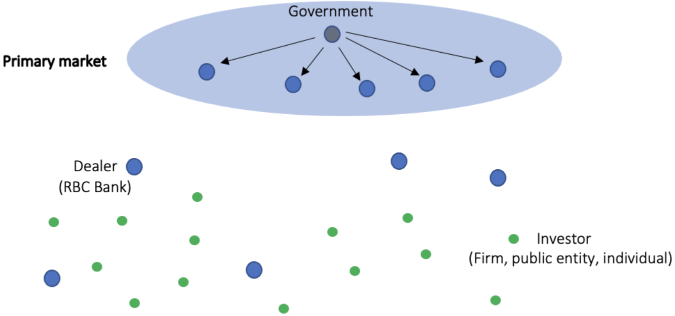
Entry and Exit in Treasury Auctions

Jason Allen, Ali Hortaçsu, Eric Richert, Milena Wittwer

Bank of Canada, University of Chicago, University of Chicago, Boston College

August 6, 2024

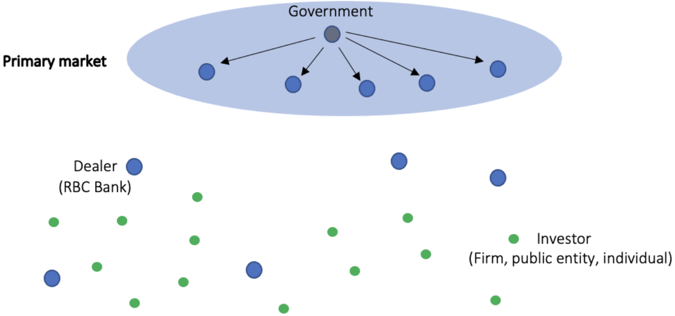
Government bond markets



Government bond markets

Dealers

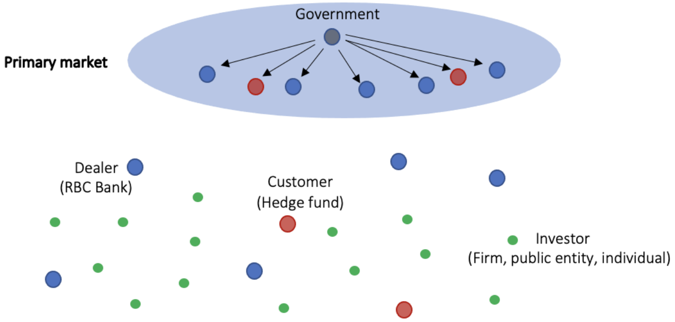
- Buy debt from the government and intermediate trades
- Obligated to regularly participate in the market
- Enjoy benefits: access to liquidity facilities, open market operations, information rents in primary market



Government bond markets

Customers

- Have entered the market
- Not obligated to regularly participate in the market



This paper

How does Customer entry affect Treasury markets?

Challenge

- Limited data because customers don't need to report their trades

$\rightarrow$ We know little about customers in Treasury markets

This paper

How does Customer entry affect Treasury markets?

Challenge

- Limited data because customers don't need to report their trades

→ We know little about customers in Treasury markets

This paper

- Canadian **primary market**
- Document dealer exit; **rising**, yet **irregular**, customer participation
- Introduce and estimate a model to
  - Measure changes in bond values for customers and dealers over time
  - Quantify effects on **competition** and **volatility** from irregular participation
  - Design alternative policies

Big picture

- Attracting irregular participants can improve **competition** but harm **volatility** in many markets, e.g.,
  - Over-the-counter markets — dealers/non-dealers
  - Exchange markets — exchange members/non-members
  - Energy markets — nuclear/wind
- Our (structural) model can be used to analyze (quantify) this trade-off

Literature: Bird's eye view

Government bond markets

- E.g., Hortaçsu, Kastl, Zhang (2018); Boyarchenko, Lucca, Veldkamp (2021); Allen and Wittwer (2023)

⇒ This paper: Focus on customers and endogenizes market entry

Customer behavior in Treasury markets

- E.g., Di Maggio (2020), Banegas et al (2021), Barth and Kahn (2021), Vissing-Jorgensen (2021)

⇒ This paper: Long time horizon

Dealer balance sheet costs/constraints

- E.g., Du et al (2018); Duffie (2018); Fleckenstein et al (2020); Allen and Wittwer (2023), Favara et al (2023)

⇒ This paper: Suggestive evidence that financial regulation might drive dealer exit

Empirical auction literature

- See Hortacsu and Perrigne (2021) for an overview

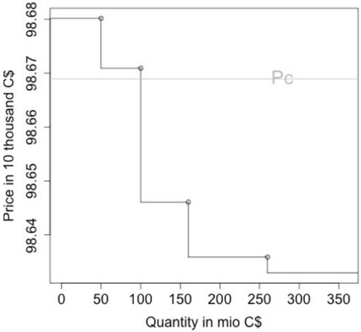
⇒ This paper: Entry/exit in multi-unit auctions, bid-updating behavior

Canadian Treasury auctions

- Bidding data with bidder IDs from all bond auctions from 1999 until 2022
  - Approximately 28 bond auctions per year
- Daily average prices from secondary, futures and repo-market (2014-2021)
- Types of Bidders:
  - Dealers (e.g., RBC, BMO, HSBC)
    - bid directly to the auctioneer
    - committ annually to regular participation
  - Customers (e.g., hedge funds)
    - must bid via a dealer who can observe the bid
- Bids are placed/updated until auction closure

Canadian Treasury auctions

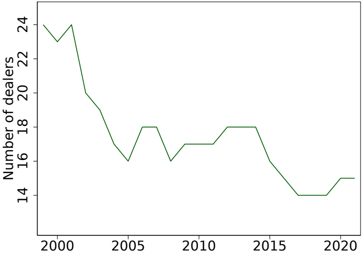
- Dealers and Customers submit step-function bids $\{b_k, q_k\}_{k=1}^K$

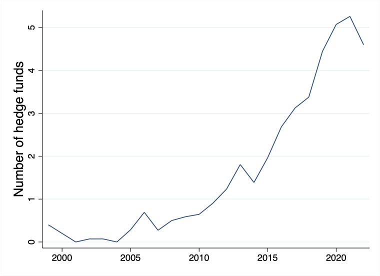


- Market clears total demand = supply
- Every bidder pays their bid for all allocated units (discriminatory price auction)

Fact 1: Entry/exit

- Dealers have left since the first auction took place
- Hedge funds entered the market

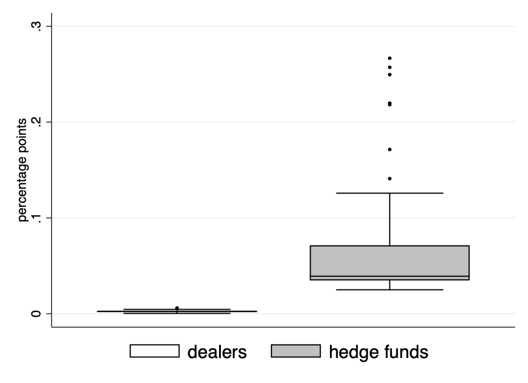




- Same trend in US

Fact 2: Hedge fund participation is volatile

Figure: Distribution of var_y^d and var_y^h across years y



var_y^d = Variance in the % of dealers bidding across auctions in year y out of all dealers active in y

var_y^h = Variance in the % of hedge funds bidding across auctions in y out of all hedge funds active in y

Fact 3: Hedge funds select into specific auctions

Number of customers	(OLS1)		(OLS2)		(Year-FE)	
Basis Trade	0.172	(0.692)	-0.0589	(0.700)	-0.331	(0.698)
Benchmark status	0.158	(0.314)	0.0129	(0.319)	-0.139	(0.318)
MPC	-1.708**	(0.766)	-1.908**	(0.772)	-1.888**	(0.760)
QE	-0.142	(0.380)	-0.350	(0.403)	-0.358	(0.409)
Exchange Rate	-0.0882***	(0.0192)	-0.109***	(0.0204)	-0.0117	(0.0374)
Spread	0.260***	(0.0579)	0.264***	(0.0588)	0.226***	(0.0599)
Number of dealers	-0.182**	(0.0900)	-0.187**	(0.0947)	0.0745	(0.137)
Lagged Number of Customers	0.158***	(0.0513)	0.123**	(0.0522)	0.0655	(0.0534)
Coupon	0.940***	(0.176)	0.973***	(0.186)	0.985***	(0.188)
Q-sold	1.043*	(0.550)	0.838	(0.669)	0.0547	(0.711)
N	326		326		326	
Extra controls	-		✓		✓	
Adjusted R^2	0.256		0.277		0.370	
Observations	327		327		327	

Fact 4: Bid-updating

- Customers submit their bid through a dealer
- Dealers change their bid in response
- A sophisticated customer should anticipate this updating

Table: Dealer updating

Change in qw-bid of dealer		
Customer's qw-bid - average customer qw-bid	$+0.047^{***}$	(0.009)
Customer's number of steps	0.032	(0.029)
Customer's total demand	$+0.001$	(0.001)
Auction Fixed Effects	Yes	
Observations	8193	
Adjusted R^2	0.21	

Model: Features

1. **Endogenous market participation**
   - Dealers decide at beginning of year whether to commit to all upcoming auctions
   - Before each auction, customers observe market conditions, decide to enter
2. **Bidding behavior**
   - Customers bid via dealers, who update bids (Hortaçsu and Kastl (2012))
   - **We add** customer bidding decisions:
     - Customers anticipate dealers will update after learning their bid

Model: Within a year

Players

- $\bar{N}^d$ potential dealers & $\bar{N}^h$ potential customers — commonly known

Sequence of events

(0) Each dealer i draws cost $\gamma_i^d \overset{iid}{\sim} G^d$ decides whether to participate in all T auctions. Number of participating dealers N^d is announced.

Model: Within a year

Players

- $\bar{N}^d$ potential dealers & $\bar{N}^h$ potential customers — commonly known

Sequence of events

(0) Each dealer i draws cost $\gamma_i^d \overset{iid}{\sim} G^d$ decides whether to participate in all T auctions.
Number of participating dealers N^d is announced.

Each customer i draws cost $\gamma_{i1}^h \overset{iid}{\sim} G^h$, decides whether to enter the next auction.
(1)

Model: Within a year

Players

- $\bar{N}^d$ potential dealers & $\bar{N}^h$ potential customers — commonly known

Sequence of events

(0) Each dealer i draws cost $\gamma_i^d \overset{iid}{\sim} G^d$ decides whether to participate in all T auctions.
Number of participating dealers N^d is announced.

Each customer i draws cost $\gamma_{i1}^h \overset{iid}{\sim} G^h$, decides whether to enter the next auction.
(1) Each bidder i of group $g \in \{d, h\}$ draws iid signal $s_{i1}^g \sim F_1^g$, and bids.

Model: Within a year

Players

- $\bar{N}^d$ potential dealers & N^h potential customers — commonly known

Sequence of events

(2) Each customer i draws cost $\gamma_{i2}^h \overset{iid}{\sim} G^h$, decides whether to enter the next auction.
Each bidder i draws of group $g \in \{d, h\}$ draws iid signal $s_{i2}^g \sim F_2^g$, and bids.

Model: Within a year

Players

- $\bar{N}^d$ potential dealers & N^h potential customers — commonly known

Sequence of events

(3) Each customer i draws cost $\gamma_{i3}^h \overset{iid}{\sim} G^h$, decides whether to enter the next auction.
Each bidder i draws of group $g \in \{d, h\}$ draws iid signal $s_{i3}^g \sim F_3^g$, and bids.

Model: Within a year

Players

- $\bar{N}^d$ potential dealers & N^h potential customers — commonly known

Sequence of events

(T) Each customer i draws cost $\gamma_{ti}^h \overset{iid}{\sim} G^h$, decides whether to enter the next auction.

Each bidder i draws of group $g \in \{d, h\}$ draws iid signal $s_{Ti}^g \sim F_T^g$, and bids.

Model: Within an Auction

Auction t

0) Each bidder i draws multi-dimensional signal $s_{ti}^{g} \overset{iid}{\sim} F_t^g$ which determines
   - WTP for amount q, $v_t^g(q, s_{ti}^g)$; decreasing in q, monotone, bounded
   - Number of steps K_{ti}
   - Probability the late bid of a dealer will make it in time
1) Each dealers bids: $\{q_k, b_k\}_{k=1}^{K_{ti}}$
2) Each customer bids via a dealer; random matching
3) Dealers observe their customer's quantity-weighted bid, may update their own bid

matching

Model: Equilibrium participation

- **A dealer commits** to participating in all T auctions of the upcoming year if

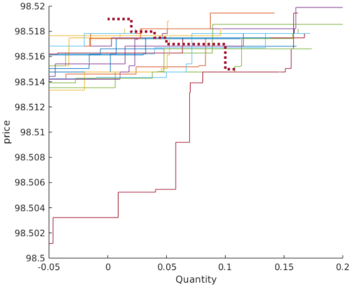
$$\text{Dealer's cost } \leq \text{Expected total surplus from bidding in all } T \text{ auctions}$$

- **A customer enters** auction t if

$$\text{Customer's cost } \leq \text{Expected surplus from bidding in auction } t$$

Model: Equilibrium bidding—dealer

Figure: Bidding Problem: Summary



Model: Equilibrium bidding–dealer

Dealer with information $\theta \supset s^d_{ti}$

- Chooses bids to maximize expected surplus from winning at auction:

$$\max_{\{b_k, q_k\}_{k=1}^{K_{ti}}} \mathbb{E}\left[surplus^d_t \middle| \theta \right]$$

Model: Equilibrium bidding–dealer

Dealer with information $\theta \supset s^d_{ti}$

- Shades her bids at all steps k but the last one:

$$v^d_t(q_k, s^d_{it}) = b_k + shading_t(b_k, b_{k+1}|\theta)$$

$$shading_t(b_k, b_{k+1}|\theta) = \frac{\Pr(b_{k+1} \geq \boldsymbol{P_t}|\theta)}{\Pr(b_k > \boldsymbol{P_t} > b_{k+1}|\theta)}(b_k - b_{k+1}), \text{ with clearing-price } P_t$$

- Ties can only occur at the last step

Model: Equilibrium bidding—customer

Customers anticipate updating

- Customers' choice of bid **causes** a shift in the residual supply curve via their dealers best response.

Customer with signal s_{ti}^{h}

- Knows that dealer only pays attention to $qwb_{ti} = \frac{b_1 q_1 + \sum_{k=2}^{K_{ti}} b_k (q_k - q_{k-1})}{q_{K_{ti}}}$

- To obtain a simple representation:
  - For each qwb^*, chooses bidding function that achieves highest expected surplus among all functions that induce the same dealer updating:

$$\max_{\{b_k, q_k\}_{k=1}^{K_{ti}}} \mathbb{E}\left[surplus_t^h \middle| s_{ti}^h \right] \text{ such that } \lambda[qwb_{ti} - qwb^*] = 0, \lambda \in \mathbb{R}$$

  - Among these functions, chooses the one with qwb^* that maximizes expected surplus

Model: Equilibrium bidding—customer

Customers anticipate updating

- Customers' choice of bid **causes** a shift in the residual supply curve via their dealers best response.

Customer with signal s_{ti}^h

- Knows that dealer only pays attention to $qwb_{ti} = \frac{b_1 q_1 + \sum_{k=2}^{K_{ti}} b_k (q_k - q_{k-1})}{q_{K_{ti}}}$
- To obtain a simple representation:
  - For each qwb^*, chooses bidding function that achieves highest expected surplus among all functions that induce the same dealer updating:

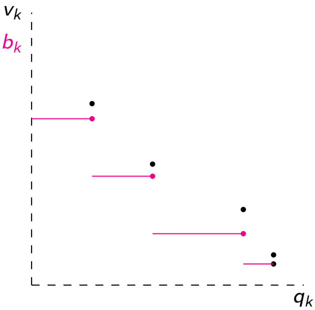
$$v_t^h(q_k, s_{it}^h) = b_k - shading_t(b_k, b_{k+1} | s_{ti}^h) + \lambda \frac{\partial qwb_{it}}{\partial q} + Ties_{it}$$

$\Rightarrow$ Can be optimal to bid above value & tie with another bidder at any step Example

Identification: Dealer Values

Dealers

- Point-identify $v_t^d(q_k, s_{ti}^d)$ from bid-equilibrium conditions (Kastl (2011))

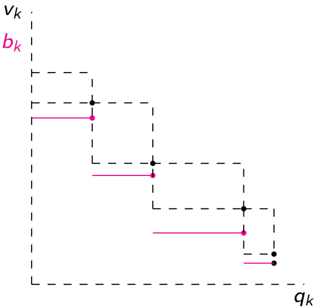


$$v_t^d(q_k, s_{ti}^d) = b_k + \frac{\Pr(b_{k+1} \geq \boldsymbol{P_t}|\theta)}{\Pr(b_k > \boldsymbol{P_t} > b_{k+1}|\theta)}(b_k - b_{k+1})$$

Identification: Customer values

- **Problem 1**: Equilibrium conditions depend on values at **ALL** q, not just submitted q_k due to ties

→ **Solution:** Use monotonicity/boundeness of $v_t^h(\cdot, s_{ti}^h)$ to reduce to a system with only values at submitted q_k



- Ties terms $E_{Q^c}[v(Q^c, s_i)\frac{\partial Q^c}{\partial q_k}|b_k = P^c]$
- Replace by $\bar{v}(q_{k-1}, s_i)E_{Q^c}[\frac{\partial Q^c}{\partial q_k}|b_k = P^c]$ and $\underline{v}(q_k, s_i)E_Q^c[\frac{\partial Q^c}{\partial q_k}|b_k = P^c]$

Identification: Customer values

- **Problem 2**: Additional unobserved component: λ_{it}

$\rightarrow$ **Solution:**

- Additional Data: Observed dealer updating behavior means the distribution of residual supplies conditional on any m, ϵ is known
- Additional Model Restriction: Optimality of the chosen quantity-weighted-average bid

$$TS(b(\cdot,\theta), m) - TS(b(\cdot,\theta), m+\epsilon) \geq \lambda\epsilon$$
$$TS(b(\cdot,\theta), m-\epsilon) - TS(b(\cdot,\theta), m) \leq \lambda\epsilon$$

- **Combine in 3 steps**:

1. Guess λ
2. Calculate implied bounds on $v_t^h(q, s_{ti}^h)$, implied total surplus and implied bounds $[\underline{\lambda}, \overline{\lambda}]$
3. Check if $\lambda \in [\underline{\lambda}, \overline{\lambda}]$

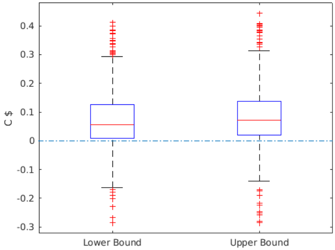
Model: Value estimates

- Customers are willing to pay 7 bps more than dealers

test time trend

→ Expect to implement more profitable trading strategies than dealers

Figure: Avg. customer value - avg. dealer value per auction



Cost Estimates (Match predicted participation probability to observed)

- Dealers: [C$3.2M, C$4.3M] per year

≈ 0.1% of the average amount a dealer wins in a year

- Customers: [C$0.4M, C$0.5M] per auction

≈ 0.3% of the average amount a customer wins in one auction

Counterfactuals

Goal: Analyze effects of customer/dealer interaction on **competition** and **volatility**

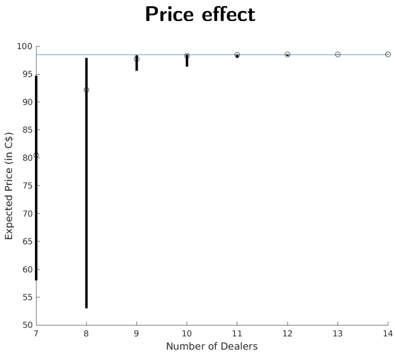
How?

- Empirical guess-and-verify approach to find equilibrium (Richert (2021))
- Solve for the distributions of bids under the counterfactual such that the distribution of values implied by these bids, and optimal bidding, are indistinguishable from the estimated value distribution.

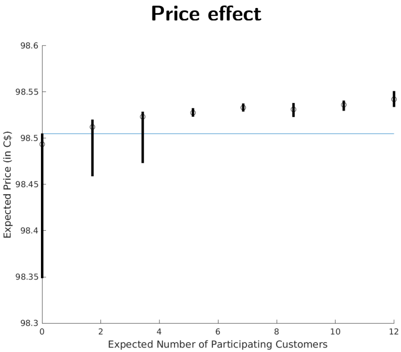
Limitation

- Big changes in allocation could impact market power in the secondary markets

Counterfactual: Varying the number of dealers per auction



Counterfactual: Vary the number of customers in typical auction



Attracting 1 customer → Expected revenue **gain** from **competition**: C$ 0.2M (1bps)
Expected revenue **loss** due to **irregular** customer participation: C$ 0.04M

Counterfactual: Policy

Question: Can we design a policy that reduces **volatility** and increases **competition**?

1. Eliminate dealer commitment $\Rightarrow$ volatility $\uparrow$
2. Introduce customer commitment $\Rightarrow$ competition $\downarrow$
3. **Yes:** Reshuffle supply across auctions to incentivize stable participation graphs
   - Predict customer participation in status quo
   - Shift up to 10% of supply from attractive auctions to non-attractive auctions
   - This increases annual revenue by C$ 12M

Conclusion

- We study **entry/exit** of market participants in the Canadian **Treasury market**
- Highlight effects on **competition**/**volatility**, evaluate policies
- Framework useful for other markets with regular/irregular participants, e.g.,
  - Renewable energy (Petersen et al (2022))

Appendix

Data

Table: Data Summary of 645 Bond Auctions between 02/1999 and 01/2022

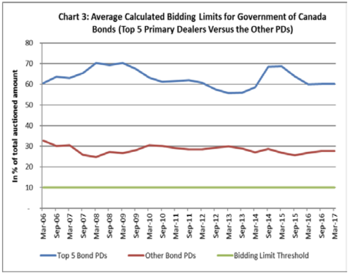
	Mean	SD	Min	Max
Issued amount (in C$ bn)	3.24	1.05	1.00	7.00
Number of Dealers	14.46	2.61	11	23
Number of Customers	6.74	2.56	1	15
Number of submitted steps of a dealer	4.34	1.71	1	7
Number of submitted steps of a customer	1.86	1.02	1	7
Comp demand of a dealer (as % of supply)	14.80	7.51	0.00	40
Comp demand of a customer (as % of supply)	5.83	4.70	0.01	25
Amount won by a dealer (as % of supply)	4.79	5.85	0	35
Amount won by a customer (as % of supply)	4.02	5.90	0	25

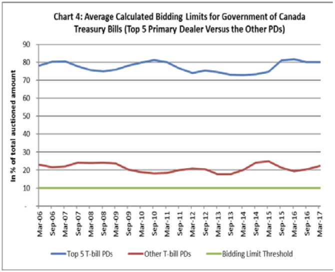
Data

Table: Data Summary of 645 Bond Auctions between 02/1999 and 01/2022

	Mean	SD	Min	Max
Issued amount (in C$ bn)	3.24	1.05	1.00	7.00
Number of Dealers	14.46	2.61	11	23
Number of Customers	6.74	2.56	1	15
Number of submitted steps of a dealer	4.34	1.71	1	7
Number of submitted steps of a customer	1.86	1.02	1	7
Comp demand of a dealer (as % of supply)	14.80	7.51	0.00	40
Comp demand of a customer (as % of supply)	5.83	4.70	0.01	25
Amount won by a dealer (as % of supply)	4.79	5.85	0	35
Amount won by a customer (as % of supply)	4.02	5.90	0	25

Bidding limits

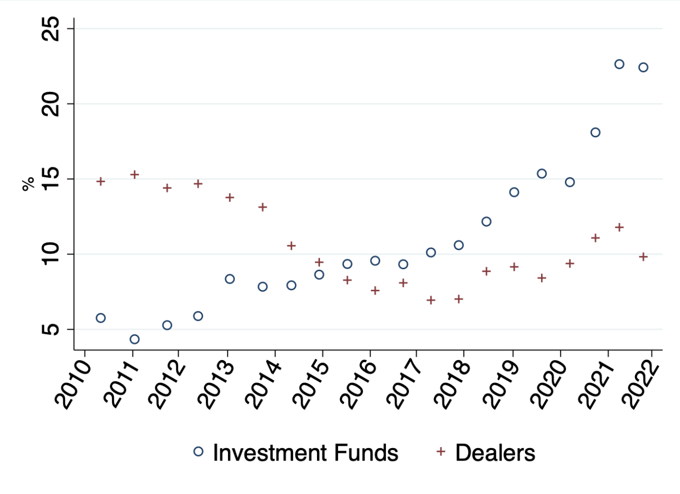




Source: Bank of Canada

- Bidding limits are calculated on a semi-annual basis
  (3x primary market share + 2x secondary market share + 0.5x share in optional operations)
- A dealer whose bidding limit falls below 10% must exit within the next 6 months

Similar trends in other markets



back

Bid-updating

Table: Dealer updating

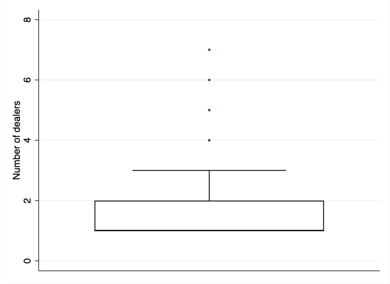
Change in qw-bid of dealer		
Customer's qw-bid - average customer qw-bid	+0.047***	(0.009)
Customer's number of steps	0.032	(0.029)
Customer's total demand	+0.001	(0.001)
Auction Fixed Effects	Yes	
Observations	8193	
Adjusted R^2	0.21	

- Dealer updates own bid upward after observing high customer bid
- Only qw-bid bid matters matters

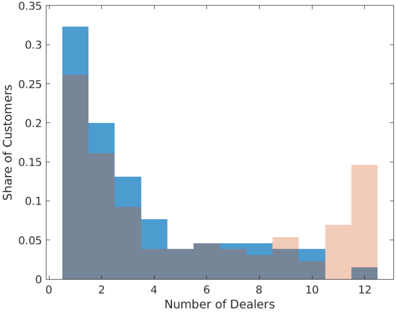
model sequence

Random matching

Figure: Random Matching of Customers to Dealers



(A) Within Auction



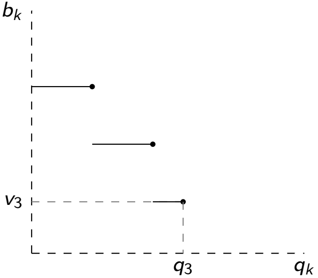
(B) Across Auctions

Figure (A) shows the distribution of how many dealers a customer places a bid through within an auction. Figure (B) plots the distribution of the number of unique dealers used by a customer in all auctions in the data (in pink) and the number of unique dealers that would be predicted for each customer under random matching (in blue).

back

Model: Customer bidding

Assume that this function would be optimal if the dealer didn't update:



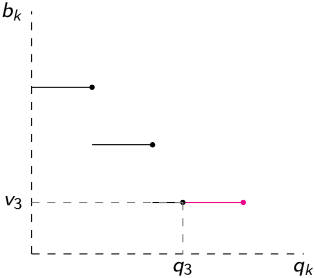
back

Model: Customer bidding

Should customer deviate?

E.g., extend the last step which lowers her quantity-weighted bid

+ Induce dealer updating that favorably affects customer's winning probabilities
− But win additional units at prices above values

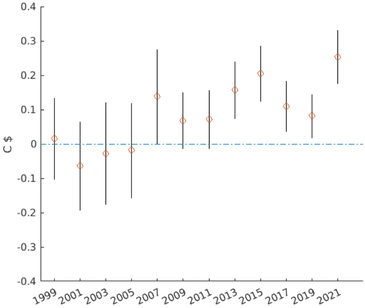


back

Model: Value estimates

- Customers are willing to pay 7 bps more per unit than dealers
- Perhaps because dealers must fulfill stringent regulations, especially post 2007-09

Figure: Time trend in value difference



back

Statistical Test

Table: Are customer vs. dealer values statistically significant from one another?

	P95	Sum	Max	CI
QWA-Value	0.00	0.00	0.00	[825, 2906]
Max-Value	0.06	0.00	0.93	[-836,2406]
Min-Value	0.00	0.00	0.00	[615, 1976]

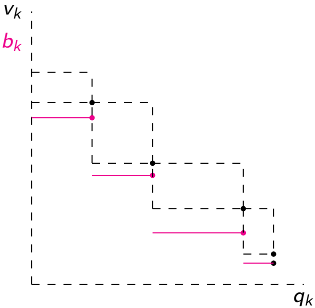
This shows the results from testing whether customer values are above dealer values. Columns P95, Sum, and Max present p-values for the test-statistics which take the 95th percentile, the sum of squared standardized differences, and the maximum difference across auctions of the average values of dealers less the lower bound of customer values. P-values are computed using the bootstrap. The confidence intervals are for interval estimates of the mean difference. The QWA-value is the average (within customers and dealers) of the individual participants quantity-weighted average values. The Max-Value row compares the within group average values of the individual bidders' maximum value (at their first submitted step). The Min-Value row compares the within group average values of the individual bidders' minimum value (at their last submitted step).

back

Identification: Customer values

1) Fix some λ
2) Optimality for bids implies unique bounds on $v_t^h(q, s_{ti}^h)$ at all q

   Optimality for the quantity-weighted bid implies unique $[\underline{\lambda}, \overline{\lambda}]$
3) Check if $\lambda \in [\underline{\lambda}, \overline{\lambda}]$



back

Identification: Cost distributions

For Customers:

$$\underbrace{\gamma_{ti}^{h}}_{\text{cost}} \leq \underbrace{\mathbb{E}_t[\boldsymbol{TS_{ti}^{h}}|N^d]}_{\text{expected surplus}}$$

- Average surplus is known given value distributions
- Participation probability is observed (# of participating customers/all customers)

For Dealers:

$$\underbrace{\gamma_{i}^{d}}_{\text{cost}} \leq \underbrace{\sum_{N^d=1}^{\bar{N}^d} \left(\sum_{t=1}^{T} \mathbb{E}_t \left[\boldsymbol{TS_{ti}^{d}} | N^d \right] \right) \Pr(\boldsymbol{N^d} = N^d)}_{\text{expected yearly surplus}}$$

- Expected yearly surplus is a known function of observables
- Participation probability is observed (# of participating dealers/all dealers) back

Estimation

1) Resampling estimation of residual supply curves to learn about values

- Augment Hortacsu and Kastl (2012) to account for correlation in dealer updates when **no** new customer arrives

2) Compute expected surplus to estimate cost distributions

- For customers: $\hat{\mathbb{E}}_t[\hat{\boldsymbol{TS}}^{\boldsymbol{h}}_{\boldsymbol{ti}}|N^d]$ = avg. exp. surplus across customers in auction t

Estimation

1) Resampling estimation of residual supply curves to learn about values

- Augment Hortacsu and Kastl (2012) to account for correlation in dealer updates when **no** new customer arrives

2) Compute expected surplus to estimate cost distributions

- For customers: $\hat{\mathbb{E}}_t[\hat{\boldsymbol{TS}}^{\boldsymbol{h}}_{\boldsymbol{ti}}|N^d]$ = avg. exp. surplus across customers in auction t
- For dealers: computing $\sum_{N^d=1}^{\bar{N}^d}(\sum_{t=1}^{T}\mathbb{E}_t[\boldsymbol{TS}^{\boldsymbol{d}}_{\boldsymbol{ti}}|N^d])\,\Pr(\boldsymbol{N^d} = N^d)$ is challenging
  - Only observe the expected surplus for the number of dealers who decided to participate, $\hat{\mathbb{E}}_t[\hat{\boldsymbol{TS}}^{\boldsymbol{d}}_{\boldsymbol{ti}}|N^d]$, not any other number of dealers
  - Approximate by summing per-auction surpluses at **counterfactual** N^d_{cf} using kernel weights over similar auctions (in other years) with that N^d_{cf}

back

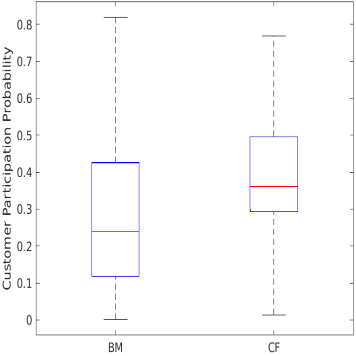
Counterfactual: Computational details

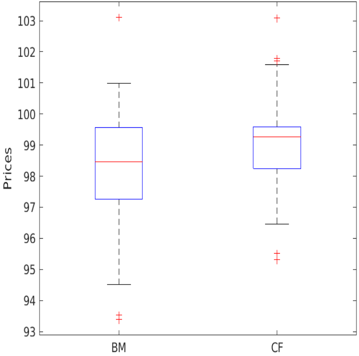
- Construct an empirical distribution of maximal demand for dealers/customers
  - One observation is the maximal percentage of supply that one of the dealers (customers) ever demanded
  - If this percentage is above 25%, we replace it by 25% to incorporate the feature that, during regular times, bidders face a bidding limit of 25% of supply
- Build on Richert (2021)'s empirical guess-and-verify approach, and solve for the counterfactual bid distributions that that
  1. Distribution of values implied by these bids, and optimal bidding, are indistinguishable from the distribution of the estimated values
  2. Counterfactual distribution of maximal demand in an auction is first-order stochastically dominated by the empirical distribution of maximal demand across all auctions

back

Counterfactual: Adjust supply

- Customer participation is stronger and more stable
- Prices are higher and less volatile

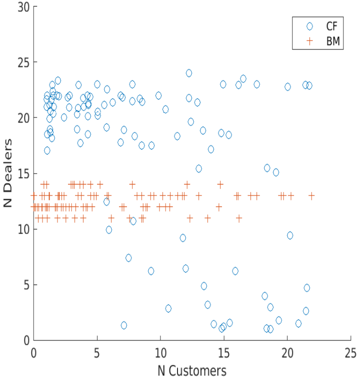


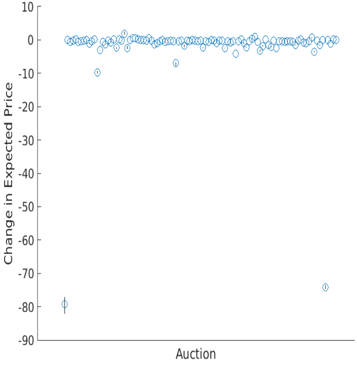


back

Counterfactual: No dealer comittment

- Due to volatile bidder participation, 2% of auctions fail
- Median exp. revenue of fully covered auctions decreases by 0.04% (C$ 1.3M)





back

Extra slides that aren't used at the moment.

Findings: Preview

Market consequences

+ More market participants ⇒ **competition** ↑
– Customers have no obligation to participate regularly ⇒ **volatility** ↑

Should we force customers to attend regularly?

- Yes! Assuming exogenous customer participation: **competition** ↑ & **volatility** ↓

Findings: Preview

Market consequences

+ More market participants $\Rightarrow$ **competition** $\uparrow$
− Customers have no obligation to participate regularly $\Rightarrow$ **volatility** $\uparrow$

Should we force customers to attend regularly?

- Unclear! Endogenous customer participation: **competition** $\downarrow$ & **volatility** $\downarrow$

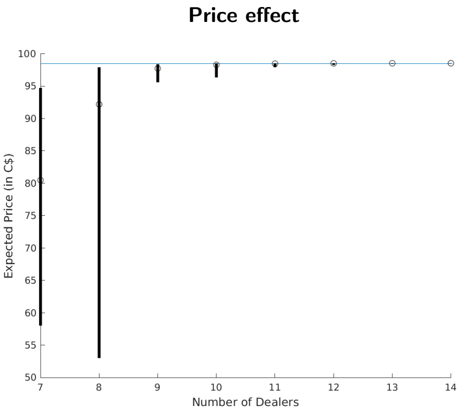
Counterfactuals: Policy

Should we force customers to attend regularly?

- With exogenous customer participation: **competition** $\uparrow$ & **volatility** $\downarrow$
- With endogenous customer participation: **competition** $\downarrow$ & **volatility** $\downarrow$

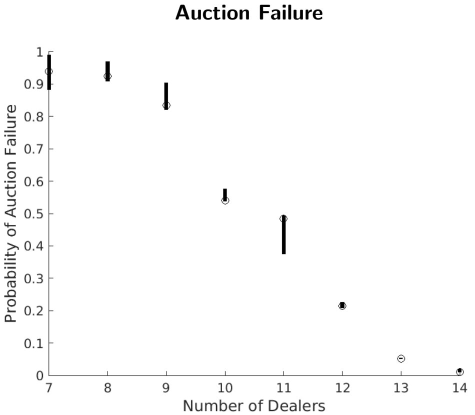
hopefully change!

Counterfactual: Vary the number of dealers in typical auction



- Going from 14 to 13 (12) dealers:
  Expected revenue ↓ by 2% (10%) due to lower competition & auction failure

Counterfactual: Vary the number of dealers in typical auction



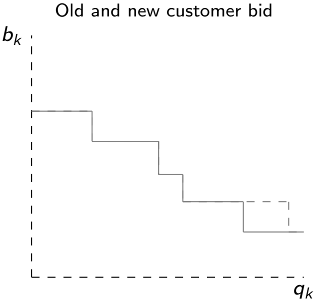
- Going from 14 to 13 (12) dealers:
  Expected revenue ↓ by 2% (10%) due to lower competition & auction failure

Competition-volatility: Revenue effects

1. **Gain from attracting one customer in expectation** $\approx$ C\$ 2.90M
   - Revenue $\uparrow$ thanks to less bid-shading
2. **Loss from across auction variation in customer participation** $\approx$ C\$ 2.85M
   - Revenue $\downarrow$ more when participation is below average than when it is above average

Example: Bid above value

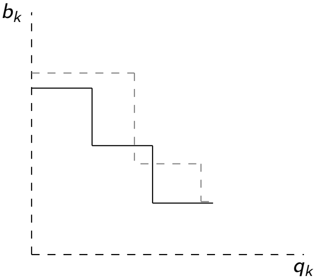
- Customer i submits a step-function such that $b_k \leq v_k$ at all k to dealer j
- Deviate to $b_4 > v_4$?



Example: Bid above value

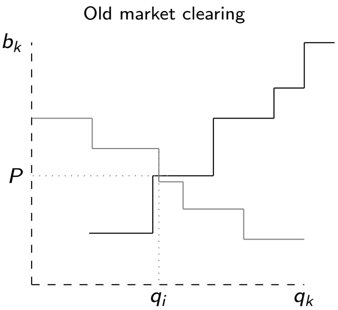
- Customer i submits a step-function such that $b_k \leq v_k$ at all k to dealer j
- Deviate to $b_4 > v_4$?

Old and updated dealer bid



Example: Bid above value

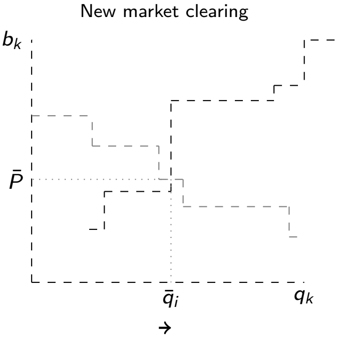
- Customer i submits a step-function such that $b_k \leq v_k$ at all k to dealer j
- It can be profitable to deviate to $b_4 > v_4$



Return

Example: Bid above value

- Customer i submits a step-function such that $b_k \leq v_k$ at all k to dealer j
- It can be profitable to deviate to $b_4 > v_4$



Return