253	18253	18253	18253

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C.4: Effect of the reform on overall savings

	(1) OLS	(2) OLS	(3) OLS
Post	-0.016**	-0.016**	-0.017**
	(0.006)	(0.006)	(0.006)
Potentially rigged	-0.060***	-0.052***	-0.048***
	(0.003)	(0.003)	(0.003)
Pot. rigged × Post	0.007*	0.012***	0.020***
	(0.003)	(0.004)	(0.004)
Bidder #2	0.082***	0.086***	0.089***
	(0.002)	(0.002)	(0.002)
Bidder #3	0.067***	0.069***	0.072***
	(0.003)	(0.003)	(0.004)
Bidder #4	0.046***	0.044***	0.045***
	(0.004)	(0.004)	(0.004)
Bidder #5	0.081***	0.074***	0.075***
	(0.004)	(0.004)	(0.004)
Bidder #2 × Post	-0.007**	-0.006*	-0.008**
	(0.002)	(0.002)	(0.003)
Bidder #3 × Post	0.006	0.006	0.007
	(0.004)	(0.004)	(0.004)
Bidder #4 × Post	0.001	0.004	-0.000
	(0.005)	(0.005)	(0.005)
Bidder #5 × Post	0.022***	0.020***	0.016**
	(0.005)	(0.005)	(0.005)
Month FE	yes	yes	yes
Year FE	yes	yes	yes
CPV Category FE	no	no	yes
Procurer FE	no	yes	yes
Adj. R2	0.33	0.37	0.39
Avg. Outcome	0.14	0.14	0.14
N	76969	76165	55654

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

C.3 Robustness: bid range 0.05%

Table C.5: Bidding in the main auction with preselection

	Competition in Stage 2:			Savings:		
	Bidders	Bids	Without bids	Stage 1	Stage 2	Total
Bidder #2	1.11***	16.48***	-0.58***	0.03***	0.06***	0.09***
	(0.02)	(0.64)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #3	0.66***	11.22***	-0.18***	0.05***	0.02***	0.07***
	(0.02)	(1.08)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #4	0.04	1.26	-0.01	0.05***	-0.00	0.04***
	(0.03)	(1.44)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #5	0.12***	0.38	-0.04***	0.09***	-0.01***	0.07***
	(0.03)	(1.38)	(0.01)	(0.00)	(0.00)	(0.00)
Colluder #1	-0.53***	-10.31***	0.20***	-0.01*	-0.03***	-0.04***
	(0.04)	(1.75)	(0.02)	(0.01)	(0.00)	(0.01)
Colluder #2	-0.12	-3.07	0.08**	-0.01	-0.00	-0.02
	(0.07)	(2.06)	(0.03)	(0.01)	(0.00)	(0.01)
Colluder #3	-0.16	-3.71	0.04	0.01	-0.01*	0.00
	(0.09)	(2.39)	(0.04)	(0.01)	(0.00)	(0.01)
Colluder #4	-0.11	0.74	0.05	0.04	0.00	0.05
	(0.19)	(4.35)	(0.08)	(0.03)	(0.01)	(0.03)
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	0.41	0.13	0.40	0.38	0.14	0.36
Avg. Outcome	1.20	17.94	0.44	0.10	0.04	0.15
N	18253	18253	18253	18253	18253	18253

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C.6: Effect of the reform on overall savings

	(1) OLS	(2) OLS	(3) OLS
Post	-0.018**	-0.018**	-0.018**
	(0.006)	(0.006)	(0.006)
Potentially rigged	-0.051***	-0.047***	-0.048***
	(0.004)	(0.004)	(0.005)
Pot. rigged × Post	0.044***	0.049***	0.052***
	(0.005)	(0.005)	(0.006)
Bidder #2	0.079***	0.084***	0.088***
	(0.002)	(0.002)	(0.002)
Bidder #3	0.063***	0.066***	0.069***
	(0.003)	(0.003)	(0.004)
Bidder #4	0.047***	0.044***	0.045***
	(0.004)	(0.004)	(0.004)
Bidder #5	0.078***	0.073***	0.074***
	(0.004)	(0.004)	(0.004)
Bidder #2 × Post	-0.008***	-0.007**	-0.008**
	(0.002)	(0.002)	(0.003)
Bidder #3 × Post	0.007	0.006	0.008*
	(0.004)	(0.004)	(0.004)
Bidder #4 × Post	-0.003	0.002	-0.002
	(0.005)	(0.005)	(0.005)
Bidder #5 × Post	0.022***	0.019***	0.015**
	(0.005)	(0.005)	(0.005)
Month FE	yes	yes	yes
Year FE	yes	yes	yes
CPV Category FE	no	no	yes
Procurer FE	no	yes	yes
Adj. R2	0.32	0.36	0.38
Avg. Outcome	0.14	0.14	0.14
N	76969	76165	55654

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

C.4 Robustness: bid range 0.005%

Table C.7: Bidding in the main auction with preselection

	Competition in Stage 2:			Savings:		
	Bidders	Bids	Without bids	Stage 1	Stage 2	Total
Bidder #2	1.11***	16.45***	-0.58***	0.03***	0.06***	0.09***
	(0.02)	(0.64)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #3	0.66***	10.98***	-0.17***	0.05***	0.02***	0.07***
	(0.02)	(1.08)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #4	-0.00	0.18	0.01	0.05***	-0.01*	0.04***
	(0.03)	(1.43)	(0.01)	(0.00)	(0.00)	(0.00)
Bidder #5	0.06	-0.74	-0.01	0.08***	-0.02***	0.07***
	(0.03)	(1.35)	(0.01)	(0.00)	(0.00)	(0.00)
Colluder #1	-0.26***	-5.41**	0.07***	-0.00	-0.01***	-0.02**
	(0.04)	(2.09)	(0.02)	(0.01)	(0.00)	(0.01)
Colluder #2	-0.05	2.89	0.03	-0.01	-0.01	-0.02
	(0.08)	(2.89)	(0.03)	(0.01)	(0.00)	(0.01)
Colluder #3	-0.12	-0.49	0.05	-0.03**	-0.01*	-0.04***
	(0.09)	(2.77)	(0.04)	(0.01)	(0.00)	(0.01)
Colluder #4	0.23	23.84**	-0.08	-0.01	0.01	-0.01
	(0.15)	(7.54)	(0.06)	(0.02)	(0.00)	(0.02)
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	0.38	0.14	0.36
Avg. Outcome	1.20	17.94	0.44	0.10	0.04	0.15
N	18253	18253	18253	18253	18253	18253

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C.8: Effect of the reform on overall savings

	(1) OLS	(2) OLS	(3) OLS
Post	-0.016**	-0.017**	-0.017**
	(0.006)	(0.006)	(0.006)
Potentially rigged	-0.053***	-0.044***	-0.038***
	(0.003)	(0.004)	(0.004)
Pot. rigged × Post	-0.007	-0.001	0.008
	(0.004)	(0.004)	(0.005)
Bidder #2	0.081***	0.085***	0.088***
	(0.002)	(0.002)	(0.002)
Bidder #3	0.064***	0.067***	0.069***
	(0.003)	(0.003)	(0.004)
Bidder #4	0.044***	0.042***	0.043***
	(0.004)	(0.004)	(0.004)
Bidder #5	0.076***	0.070***	0.070***
	(0.004)	(0.004)	(0.004)
Bidder #2 × Post	-0.007**	-0.006*	-0.008**
	(0.002)	(0.002)	(0.003)
Bidder #3 × Post	0.008*	0.008*	0.009*
	(0.004)	(0.004)	(0.004)
Bidder #4 × Post	0.003	0.005	0.001
	(0.005)	(0.005)	(0.005)
Bidder #5 × Post	0.025***	0.024***	0.020***
	(0.005)	(0.005)	(0.005)
Month FE	yes	yes	yes
Year FE	yes	yes	yes
CPV Category FE	no	no	yes
Procurer FE	no	yes	yes
Adj. R2	0.33	0.37	0.39
Avg. Outcome	0.14	0.14	0.14
N	76969	76165	55654

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

D Supplementary Information

D.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.[33] 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.

While the lion's share of these cases of cartel behavior originate in public procure-

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

ment, none of the published cases was actually documented in the EKS, the market studied in this paper. However, 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 is not yet legally binding, the details of the case remain scant and the identity of bidders is unknown.

In 2016, the AMO SR started analysing behavior of bidders in auctions on the EKS platform after receiving multiple complaints and later published its findings, consisting primarily of anecdotal evidence, in a short policy document (AMO SR, 2017). In response to the increased interest and complaints the EKS modified its auction rules on February 2017 without giving 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.

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