Does Strategic Ability Affect Efficiency? Evidence from Electricity Markets?

Hortacsu et.al. (2019), AER

Environmental Reading Group session 18

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Context: Texas Electricity Market

- **Day-ahead Market:**bilateral market to schedule an initial plan for the next day's production.(95-98%)
- **Balancing Market:**Centralized Auction to procure (sell) additional supply in order to balance actual demand.(2-5%)
- **This paper looks into balancing market.**

Context: Bid

- Step-wise price-quantity bid. $S(p, Q)$
- one auction for each hour, in total 24 auctions per day.
- e.g. $S_1(30, 100), S_2(40, 100), \ldots$. Generally 10 steps, but at maximum 40 is allowed.

Context: Characteristics in Texas Market

- Heterogeneous generating firms:
  - Size difference: large incumbents, large private investors, small municipal utilities.
  - Generating units difference: coal, gas, oil, wind, solar, nuclear, hydro etc.
- Cost is public information. So asymmetric information is day-ahead position.

Research Question

- **Puzzle:** Bayesian Nash Equilibrium$\neq$ Actual Bid Function. heterogeneity in this deviation.
- Does this deviation come from bounded rationality of generating firms? If so, does this deviation relate to the size/profession of the firm?

Descriptive Analysis

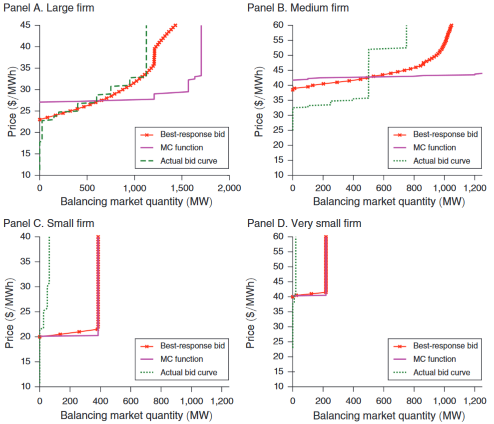


Figure 4. Actual Bids versus Best-Response Bids for Different-Sized Firms

Setup

Multi-unit Auction Model + Cognitive Hierarchy Auction Model (CH model)

- Multi-unit Auction Model: Winners produce share of total quantity.
- Cognitive Hierarchy Auction Model: bidders are ranked by their strategic ability to play. k levels:
    - type 0: non-strategic, vertical bid
    - type 1: all others are type 0, then to maximize expected profit
    - type 2: all others are combination of type 0 and type 1, then to maximize expected utility.
    - type k: all others are combination between type 0 and $k-1$, then to maximize expected utility.

Bidding Rule

- $\#$I Generators, for each firm i is a k-step thinker, so k_i. Each firm i has day-ahead position for hour t, so QC_{it}. Both are private information, anything else is public.
- Each firm i submit $S_{it}^k(p, QC_{it})$.
- Market clearing price p_t^c is determined by:

$$\sum_{i=1}^{N} S_{it}(p_t^c, QC_{it}) = D_t(p_t^c) + \varepsilon_t \tag{1}$$

- Win the auction if $p < p_t^c$, the probability of winning is:

$$1 - H_{it}(p, \hat{S}_{it}(p); k_i, QC_{it}) = Pr(p < p_t^c | \hat{S}_{it}(p), k_i, QC_{it}) \tag{2}$$

Maximization Problem

$$\max_{\hat{S}_{it}(p)} \int_{\underline{p}}^{\bar{p}} U(p \cdot \hat{S}_{it}(p) - C_{it}(\hat{S}_{it}(p)) - (p - PC_{it})QC_{it}) dH_{it} H_{it}(p, \hat{S}_{it}(p); k_i, QC_{it}) \tag{3}$$

FOC:

$$p - C_{it'}(S^*_{it}(p^c_t, QC_{it})) = (S^*_{it}(p^c_t, QC_{it}) - QC_{it}) \frac{H^*_s(p, \hat{S}_{it}(p); k_i, QC_{it})}{H^*_p(p, \hat{S}_{it}(p); k_i, QC_{it})} \tag{4}$$

CH model distribution

Type follows poisson distribution: $\tau_i = \exp(X_i'\gamma)$,$X_i'$ is the characteristics, we need to estimate γ.

Error Minimization

$$\hat{\gamma} =_{\gamma} \sum_{i}\sum_{t}\left[\sum_{k}\left[\sum_{p}\left(\frac{b_{it}^{data}(p) - b_{it}^{model}(p|k)}{data(p|K) - b_{it}^{model}(p|0)}\right)^{2} \times P(p)\right] P_i(k||K|,\hat{\gamma})\right] \quad (5)$$

Data

01/08/2002-31/01/2003, 6 p.m. firm level

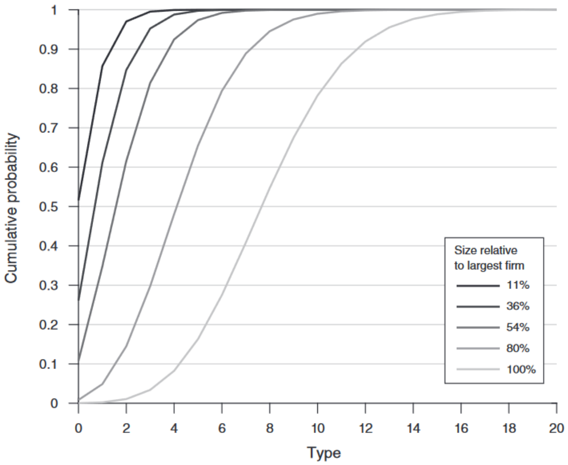
- Fuel costs
- Hourly bid
- heat rate
- hourly demand
- balancing price

γ Estimation

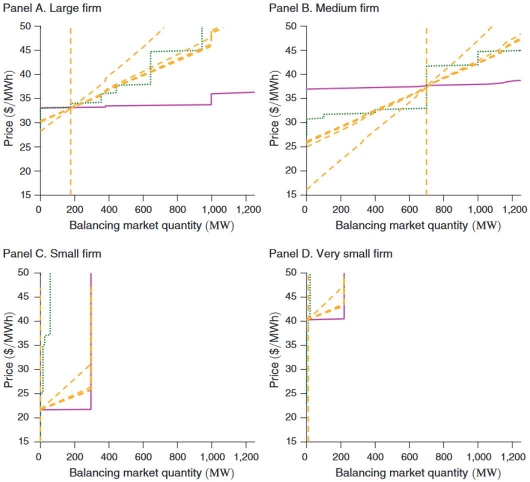
TABLE 1—STRUCTURAL MODEL: ESTIMATED PARAMETERS OF TYPE FUNCTION

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	−0.726	−0.196	−3.395	−0.749	−3.493	−0.691	−0.675
	(0.031)	(0.037)	(0.269)	(0.049)	(0.796)	(0.041)	(0.072)
Size	14.594	−1.163	25.789	13.619	3.090	11.933	13.776
	(0.301)	(0.464)	(3.385)	(0.603)	(0.847)	(0.546)	(0.629)
Size^2		86.191					
		(4.035)					
Merchant			−1.562				
			(0.295)				
AAU University				0.376			
				(0.059)			
Degree in economics, business or finance					5.626		
					(0.764)		
Economics degree						1.633	
						(0.115)	
Time trend							0.051
							(0.016)
Obj. fn./number of auctions	208.512	208.354	208.526	208.485	206.386	208.308	208.520

Estimated CDFs



Fitness


Panel A. Large firm
Panel B. Medium firm
Panel C. Small firm
Panel D. Very small firm
Price ($/MWh)
Balancing market quantity (MW)
50
45
40
35
30
25
20
15
0
200
400
600
800
1,000
1,200

Fitness 2

TABLE 2—MODEL FIT: COMPARISON OF COGNITIVE HIERARCHY MODEL TO UNILATERAL BEST-RESPONSE MODEL

	CH (1)	BR (2)	Both (3)
Profits under cognitive hierarchy	0.803		0.642
	(0.069)		(0.127)
Profits under best-response		0.428	0.137
		(0.044)	(0.062)
Constant	−328.17	−241.74	−374.17
	(141.98)	(120.72)	(125.79)
Observations	1,058	1,058	1,058
R^2	0.67	0.49	0.69

Notes: This table reports results from a regression of observed profits from actual bidding behavior on firm profits as predicted by the Cognitive Hierarchy model (column 1), firm profits that would be achieved from a model of unilateral best-response to actual rival bids (column 2), and both (column 3). An observation is a firm-auction. Standard errors clustered at the firm level are reported in parentheses.

Cost

TABLE 3—EVIDENCE OF NON-STRATEGIC BIDDING: BIDDING RESPONSE TO NUCLEAR OUTAGE

	Largest three firms			Smallest three firms		
	(1)	(2)	(3)	(4)	(5)	(6)
Outage	−47.81	−31.13	−19.42	−0.02	0.17	0.36
	(7.50)	(8.30)	(5.19)	(0.18)	(0.19)	(0.18)
Own MC $\left(\frac{\partial q_{it}}{\partial MC}\right)$		0.15	0.26		0.04	0.09
		(0.05)	(0.04)		(0.01)	(0.01)
Constant	73.42	38.08	−8.61	1.32	0.65	0.63
	(7.18)	(12.37)	(8.84)	(0.12)	(0.18)	(0.19)
Bidder fixed effects	No	No	Yes	No	No	Yes
Observations	189	189	189	189	189	189
R^2	0.21	0.25	0.59	0.00	0.17	0.25

Notes: In all columns, the dependent variable is the slope of each firm's inverse bid function in auction t $(\partial S_{it}/\partial p)$. Each column reports estimates from a separate regression of the slope of a firm's bid function on an indicator variable that the auction occurred during the fall 2002 nuclear outage. An observation is a firm-auction. The dependent variable is the slope $(\partial S_{it}/\partial p)$ of firm i's (inverse) bid function in auction t where the slope is linearized plus and minus \$10 around the market-clearing price. *Own MC* is the slope of the firm's own (inverse) marginal cost function linearized plus and minus \$10 around the market-clearing price. White standard errors are reported in parentheses.

Profit

TABLE 4—EXPLAINING VARIATION IN REALIZED PROFITS DURING THE OUTAGE PERIOD

	Realized profits		
	(1)	(2)	(3)
Profits under cognitive hierarchy		0.703	0.642
		(0.136)	(0.211)
Profits under best-response	0.263		0.061
	(0.052)		(0.091)
Constant	−64.484	−248.599	−264.619
	(156.308)	(101.941)	(97.348)
Observations	426	426	426
R^2	0.25	0.56	0.57

Notes: In all columns, the dependent variable is profits from the firms' actual bids. The covariates are firm profits as predicted by the Cognitive Hierarchy model (column 1), firm profits that would be achieved from a model of unilateral best-response to actual rival bids (column 2), and both (column 3). Predicted profits under CH are based on a sample of auctions that excludes the period of the nuclear outage. Standard errors clustered at the firm level are reported in parentheses.

Sophistication

Table 5—Exogenous Increase in Sophistication: Change in Production Costs

Counterfactual	INC side (%) Public	INC side (%) Private	DEC side (%) Public	DEC side (%) Private
Small firms to median	−6.95	−6.22	−18.4	−17.6
Above median firms to highest	−2.71	−1.96	−13.42	−12.46
Three smallest to median	−4.67	−3.75	−14.24	−13.64

Merger

TABLE 6—INCREASING SOPHISTICATION VIA MERGERS: CHANGE IN PRODUCTION COSTS

Merging firms	INC side (%)	DEC side (%)
Smallest and largest firms	−2.62	−6.49
Median and largest firms	+10.29	+10.37
Two largest firms	+18.38	+48.72

Main Takeaways

- Firms exhibit heterogeneity in bidding strategy. Large firms are able to take more sophisticated strategy which corresponds to Nash equilibrium.
- Merger between small and large firms can increase efficiency by increasing the ability of sophistication.

Reference

Hortaçsu, A., Luco, F., Puller, S. L., Zhu, D. (2019). Does strategic ability affect efficiency? Evidence from electricity markets. American Economic Review, 109(12), 4302-4342.