Detection of Collusive Networks in Multistage Auctions

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Introduction

- The public procurement market is worth 12% of global GDP [Bosio et al, 2020]
  $\Longrightarrow$ collusion is an important concern for academics and practitioners
- We propose a new method for detecting cartels in multi-stage auctions
  $\Longrightarrow$ intuition: close initial bids $\rightarrow$ incentive to undercut rival (if bids shaded)
  $\Longrightarrow$ detect firm pairs that systematically fail to follow this incentive
- We apply this method to the universe of Ukrainian procurement auctions (2016-2019)
- We validate the method using court data on 1,042 firms penalized for collusion
  $\Longrightarrow$ firm pairs classified as collusive are 8.98x (SE 2.65x) more likely to be penalized
- We find 578 cartels associated with a 2% price increase, participating in 16% of auctions

Literature Review

Collusion Detection

- Porter and Zona (1993), Porter and Zona (1999), Bajari and Ye (2003), Conley and Decarolis (2016), Chassang and Ortner (2019)
- Utilization of Prosecution Data: Asker (2014), Kawai and Nakabayashi (2021), De Leverano (2023), Clark et al. (2025), Duarte and Chaves (2025), Kawai, Nakabayashi and Ortner (2025)

Procurement Inefficiency due to Illicit Activities

- Corruption: Mironov and Zhuravskaya (2016); Kang and Miller (2020)
- Political connections: Schoenherr (2019); Baranek and Titl (2024); Titl and Geys (2019)
- Electronic auctions or audits: Lewis-Faupel et al. (2016); Olken (2007); Lichand and Fernandes (2019); Gerardino et al.(2024)

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Contribution

1. identification of *whole* bidding cartels
2. setting is a *developing* economy

Agenda

The ProZorro Auction

1. Both bidders simultaneously submit bids & docs
2. Bids (but not docs) made public and online auction begins:
   1. First, initial loser can lower his bid publicly.
   2. Then, initial winner can lower her bid.
3. Lowest final bid wins.

$\Longrightarrow$ sequential Bertrand game; bid for chance to be last-mover!

Equilibrium of Auction: Intuition

- Assume initial bids fully reveal costs, solve game backwards.
- Last mover is initial winner; he undercuts if he can do so profitably.
- Anticipating this, how does initial loser behave?
  - If his costs are lower, he just undercuts the initial winner's costs.
  - If his costs are higher, he loses no matter what, so need a refinement.

  $\Longrightarrow$ If $p > 0$ chance of bid submission failure, he just undercuts initial winner's current bid.
- Given these continuation strategies, initial bids are like first-price bids.
  - Thus, initial bids are *shaded away from cost*.
- Implication: close initial bids $\Longrightarrow$ close costs, but room for undercutting.
  - With competition, should always see undercutting after close initial bids.
- In paper, we solve this for 2 players and 1 updating round (to keep proof tractable).

Modelling the Auction

- Let b_j^t be the t-th round bid by firm j; use $j = \ell$ ($j = w$) for initial loser (winner).
- Assume: (i) a small chance p of bid submission failure: $p > 0$, (ii) in case of tie latest bid wins (iii) that there is $b(\cdot)$ s.t. $b_i^1 = b(c_i)$, $b' > 0$ (i.e. initial bids are informative)
- We solve for a Perfect Bayesian Equilibrium (PBE) using backwards induction.
- Initial winner strategy in updating round (recall the initial winner moves last):

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- Initial winner strategy in updating round (recall the initial winner moves last):

$$b_w^2 = \begin{cases} b_w^1 & \text{if } b_\ell^2 > b_w^1 \\ b_\ell^2 & \text{if } b_\ell^2 \leq b_w^1 \text{ and } b_\ell^2 > c_w \\ \{b : b > b_\ell^2\} & \text{if } b_\ell^2 \leq b_w^1 \text{ and } b_\ell^2 \leq c_w. \end{cases}$$

1. The initial winner w undercuts as long as it is profitable (and necessary to win).

Modelling the Auction

- Initial loser strategy (discussion below in order of cases):

$$b_\ell^2\left(b_\ell^1,\, b_w^1;\, c_\ell\right) = \begin{cases} \hat{c}_w & \text{if } \hat{c}_w \geq c_\ell \text{ and } b_w^1 \geq \hat{c}_w \text{ and } \mathbb{E}[\pi_\ell \mid \text{gambling}] < \hat{c}_w - c_\ell \\ b_w^1 & \text{if } \hat{c}_w \geq c_\ell \text{ and } b_w^1 \geq \hat{c}_w \text{ and } \mathbb{E}[\pi_\ell \mid \text{gambling}] \geq \hat{c}_w - c_\ell \\ b_w^1 & \text{if } \hat{c}_w < c_\ell \leq b_w^1 \\ \{b : b > b_w^1\} & \text{if } b_w^1 < c_\ell \end{cases}$$

1. If cost c_ℓ is below initial winner's (inferred) cost $\hat{c}_w$, initial loser bids $\hat{c}_w$ so initial winner cannot profitably undercut in final move.
2. Technically, if p large, initial loser may gamble on bid submission failure and just undercut the standing winning bid b_w^1; but this disappears as $p \to 0$.
3. If cannot beat initial winner's inferred cost, can still undercut standing winning bid b_w^1 instead and hope for bid submission failure.
4. If even that yields a bid below cost, ensure you lose (cannot win profitably).

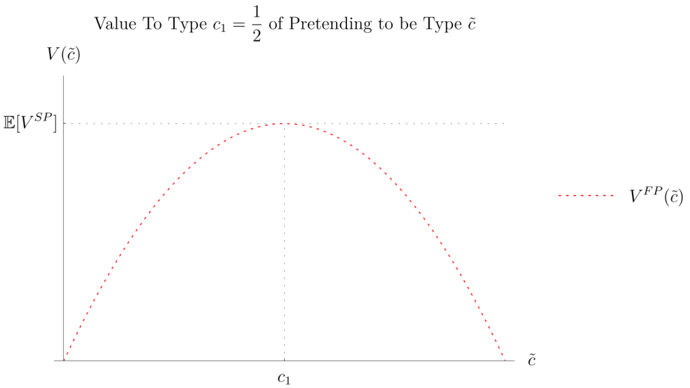
Modelling the Auction: Initial Bids

If $p \to 0$, the payoff to type c_1 from pretending to be type $\tilde{c}$ is

$$
\begin{aligned}
V^{PZ}(\tilde{c}) &= \mathbb{P}\Big(b(\tilde{c}) < b(c_2) \cap c_1 < c_2\Big)\Big(b(\tilde{c}) - c_1\Big) + \\
&\quad \mathbb{P}\Big(b(\tilde{c}) < b(c_2) \cap c_1 > c_2\Big)\Big(b(\tilde{c}) - c_1\Big) + \\
&\quad \mathbb{P}\Big(b(\tilde{c}) > b(c_2) \cap c_1 < c_2\Big)\mathbb{E}[c_2 - c_1 | c_1 < c_2, b(\tilde{c}) > b(c_2)] + \\
&\quad \mathbb{P}\Big(b(\tilde{c}) > b(c_2) \cap c_1 > c_2\Big) \times 0 \\
&= V^{FP}(\tilde{c}) + \mathbb{P}(b(\tilde{c}) > b(c_2))\mathbb{E}[V^{SP} | c_2 < \tilde{c}]
\end{aligned}
$$

Suppose $b(\cdot)$ was like in a first-price auction. What type would you want to imitate?

The Equilibrium Illustrated



$$V^{PZ}(\tilde{c}) = V^{FP}(\tilde{c}) + \mathbb{P}\Big(b(\tilde{c}) > b(c_2)\Big)\mathbb{E}[V^{SP}|c_2 < \tilde{c}]$$

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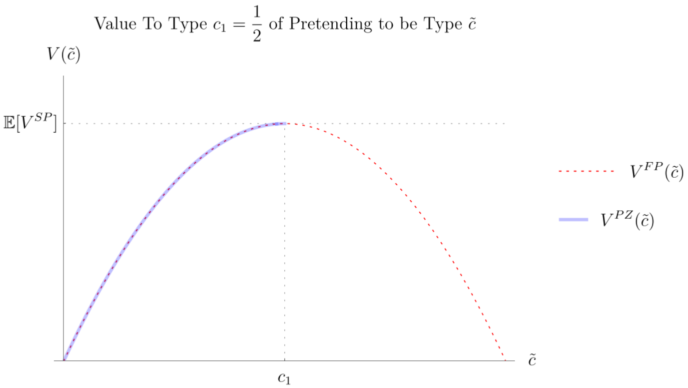

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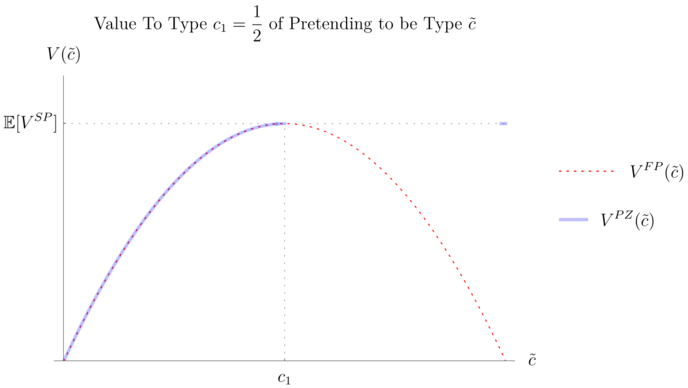

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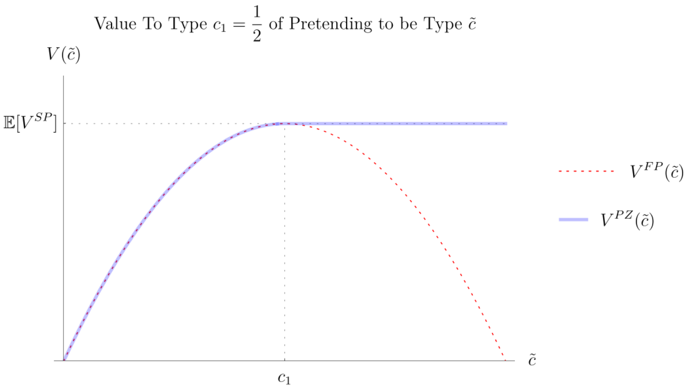

$$V^{PZ}(\tilde{c}) = V^{FP}(\tilde{c}) + \mathbb{P}\Big(b(\tilde{c}) > b(c_2)\Big)\mathbb{E}[V^{SP}|c_2 < \tilde{c}]$$

The Key Result

Proposition

If $b^1(c)$ is the equilibrium bidding strategy of a first-price auction with $c_i \sim F(\cdot)$, then $\left(b^1(\cdot), b^2_\ell, b^2_w\right)$ form a PBE.

Hence:

1. initial bids are shaded away from costs, and hence
2. close initial bids should lead to undercutting.

Agenda

1. Introduction
2. Model
3. **Data & Descriptives**
4. Collusion Detection
5. Conclusion

Data

- ProZorro (e-procurement)
  - Think eBay for public procurement
  - Tracks all procurer-tenderer interactions digitally (since 8/16)
  - Free public API access to most data (final bids, who won, CPV code, etc)
  - Data on 308k contracts tendered from 8/16 to 8/19
- Scraped Bid Data (intermediate bids)
  - All 3.05M intermediate bids for universe of auctions from 8/16 to 8/19
- Anti-Monopoly Committee of Ukraine (court data)
  - $\approx$ 1k firms penalized for collusive conduct
  - Know which firms penalized as part of same proceeding

Summary Statistics

- There is low competition in the market.
  - # bidders: 2.47 avg, 2 median (cancelled if < 2)
- Not updating is common, yet leaves money on table.
  - 68% of bids never updated, no 'competition' for 46% of contracts (i.e., no updates throughout all three auction rounds)
  - If initial loser updates, she has 20% chance of winning (but not necessarily causal!)
- Realized bid updates are small (median -2.09%)
- According to regulators, collusion is a widespread phenomenon.
  - 1,042 companies penalized for collusion
  - They participated in 20.3k tenders, 6% of contracts, 5% of value

Motivation: There May Be Collusion

- Here is the first auction we came across that worried us.

(31 864 889.19 UAH $\approx$ \$1,145,059.38)

Initial bids

ТДВ Облдоррембуд	31 864 899,19 UAH / 1,00 minimum
ТОВ "СЛАВДОРСТРОЙ"	31 864 900,00 UAH / 1,00

- Bidders should not know each other's bids, how did they end up so close?
- If they are this close, very likely one should undercut other

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Round 1

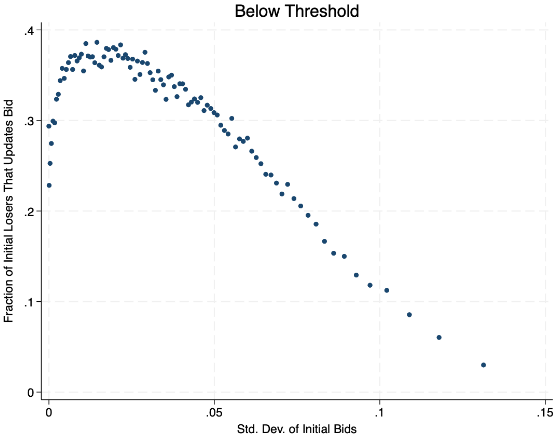
ТОВ "СЛАВДОРСТРОЙ"	31 864 900,00 UAH / 1,00
ТДВ Облдоррембуд	31 864 899,19 UAH / 1,00 minimum

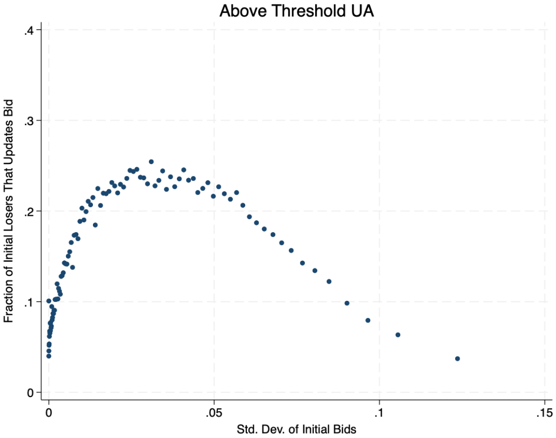
Below- vs Above-Threshold Tenders

- Above (below): auction (not) compulsory; (not) cancelled if just one bidder
- Threshold: \$7k to \$177k (varies by procurer type, works vs services)

Suspicious Behaviour I: Data

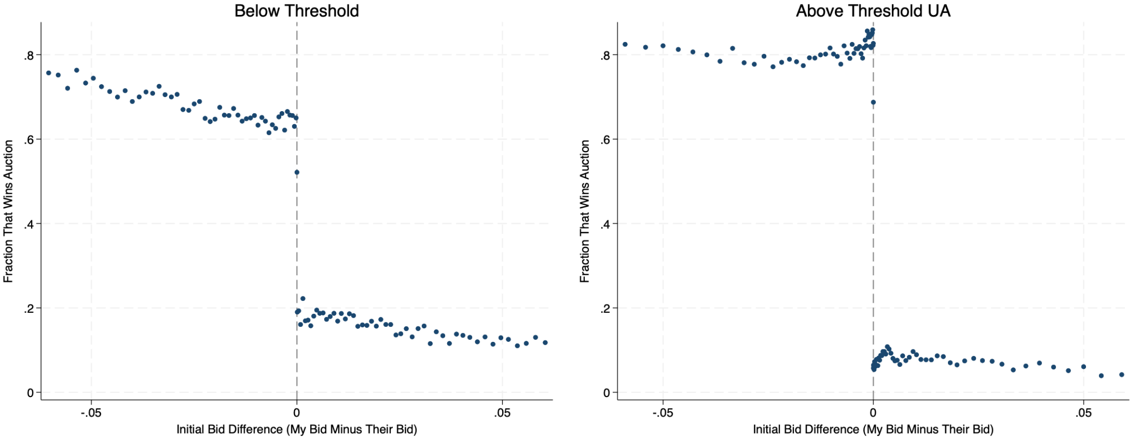
Competitive Equilibrium: close bids $\Longrightarrow$ close costs $\Longrightarrow$ frequent undercutting. Yet...





Suspicious Behaviour II: Data

Competitive Equilibrium: lower bid $\implies$ lower costs $\implies$ more likely to win. Yet...



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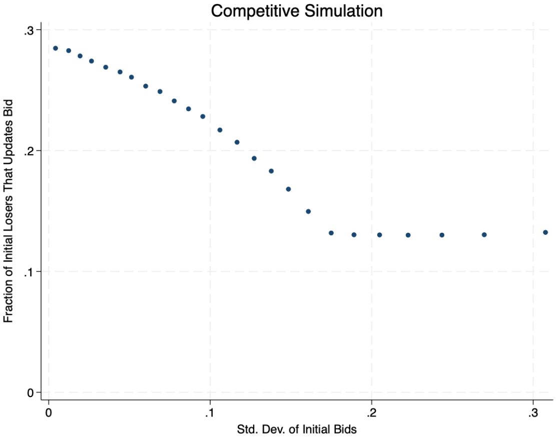

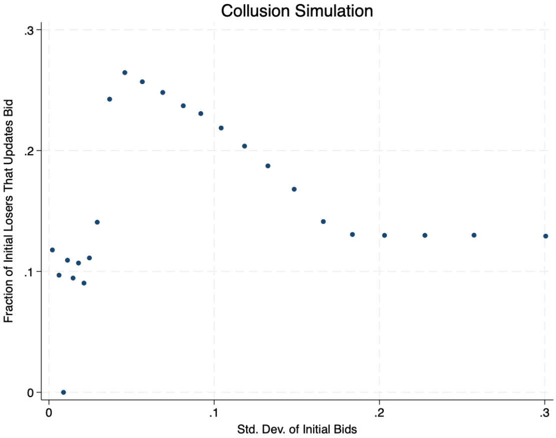

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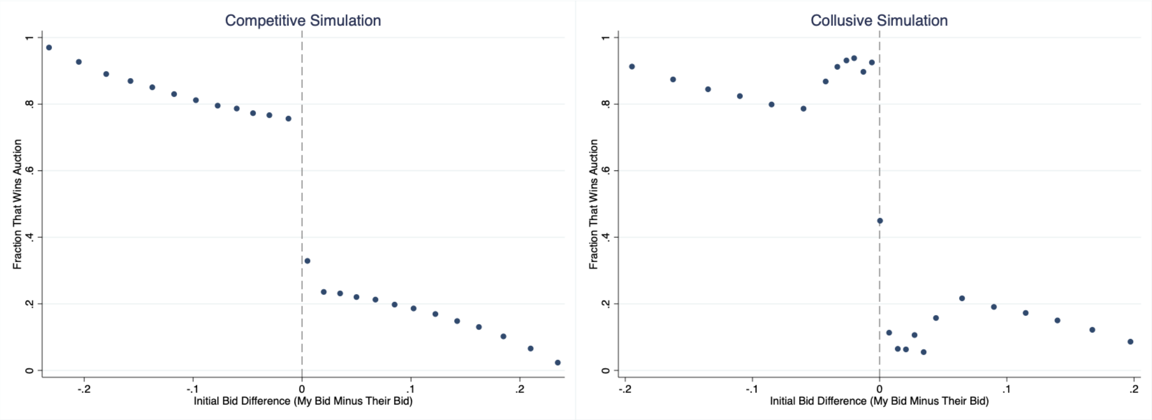

Agenda

Collusion Detection

- Intuition
  - Given equilibrium, we know when firms should undercut.
  - *Repeated* failure to undercut against *specific* firms is unlikely to be innocent.
- Formalization
  - Let $b^t_{\ell(a)}$ be t-th round bid by initial loser $\ell(a)$ in auction a (equiv. $b^t_{w(a)}$ for winner $w(a)$); then

$$\begin{aligned} 1\{b^2_{\ell(a)} < b^1_{\ell(a)}\} &= 1\{b^{-1}(b^1_{\ell(a)}) < b^1_{w(a)}\} \\ &= 1\{b^1_{w(a)} - \phi(b^1_{\ell(a)}) + \delta_{\ell(a),w(a)} + \epsilon_a \geq 0\} \end{aligned}$$

    where $\phi(b^1_{\ell(a)}) \approx b^{-1}(b^1_{\ell(a)})$ and $\delta_{\ell(a),w(a)}$ is pairwise fixed effect.
  - We estimate: $u_a = b^1_{w(a)} - \phi(b^1_{\ell(a)}) + \delta_{\ell(a),w(a)} + \nu_a$
  - Assume ϵ_α is an idiosyncratic exogenous auction-specific shock, with distribution such that we run a linear probability model.

Market-Wide Test for Collusion

- Under the null of competition, $\delta_{ij} = 0$ for all firms i and j; and hence $\hat{\delta}_{ij}$ is a noisy estimate of zero.
- We employ randomization inference (Fisher, 1935; Young, 2018).
- Collusion implies δ_{ij} negative for some pairs $\Rightarrow$ Formally, can test whether skewness is identical for observed and permuted pairwise FEs.

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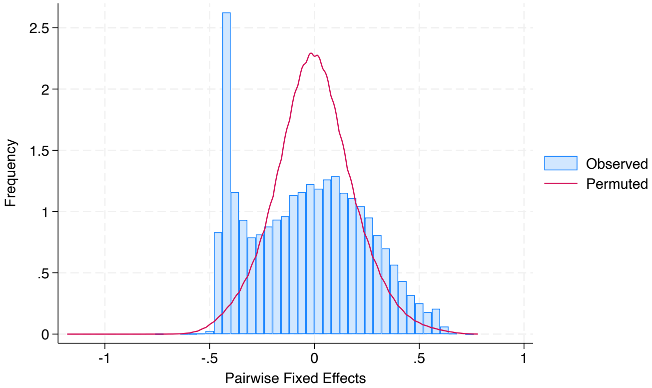
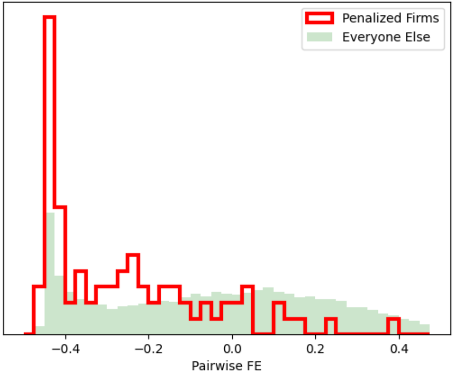
  - We reject this null at p=0.002.



FEs for Firms Penalized for Collusion vs. Others

We also find that firm pairs that have been penalized for collusion as part of the same case have more negative FE:



FE Predict Ban for Colluding

$\hat{\delta}$ have SEs $\implies$ get p-values for competition; reject if $p < 0.05$

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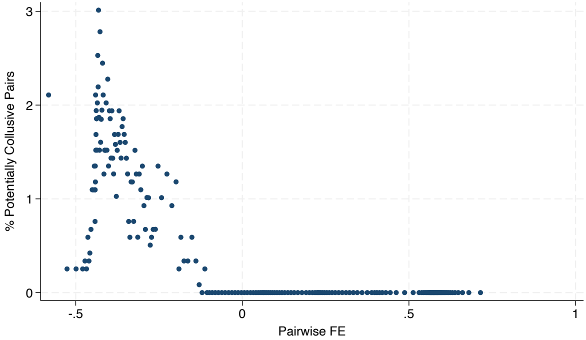

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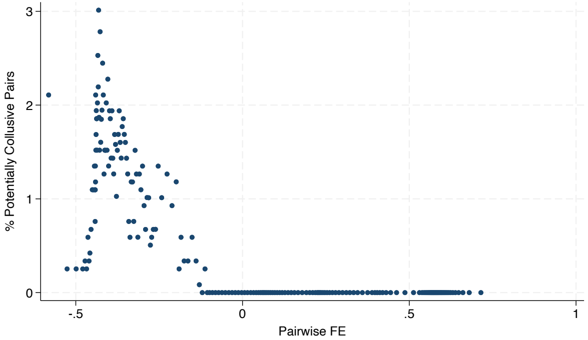

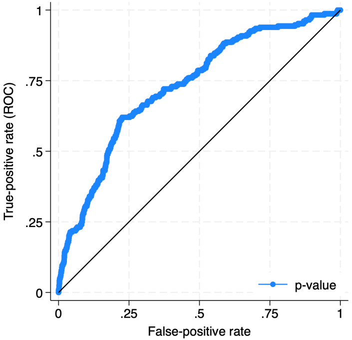

RHS plot shows evidence of quality of p-value as signal of penalization; random signal would lie on 45-deg line. To summarize quality, next investigate ROC AUC (area under curve).

Robustness of Detection Result

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Detection Quality							
ROC AUC	0.73	0.74	0.74	0.74	0.74	0.74	0.63
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
N Pairs	237,127	237,127	237,127	237,127	237,127	237,127	226,021
Panel B: Control Variables							
Initial Bid	−5.36	−5.35	−5.35	−5.38	−5.37	−5.38	−5.38
	(0.54)	(0.54)	(0.54)	(0.55)	(0.55)	(0.55)	(0.55)
Initial Bid Squared	6.81	6.80	6.79	6.87	6.85	6.87	6.87
	(0.71)	(0.72)	(0.72)	(0.73)	(0.72)	(0.73)	(0.73)
Initial Bid Cubed	−3.29	−3.29	−3.28	−3.33	−3.33	−3.33	−3.33
	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)
Log Value		0.67	0.69	0.68	0.68	0.68	0.68
		(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
# Projects Bid On			−0.26	−0.23	0.40	0.43	0.43
			(0.03)	(0.03)	(0.08)	(0.08)	(0.08)
Avg Final Bid				0.22	0.22	0.21	0.21
				(0.02)	(0.02)	(0.02)	(0.02)
# Projects Awarded					−0.75	−0.76	−0.76
					(0.10)	(0.10)	(0.10)
Procurer–Tenderer Dist. (km)						−0.04	−0.04
						(0.01)	(0.01)
Constant	1.28	1.20	1.21	1.01	1.01	1.03	1.03
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Firm FE	No	No	No	No	No	No	Yes
N Auctions	305,556	305,556	305,556	305,556	305,556	305,556	305,556
R^2	0.566	0.5661	0.5663	0.5664	0.5666	0.5667	0.5667

Recall: ROC AUC $\in [0.5, 1]$, 0.5 is random, 1 is perfect.

So in all specifications, detection is stat. signif. better than random ($t \approx 6$)

Characteristics of Detected Colluders

- Colluding pairs are co-located
  - 9.5% of colluding pairs share exact ZIP (vs 4.5% of all co-bidding firms)
  - 33.3% of colluding pairs share first two ZIP digits (vs. 18.4%)
  - Possible explanation: co-location helps with monitoring, coordination
- Most cartels are small
  - 59% of detected colluders participate in a two-firm cartel
  - Speculation: larger cartels more easily detected, break down more easily

Cost Effects: Cross-Validation

We use a cross-fitting procedure (predicting whether participants on auction *i* are members of a cartel based on *other* auctions) to investigate cost effects of cartel participation.

	(1) Normalized Price	(2) Normalized Price	(3) Normalized Price	(4) Normalized Price	(5) Normalized Price
Cartel Participation	0.0167	0.0237	0.0237	0.0199	0.0195
	(0.0018)	(0.0015)	(0.0014)	(0.0009)	(0.0011)
No of Bids	-0.0221	-0.0230	-0.0230	-0.0213	-0.0183
	(0.0004)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Below-the-Threshold	-0.0473	-0.0365	-0.0351	-0.0257	-0.00641
	(0.0012)	(0.0012)	(0.0011)	(0.0010)	(0.0011)
Industry FE	No	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	Yes	Yes
Procurer FE	No	No	No	Yes	Yes
Firm FE	No	No	No	No	Yes
N	291368	291368	291368	291368	291368

Conclusion: cartel participation associated with 2% higher prices.

Agenda

Conclusion

- We proposed a new method for detecting cartels in multi-stage auctions
  - Intuition: close initial bids $\implies$ incentive to undercut (if bids shaded)
  - Systematic failure to undercut $\implies$ (suggestive) evidence of collusion
- Developed a structural model of Ukrainian multi-stage auction to verify intuition
- Exhibited several suspicious patterns in raw bidding data, suggesting collusion
- Applied our method to detect collusive pairs in the data & validated using court data
  - Found ROC AUC of 0.63 to 0.74 for penalization label
- Found 1,857 collusive firms participate in 16% of auctions
- Cartel participation associated with 2% price increase