Strategic Bidding Behavior in Electricity Auctions

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Energy Trading Through Spot Auctions

- Auctions allow for in-depth analysis of bidders' strategic decision-making
  - harder for bilateral markets
- ERCOT balancing market
- California – ISO/PX prior to 2001

Two Types of Inefficiencies

1) Bidding is not "perfectly competitive"
   - Fail to achieve least cost production
   - Interest to market monitor
2) Profitable trades left on the table
   - Role for sophisticated traders to "find" the profitable trades
   - In Texas case, can document that more sophisticated trading (in a particular sense) can reduce production costs

- Implications are "descriptive" rather than "prescriptive"

Some Evidence from Texas

Based upon Hortacsu and Puller "Understanding Strategic Bidding in Multi-Unit Auctions: A Case Study of the Texas Electricity Spot Market"

ERCOT's Balancing Market

- Bilateral trades scheduled day-ahead
  - may be short or long on contract position
- Spot market run in "real-time" to balance supply (generation) and demand (load)
- Approx 2-5% of energy traded ("up" and "down")
  - "up" → bidding price to receive to produce more
  - "down" → bidding price to pay to produce less
- Uniform-price auction using hourly portfolio bids that clear every 15-minute interval
- Bids: monotonic step functions with up to 40 "elbow points" (20 up and 20 down)
- Zonal pricing of congestion – we focus on uncongested hours

Who are the Players?

Table 1: Generation Ownership

Owner	% of Installed Capacity
TXU	24
Reliant	18
City of San Antonio Public Service	8
Central Power & Light	7
City of Austin	6
Calpine	5
Lower Colorado River Authority	4
Lamar Power Partners	4
Guadalupe Power Partners	2
West Texas Utilities	2
Midlothian Energy	2
Dow Chemical	1
Brazos Electric Power Cooperative	1
Others	16

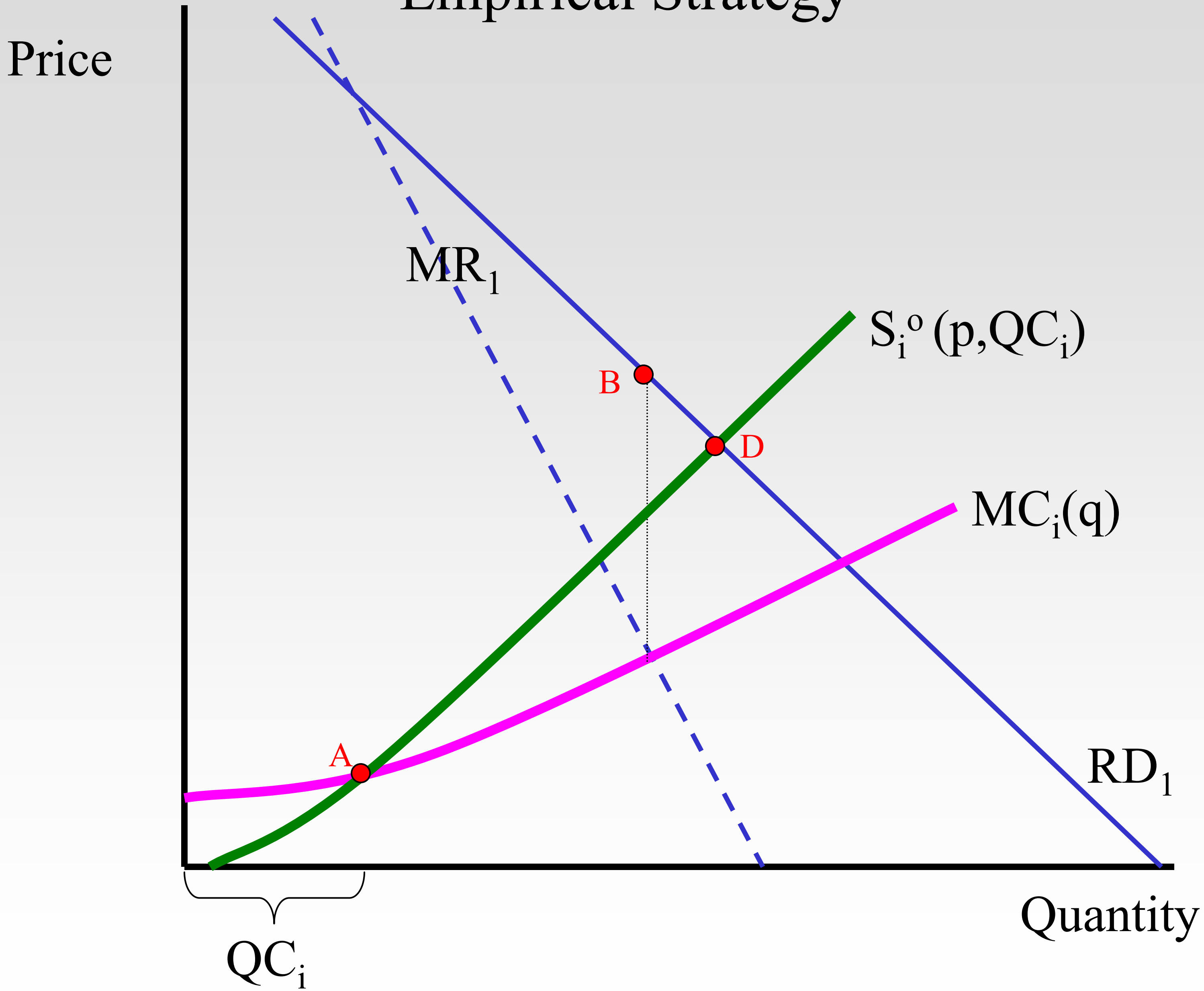
Data (Sept 2001 thru Jan 2003)

- 6:00-6:15pm each day
- Bids
  - Hourly firm-level bids
- Demand in balancing market – assumed perfectly inelastic
- Marginal Costs for each operating fossil fuel unit

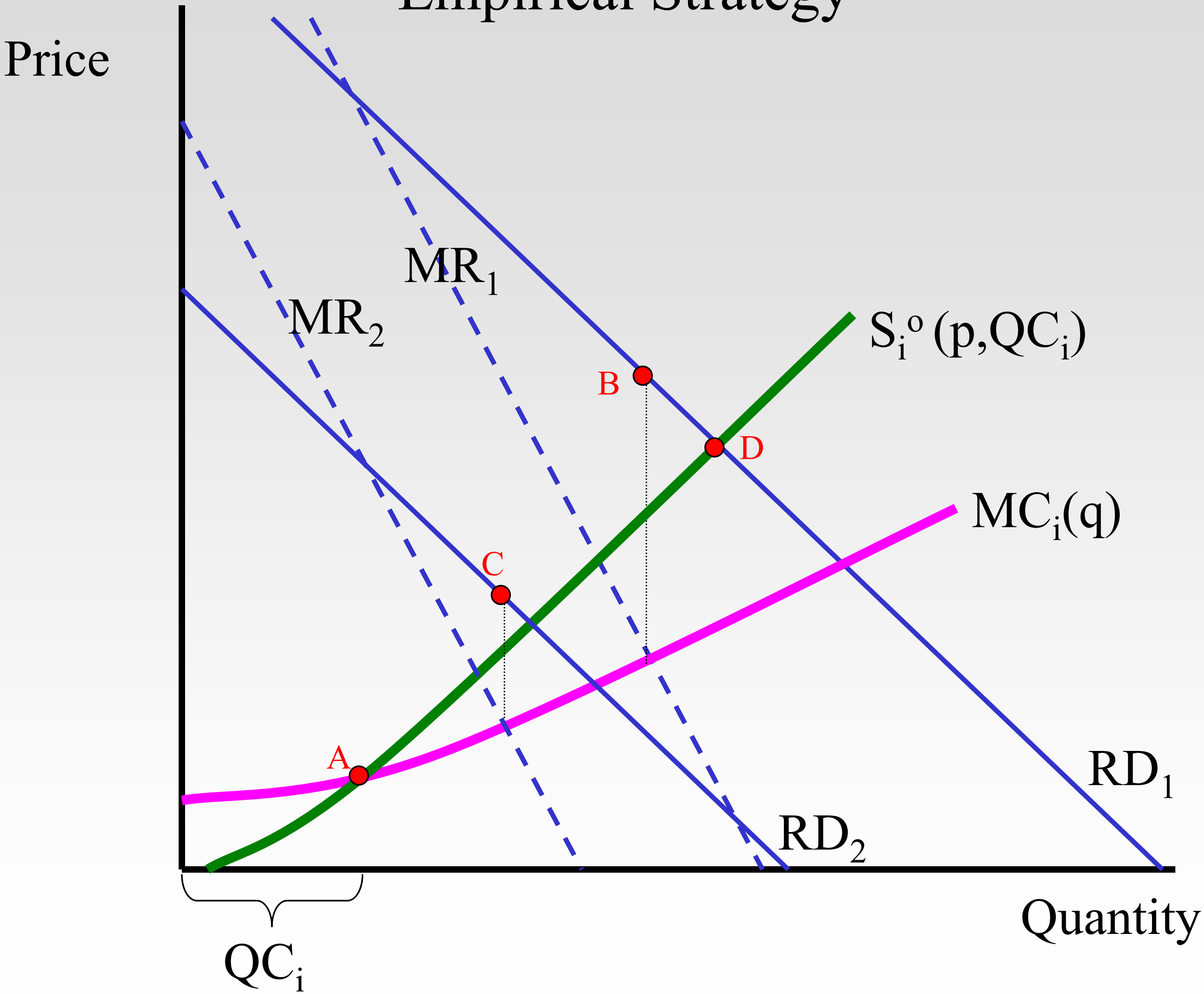
Incentives to Exercise Market Power

- Suppose no further contract obligations upon entering balancing market
- INCremental demand periods
  - Bid above MC to raise revenue on inframarginal sales
  - Just "monopolist on residual demand"
- DECremental demand periods
  - Bid below MC to reduce output
  - Make yourself "short" but drive down the price of buying your short position (monopsony)

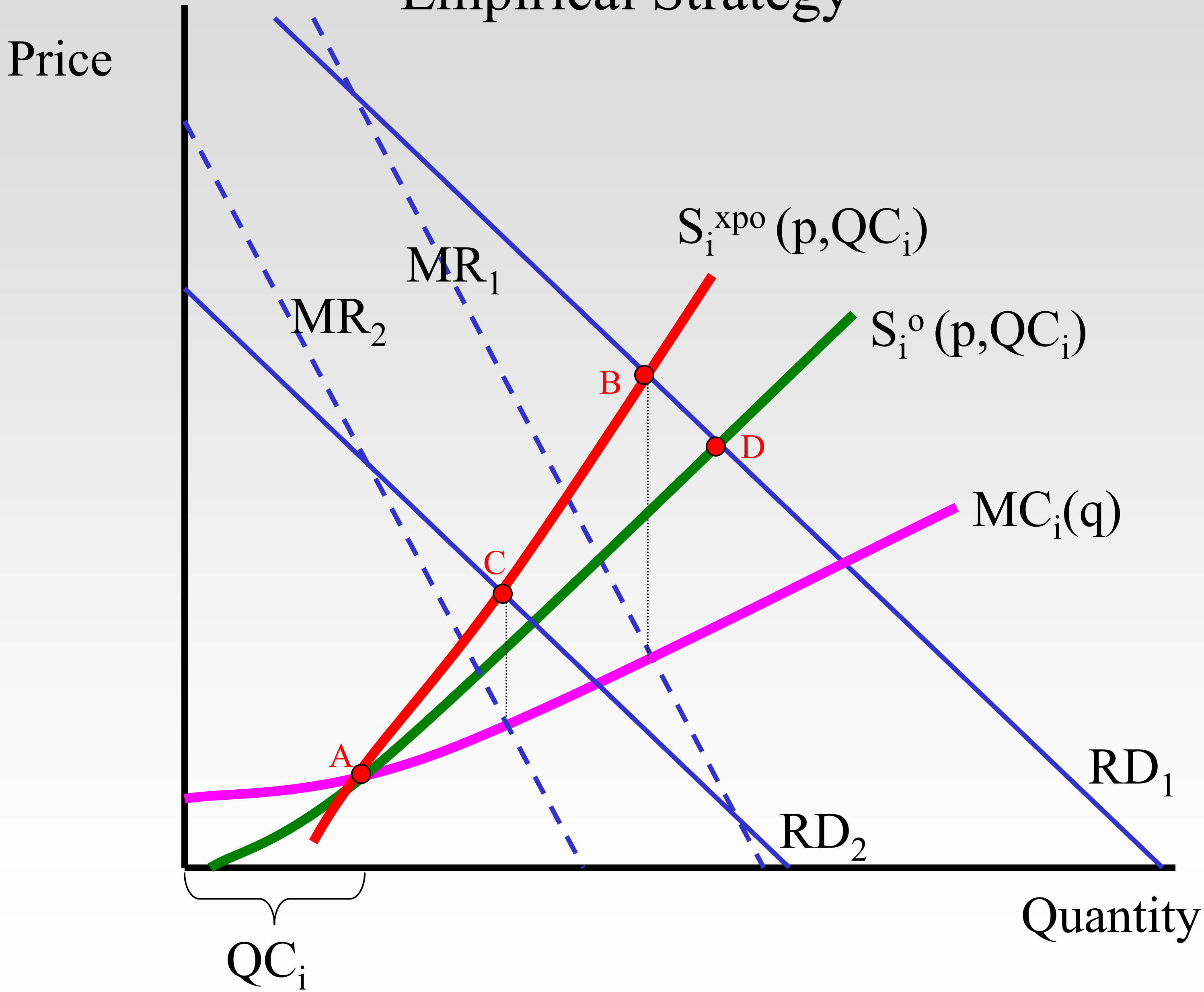
Empirical Strategy



Empirical Strategy



Empirical Strategy



Solving for Equilibrium Bids

Ex ante problem:

$$\underset{S(p)}{Max} \quad \underset{p^*(S(p))}{E} \quad [\text{Market profits } (p^*) \ - \ \text{Imbalance on Contracts } (p^*)]$$

If supply functions take form: $S_i(p,QC_i)=\alpha_i(p)+\beta_i(QC_i)$

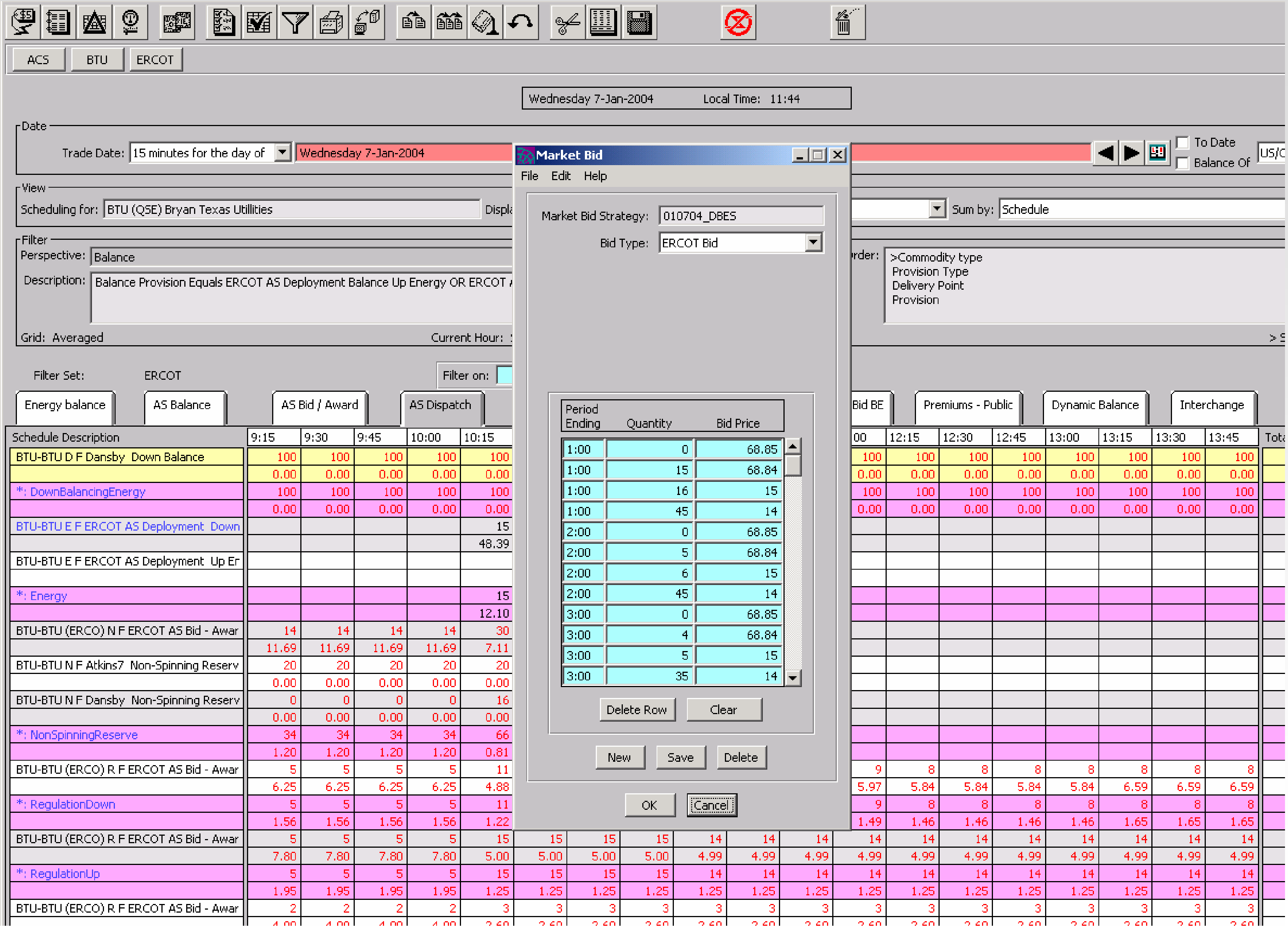
Then ex post best response is a (Bayesian Nash) equilibrium

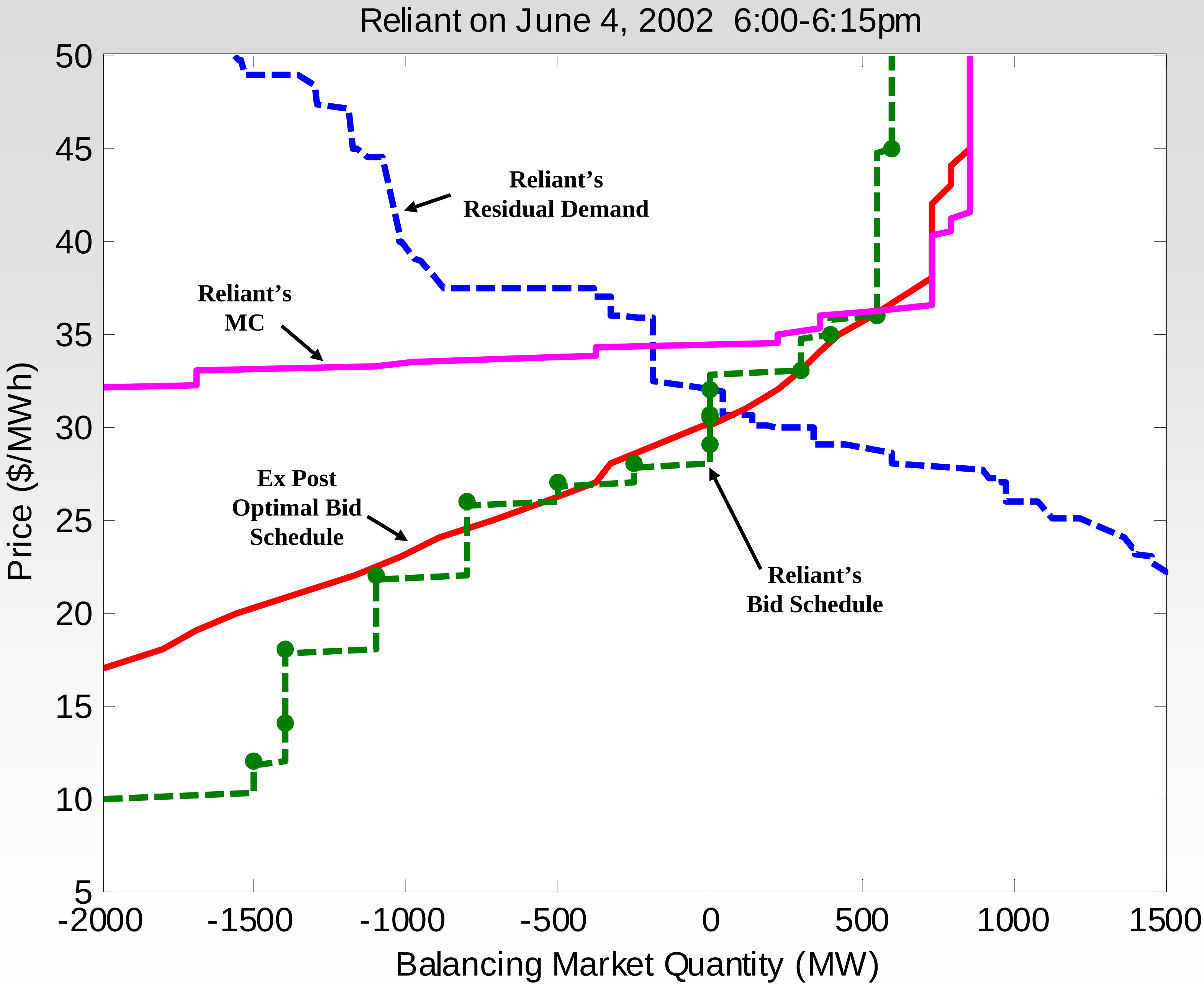
➔ Uncertainty shifts residual demand parallel in & out

➔ Can trace out ex post optimal / equilibrium bids

$$p - MC_i(\underbrace{S_i^*(p)}_{Unknown}) = \frac{\overbrace{S_i^*(p)}^{Unknown} - QC_i}{RD_i'(p)} \qquad (\text{"inverse elasticity rule"})$$

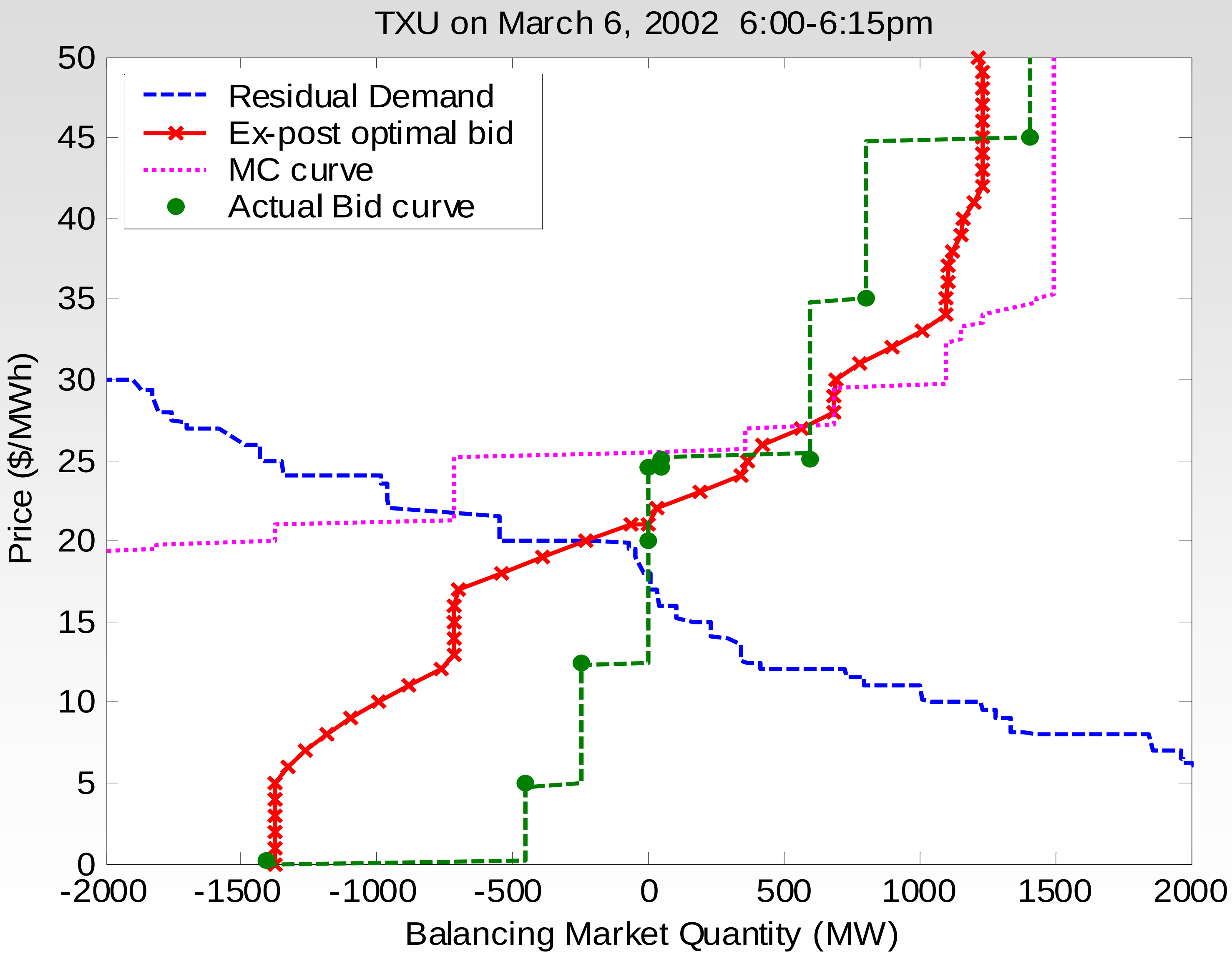
Sample Bidding Interface



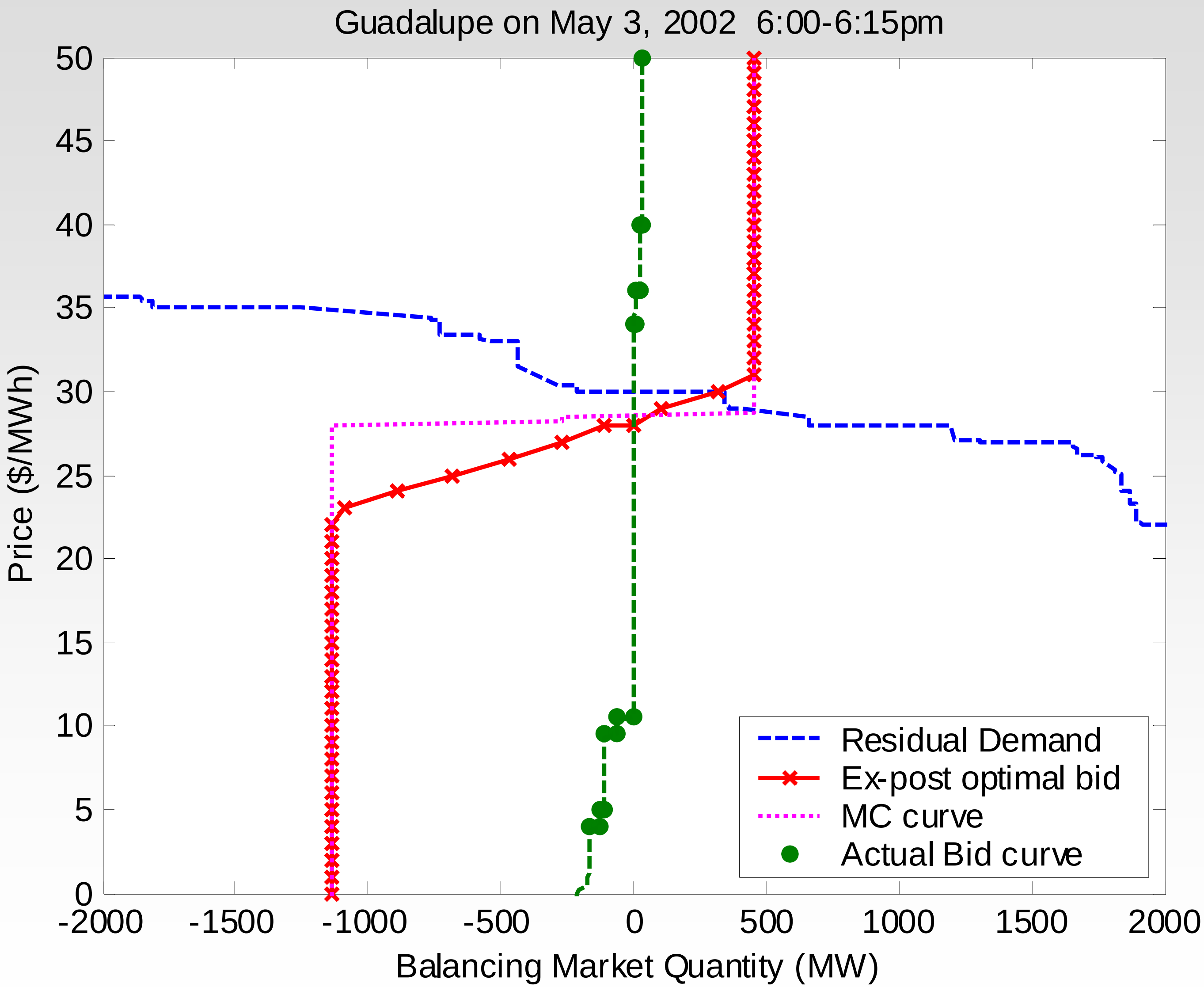


Reliant on June 4, 2002 6:00-6:15pm
Price ($/MWh)
Balancing Market Quantity (MW)
50
45
40
35
30
25
20
15
10
5
-2000
-1500
-1000
-500
0
500
1000
1500
Reliant's Residual Demand
Reliant's MC
Ex Post Optimal Bid Schedule
Reliant's Bid Schedule

TXU (2nd biggest seller) Example



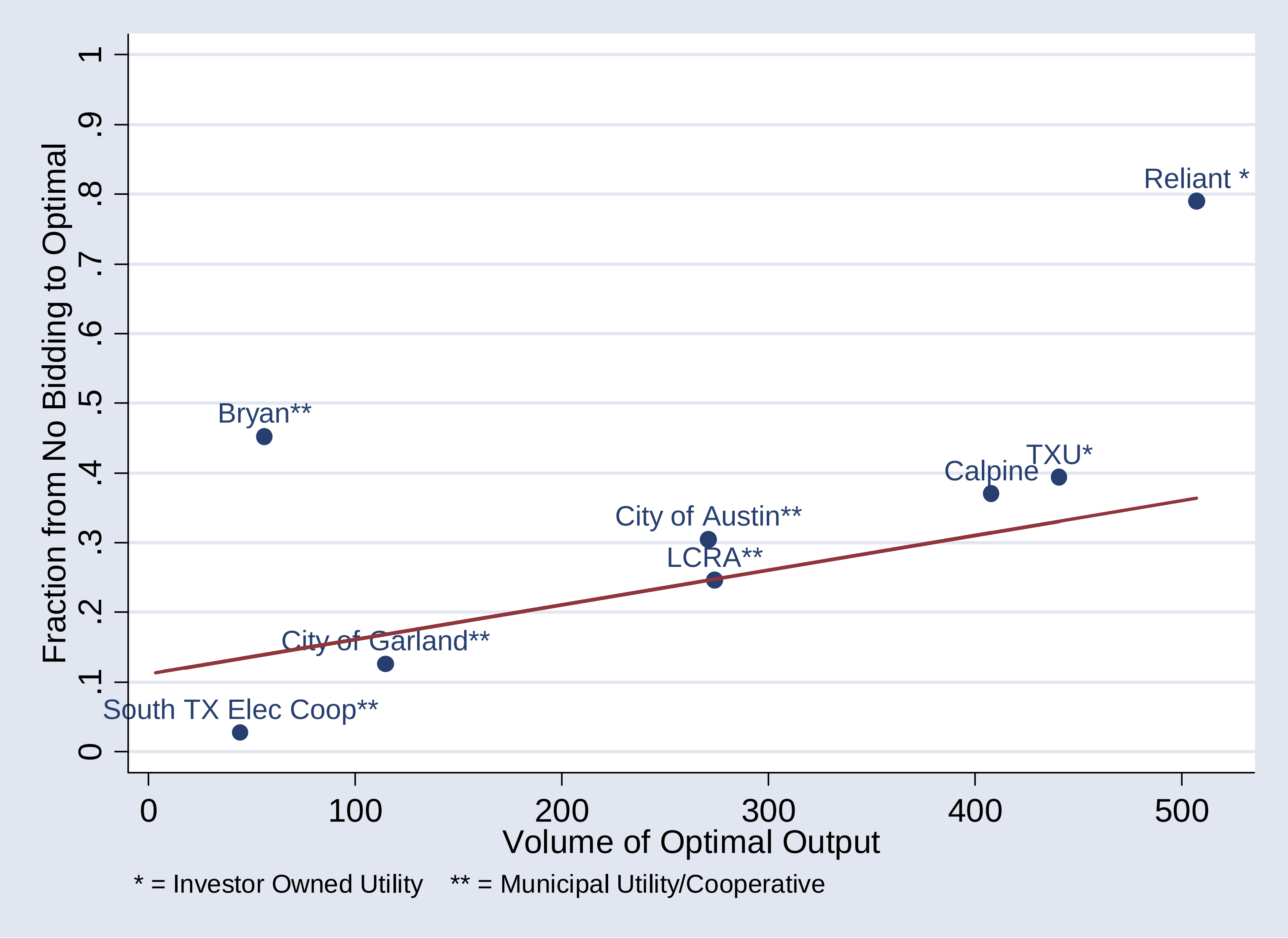
Guadalupe (small seller) Example



Firm	Percent Achieved Relative to: Ex-post Optimal	Percent Achieved Relative to: Naïve Best Response	Producer Surplus ($/hour): Actual	Producer Surplus ($/hour): Naïve Best Resp.	Producer Surplus ($/hour): Ex-post Optimal	Upper Bound of Total Profitability
Reliant	79%	80%	3,422	4,268	4,333	98%
Brownsville PUB	50%	50%	173	343	343	88%
City of Bryan	45%	45%	221	488	488	85%
Tenaska Gateway Partners	41%	41%	456	1,111	1,115	88%
TXU	39%	41%	1,243	3,056	3,159	97%
Calpine Corp	37%	38%	820	2,168	2,214	91%
Denton Municipal Electric	35%	35%	11	31	31	98%
Ingleside Cogeneration	31%	31%	171	541	541	79%
City of Austin	30%	31%	581	1,889	1,907	84%
Rio Nogales LP	28%	28%	109	393	393	93%
Lower Colorado River Auth	25%	25%	367	1,471	1,488	88%
City of San Antonio	23%	24%	290	1,221	1,241	90%
Gregory Power Partners	20%	20%	143	720	722	82%
Midlothian Energy	17%	17%	171	1,016	1,024	86%
Cogen Lyondell Inc	16%	16%	408	2,523	2,523	67%
Tractebel Power Inc	16%	16%	127	795	795	79%
Brazos Electric Power Coop	15%	15%	101	676	677	79%
Lamar Power Partners	15%	15%	266	1,800	1,808	79%
Mirant Wichita Falls	14%	14%	16	114	114	83%
BP Energy	14%	14%	134	993	994	80%
City of Garland	13%	13%	128	1,018	1,019	80%
Hays Energy	8%	8%	64	775	777	82%
West Texas Utilities	8%	8%	132	1,635	1,635	82%
Central Power & Light	8%	8%	185	2,375	2,407	80%
Guadalupe Power Partners	6%	6%	140	2,356	2,380	77%

Incumbent Utility   Municipal Utility   Merchant Generator   Cooperative

Do Stakes Matter?



What the Traders Said

1. Lack of sophistication at beginning of market
   - Some firms' bidders have no trading experience; traders are from generation & distribution
2. Heuristics
   - Most don't think in terms of "residual demand"
   - Rival supply not entirely transparent b/c
     - Eqbm mapping of rival costs to bids too sophisticated
     - Some firms do not use lagged aggregate bid data
   - Bid in a markup & have guess where price will be
3. Newer generators
   - If a unit has debt to pay off, bidders follow a formula of % markup to add
4. Small players (e.g. munis)
   - "scared of market" – afraid of being short w/ high prices
   - Don't want to bid extra capacity into market because they want extra capacity available in case a unit goes down

Increases in Production Costs from Observed Bidding Behavior

- Which source of inefficiency is larger?
  - Exercise of market power by large firms?
  - Bidding "to avoid the market" by "unsophisticated" firms?

Bidding Counterfactual	Average Production Cost
Actual Bids for all firms	\$29,874
"Strategic" firms Bid MC, Others Bid Actual	\$28,671
All Firms Bid MC (Vickrey auction)	\$23,571
Total Efficiency Losses	\$6,303
"Strategic Bidders"	\$1,203
"Non-Strategic Bidders"	\$5,100

  - Total efficiency loss = 27%
  - Fraction "strategic" = 19%   Fraction "unsophisticated"=81%!!

Some Evidence from California

Inefficiencies in ISO/PX

- Borenstein, Bushnell & Wolak, *American Economic Review*, 2002
  - Competitive benchmarking analysis
  - Found production inefficiencies & substantial rent transfers
- Wolak, *American Economic Review*, 2003
  - Measured potential market power of 5 large players bidding into ISO real-time market during summers ’98-’00
  - Skyrocketing prices in 2000 consistent with an increase in potential *unilateral* market power

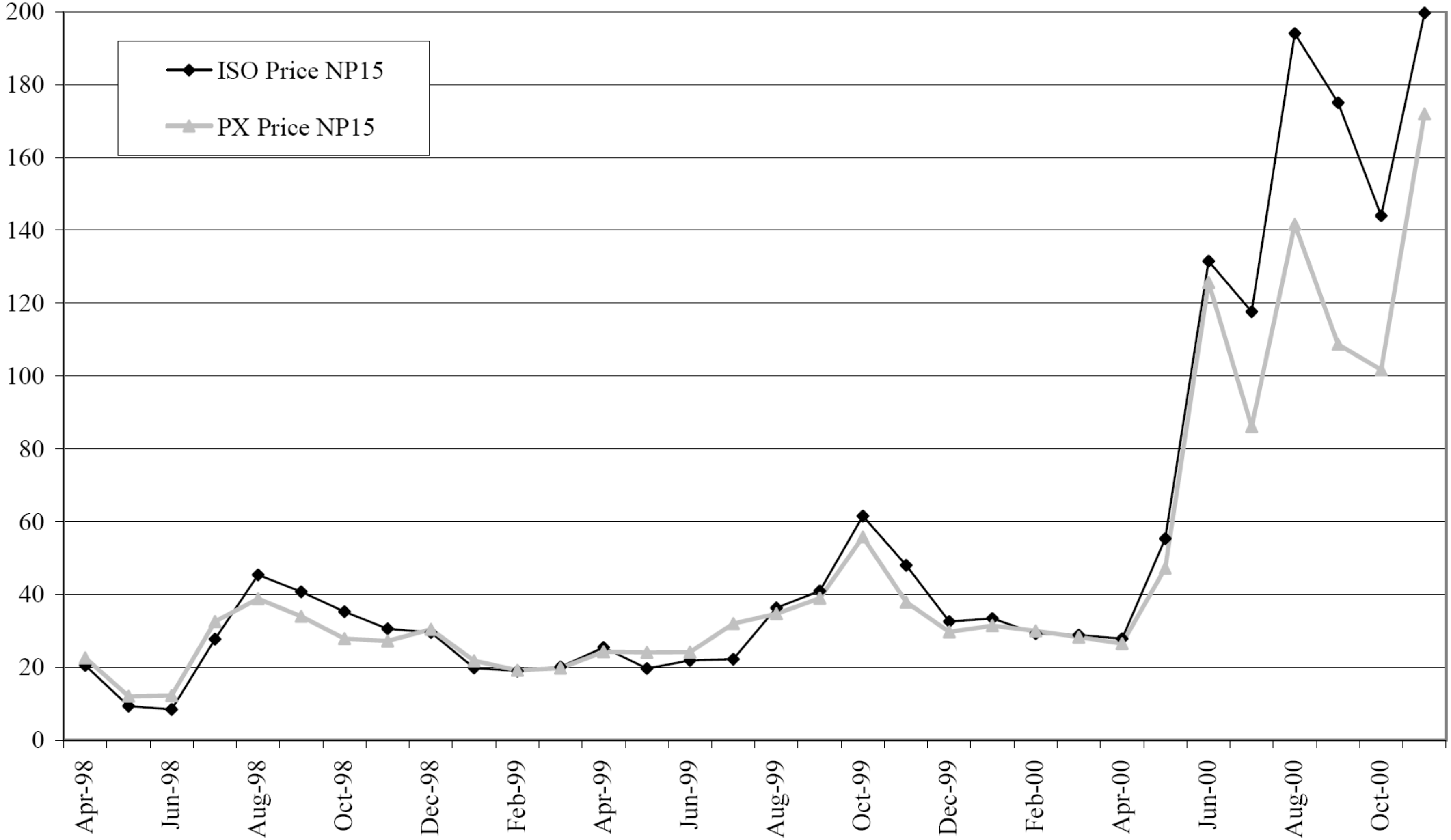
Trading Inefficiencies in California 1998-2000

- Borenstein, Bushnell, Knittel and Wolfram, *Journal of Industrial Economics*, forthcoming
- Markets to purchase both Day-ahead (PX) and imbalance (ISO) may create arbitrage trading opportunities

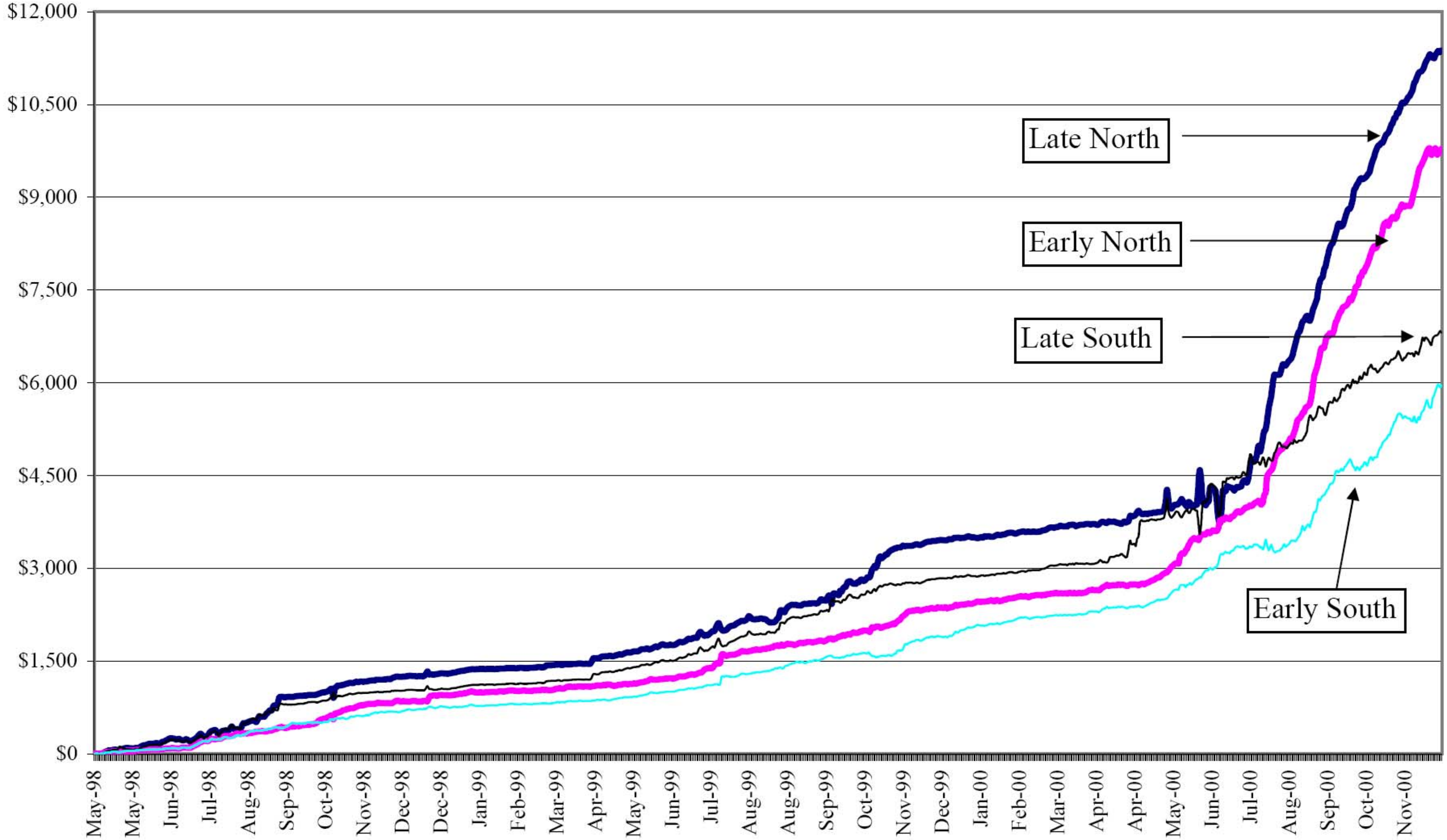
$$P_t^{ISO} = P_t^{PX} + \varepsilon_t$$

- If there are minimal costs to trading and no regulatory restrictions on “speculative trading”, the arbitrage opportunities should disappear.

Monthly Price Averages (all hours in NP15 - $/MWh)



Cummulative Profits: Weekly Trading Rule



Explanations?

- BBKW provide evidence that
  - NOT result of transaction costs
  - Risk is minimal relative to returns
  - ➔ not a competitive financial market for power
    - Some utilities & arbitrageurs had "market power" in trading opportunities

Conclusions

- Stakes appear to matter in strategic sophistication (ERCOT)
- Production inefficiencies arise from both:
  - Sophistication ("market power") (ERCOT & CA)
  - and lack of sophistication ("avoid the market") (ERCOT)
- If (unmasked) bid data are made available, can analyze efficiency of other markets/time periods

The End

Calculating Deviation from Optimal Producer Surplus

$

Optimal: $$\text{Profit} = P^{EPO} \cdot q_i^{EPO} - TC(q_i^{EPO}) - (P^{EPO} - PC)QC_i$$

Actual: $$\text{Profit} = P^{BAL} \cdot q_i^{BAL} - TC(q_i^{BAL}) - (P^{BAL} - PC)QC_i$$

Avoid: $$\text{Profit} = P_{Avoid}^{BAL} \cdot 0 - TC(0) - (P_{Avoid}^{BAL} - PC)QC_i$$

(1) Foregone Profits $= \pi^{Optimal} - \pi^{Actual}$

(2) Percent Achieved $= \dfrac{\pi^{Actual} - \pi^{Avoid}}{\pi^{Optimal} - \pi^{Avoid}}$

Would a (very) simple trading rule be profitable?

- For last week, find low & high price market.
- In coming week, buy 1 MWh in market with low prices last week and sell 1 MWh in market with high prices last week.

Uniform-Price Auction Model of ERCOT

- Setup
  - Static game, N firms, costs of generation $C_{it}(q)$
  - Contract quantity (QC_{it}) and price (PC_{it})
  - Total demand $\tilde{D}_t = D + \varepsilon_t$
  - Generators bid supply functions $S_{it}(p)$
  - Note: in "balancing market" terminology, these bids take form of INCrements and DECrements from "day-ahead" scheduled quantities
- Market-clearing price (p^c) given by (removing t subscript from now on):

$$\sum_{i=1}^{N} S_i(p^c) = \tilde{D}$$

Model (cont'd)

- Ex-post profit:

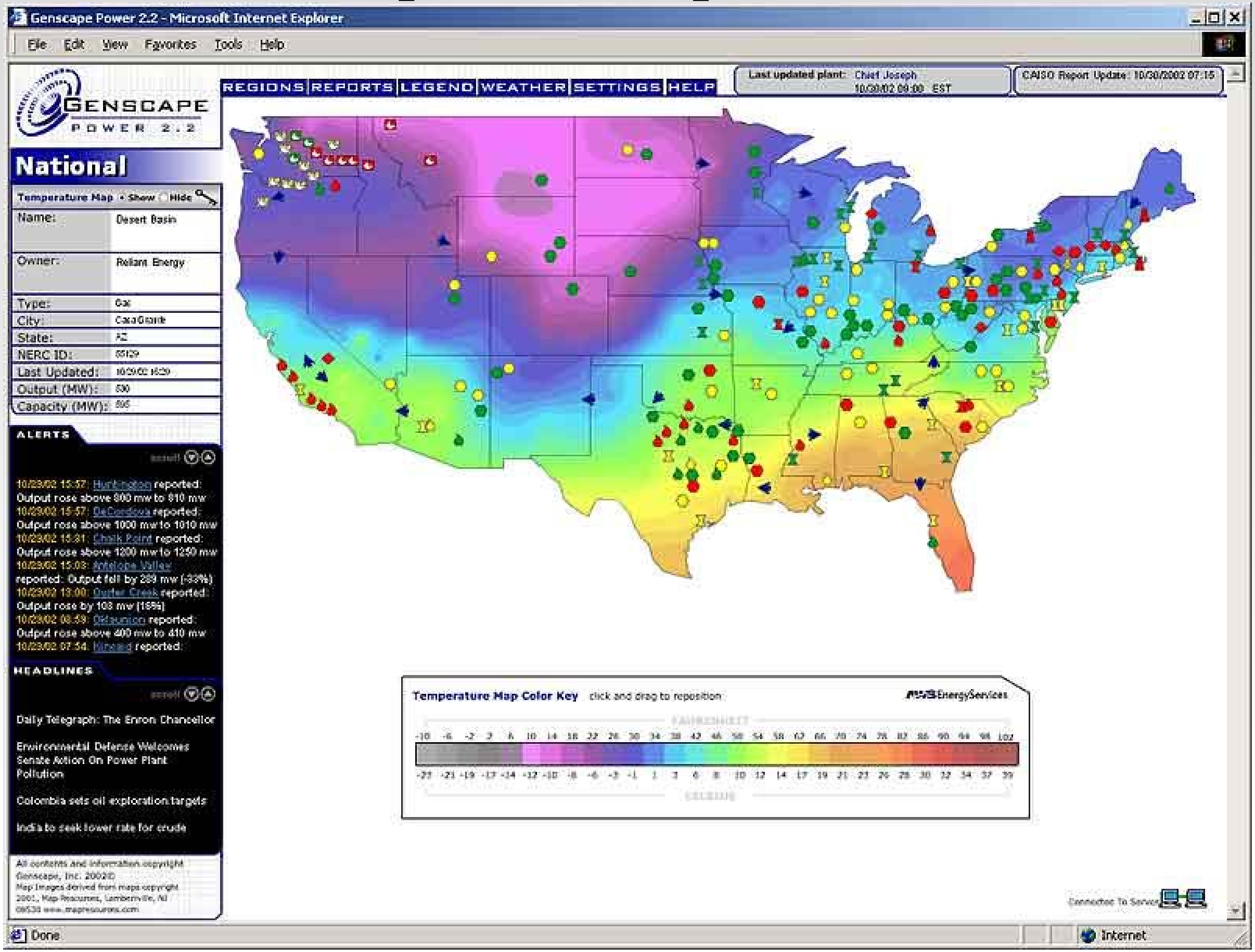
$$\pi_i = S_i(p^c)p^c - C_i(S_i(p^c)) - (p^c - PC_i)QC_i$$

- Information Structure
  - $C_i(q)$ common knowledge
  - Private information:
    - QC_i
    - PC_i – but does not affect maximization problem
  - $\widetilde{D}$ is unknown, but this is aggregate uncertainty

➔ important sources of uncertainty from perspective of bidder i

- Rival contract positions (QC_{-i}) and total demand (ε)

Sample Genscape Interface



Characterization of Bayesian Nash Equilibrium

Strategies : $S_i(p, QC_i)$

$QC_{-i}, \widetilde{D}$ have joint distribution $F(QC_{-i}, \widetilde{D} \mid QC_i)$ (possibly correlated)

Following Wilson's (1979) share auction model, define the probability distribution of market - clearing price, conditional on supply function $\hat{S}_i(p)$ and QC_i, given that other firms follow strategy profile $S_{-i}(p, QC_{-i})$:

$$H(p, \hat{S}_i(p)) \equiv \Pr\{p^c \leq p \,\Big|\, QC_i, \hat{S}_i(p)\}$$

$$= \Pr\{\sum_{j \in -i} S_j(p, QC_j) + \hat{S}_i(p) \geq \widetilde{D} \,\Big|\, QC_i, \hat{S}_i(p)\}$$

$$= \int_{QC_{-i} \times \varepsilon} 1\{\sum_{j \in -i} S_j(p, QC_j) + \hat{S}_i(p) \geq D + \varepsilon\} dF(QC_{-i}, \varepsilon \mid QC_i)$$

Equilibrium (cont'd)

Bidders choose supply functions to maximize expected profits

$$\max_{\hat{S}_i(p)} \int_{\underline{p}}^{\overline{p}} p\hat{S}_i(p) - C_i(\hat{S}_i(p)) - (p - PC_i)QC_i \, dH_i(p, \hat{S}_i(p); QC_i)$$

If *H(.)* is differentiable, necessary condition for pointwise optimality of $S_i^*(p)$:

$$p - C_i'(S_i^*(p)) = (S_i^*(p) - QC_i)\frac{H_S(p, S_i^*(p); QC_i)}{H_p(p, S_i^*(p); QC_i)}$$

Note: also holds under risk aversion (maximizing $E(U(\pi))$ where $U'' \neq 0$)

Equilibrium (cont'd)

CLAIM: If we restrict the class of supply functions:

$$S_i(p) = \alpha_i(p) + \beta_i(QC_i)$$

then (ex ante) equilibrium bids are ex post best responses:

$$p - C_i'(S_i^*(p)) = \frac{RD_i(p) - QC_i}{RD_i'(p)}$$

where

$$RD_i(p) = D(p) - \sum_{j \neq i} S_j(p)$$

Computing Ex Post Optimal Bids (Prop 3)

Ex post best response is Bayesian Nash Eqbm

➔ Uncertainty shifts residual demand parallel in & out

(observed realization of uncertainty provides "data" on $RD_i'(p)$ for all other possible realizations)

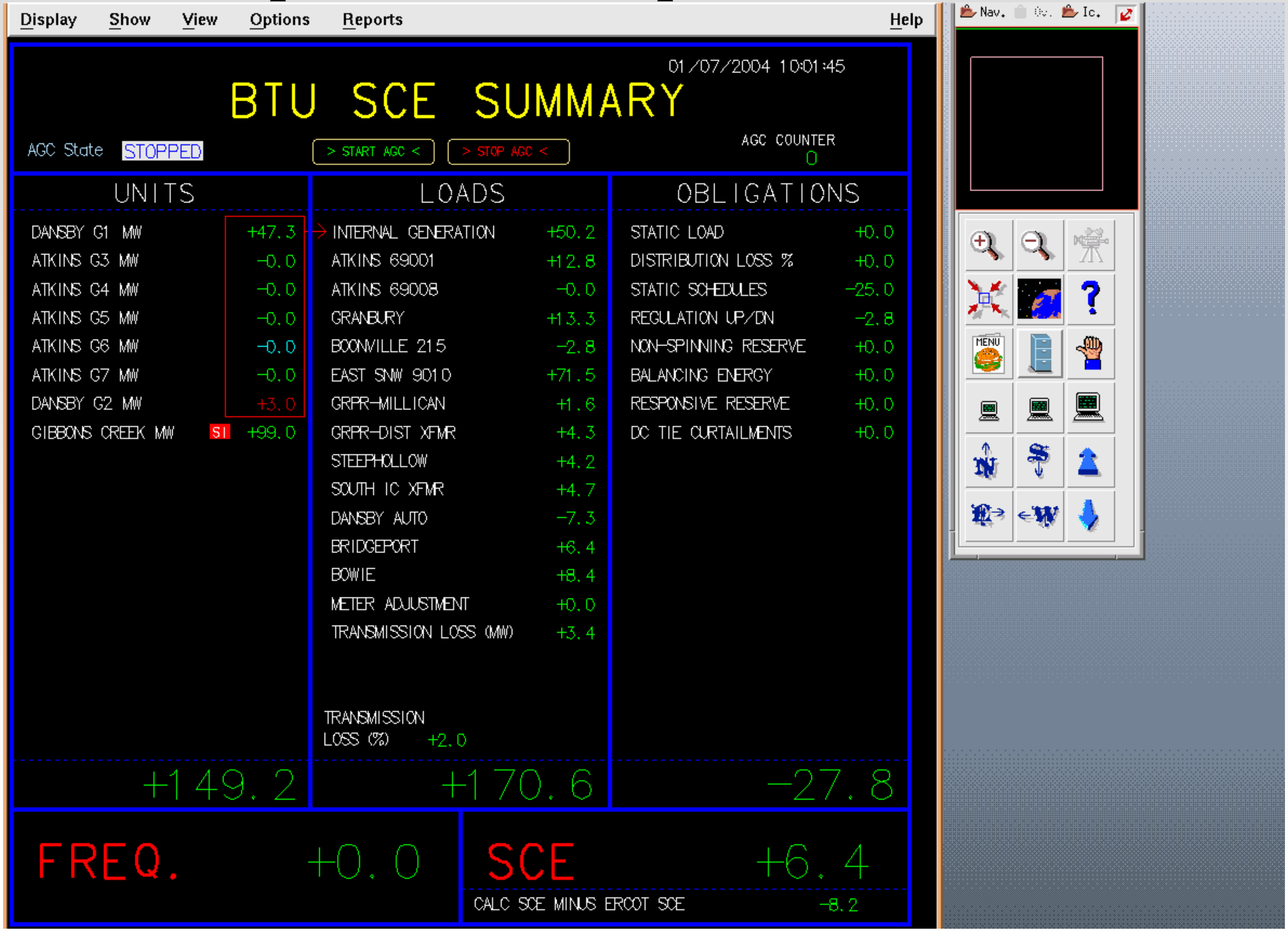
➔ Can trace out ex post optimal/equilibrium bidpoint for every realization of uncertainty (distribution of uncertainty doesn't matter)

$$p - MC_i(\underbrace{S_i^*(p)}_{Unknown}) = \frac{\overbrace{S_i^*(p)}^{Unknown} - QC_i}{RD_i'(p)} \quad (\text{"inverse elasticity rule"})$$

Do We Expect to See Optimal Bidding?

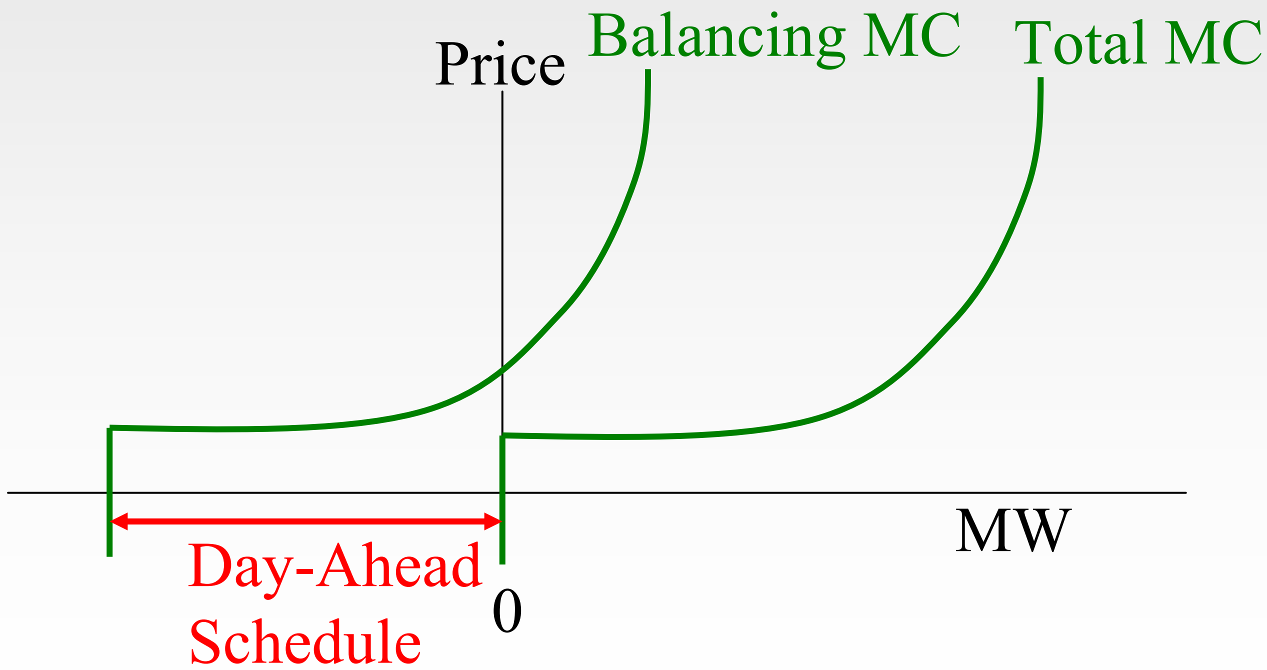
- First year of market
  - Some traders experienced while others brought over from generation and transmission sectors
- Many bidding & optimization decisions being made
- Real-time information?
  - Frequency charts & Genscape sensor data ➔ rival costs
  - Aggregate bid stacks with 2-3 day lag ➔ "adaptive best-response" bidding?
- Is there enough $$ at stake in balancing market?
  - Several hundred to several thousand per hour
- "Bounded rationality"

Sample Bidder's Operations Interface



Measuring Marginal Cost in Balancing Market

- Use coal and gas-fired generating units that are “on” and the daily capacity declaration
- Calculate how much generation from those units is already scheduled == Day-Ahead Schedule



Testing Expected Profit Maximizing Behavior

1) Restrict economic environment so ex-post optimal = ex-ante optimal
2) No restrictions – uncertainty can "shift" and "pivot" RD
    1) Can simple trading rules improve upon realized profits?
    2) Check (local) optimality of observed bids (Wolak, 2001)

“Naïve Best Reply Test” of Optimality

- Bidders can see aggregate bids with a few day lag
- Simple trading rule: use bid data from *t-3*, assume rivals don’t change bids, and find ex post optimal bids (under parallel shift assumption)
- Does this outperform actual bidding?

Generator's Ex-Ante Problem

- Max $E_{\varepsilon}[\pi(p,\varepsilon)]$

  uncertainty (ε) can enter *RD(p,ε)* very generally

- Wolak test for (local) optimality:
  - H_o: Each bidpoint chosen optimally
  - Changing the price/quantity of each (p_k,q_k) will not incrementally increase profits *on average*

Test for (Local) Optimality of Bids

Choose bid vector $\Omega \equiv (p_1, q_{1,} \ldots p_K, q_K)$

$$\Pi(\Omega,\varepsilon) = RD(p(\varepsilon,\Omega),\varepsilon)\,p(\varepsilon,\Omega) - C(S(p(\varepsilon,\Omega),\Omega))$$
$$-(p(\varepsilon,\Omega) - PC)QC$$

$$E_\varepsilon\left(\frac{\partial\Pi(\Omega,\varepsilon)}{\partial q_k}\right) = 0$$

Moment condition for each bidpoint on day *t*:

$$\frac{\partial\Pi(\Omega,\varepsilon)}{\partial q_k} = \left[\frac{\partial RD}{\partial p}p(\varepsilon,\Omega) + RD(p,\varepsilon) - QC - \frac{\partial C}{\partial S}\frac{\partial S}{\partial p}\right]\frac{\partial p}{\partial q_k} - \frac{\partial C}{\partial S}\frac{\partial S}{\partial q_k}$$

$\mathrm{H_o}$: Vector of k moments for day $t \equiv \vec{u}_t = \vec{0}$?

$$T \cdot J_T = ([\tfrac{1}{T}\sum_{t=1}^{T} u_t]'\, S_T^{-1}\, [\tfrac{1}{T}\sum_{t=1}^{T} u_t]) \text{ distributed } \chi_k^2$$

Test for (Local) Optimality of Bids

Table 4: J-Tests of Expected Profit Maximization

Firm	TJ_T	P-value	T	Reject $E[\pi]$ max?
Reliant (pre-Nov 2002)	13.1	0.71	116	No
Reliant	33.4	0.99	154	Yes
Brownsville	24.27	0.99	53	Yes
Bryan	91.3	1	220	Yes
Tenaska	75.61	1	82	Yes
TXU	146.1	1	220	Yes
Calpine	115.3	1	171	Yes

Notes: Section 4.3.2, Equation (6) was used form the moments. Specifically, the quantity derivative of the firm's profit function was taken at 11 equally spaced prices between $16 and $36. Hansen's J-statistic, J_T, is given by Equation (7). The p-value is based on a χ^2 distribution with 11 degrees of freedom. The 5% critical value is 19.7.

Possible Explanations for Deviations from Benchmarks

1. Unmeasured “adjustment costs”
2. Transmission constraints
3. Collusion / dynamic pricing
4. Type of firm
5. Stakes matter

Adjustment Costs?

1. Flexible gas-fired units often are marginal
   - 70-90% of time for firms serving as own bidders

2. "Bid-ask" spread smaller for firms closer to benchmark
   - Decreases over time for higher-performing firms

Table 5: Characteristics of Bid Functions By Percent Achieved

Firm	**Percent Achieved**	**Mean Bid Points**	**Mean Bid-Ask Spread ($/MWh)**
Reliant	79%	22.2	$2.06
City of Bryan	45%	6.5	$22.58
TXU	39%	12.6	$20.60
Calpine Corp	37%	7.5	$12.55
City of Austin	30%	10.0	$25.92
Lower Colorado River Authority	25%	9.1	$25.98
City of Garland	13%	6.1	$20.32
South Texas Electric Coop	3%	3.7	$68.66

Transmission Constraints?

- Does bidding strategy from congested hours spillover into uncongested hours?

Table 6: Relationship Between Profitability and Transmission Congestion

Dependent Variable: Monthly *PercentAchieved* by Firm *i*

	All Firms	Own Bidders
Pct Intervals Congested	-0.16	-0.17
	(0.09)	(0.14)
Volume Optimal Output (GWh)	0.34	0.09
	(0.21)	(0.25)
Monthly Fraction DEC	-0.05	0.03
	(0.06)	(0.11)
R-squared	0.48	0.47

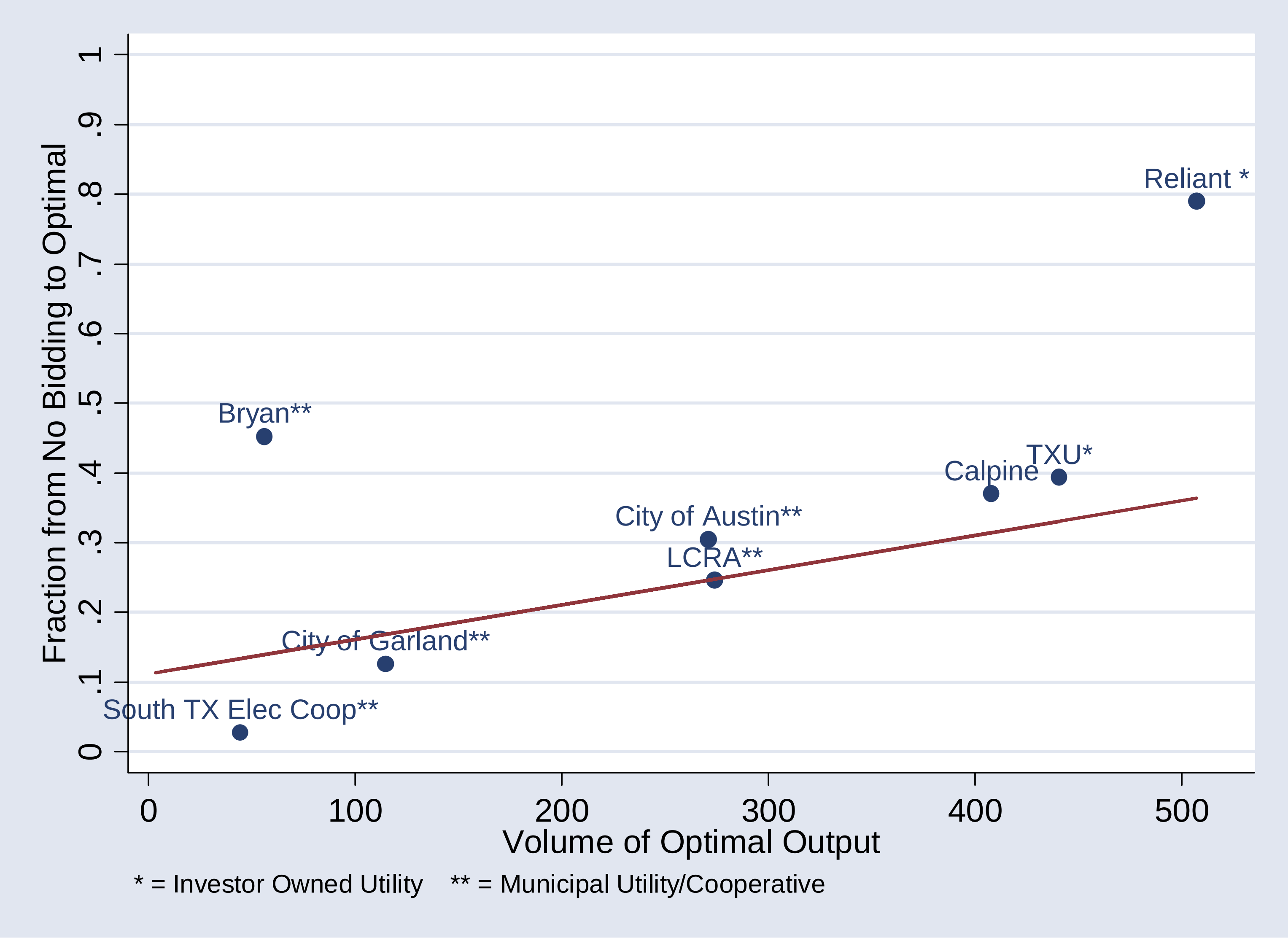
Model includes firm fixed effects.
Robust standard errors in parentheses.
Note: *PercentAchieved* is the monthly fraction of potential profits achieved relative to not bidding, defined in section 4.2.

- 1 std dev increase in percent congestion ➔ only 3% ↓Pct Achieved

Collusion?

- Collusion not consistent with large bid-ask spreads
  - Collusion → smaller sales than ex-post optimal
  - Bid-ask spread → no sales
- Would be small(!) players - unlikely

Do Stakes Matter?



Explaining "Percent Achieved" Across Firms

	(1)	(2)	(3)	(4)	(5)
Size (MWh)	0.00052	0.00047	0.00035	-0.00015	-0.00035
	(0.00031)*	(0.00026)*	(0.00028)	(0.00025)	(0.00024)
Size*OwnBidder				0.00101	0.00132
				(0.00044)**	(0.00042)***
OwnBidder				-0.071	-0.215
				(0.111)	(0.109)*
Merchant Firm		-0.098	-0.167		-0.170
		(0.135)	(0.146)		(0.098)*
Municipal		0.048	0.025		0.047
		(0.135)	(0.142)		(0.089)
Coal			-0.021		0.043
			(0.113)		(0.120)
Combined-Cycle			0.082		0.127
			(0.058)		(0.071)*
Constant	0.100	0.158	0.200	0.158	0.262
	(0.054)*	(0.142)	(0.152)	(0.058)**	(0.098)**
Observations	34	34	34	34	34
R-squared	0.15	0.28	0.31	0.34	0.50

Notes: Dependent variable is the Percent Achieved for firm *i* over the entire sample as defined in section 4. Parameters are estimated by OLS. White standard errors are in parentheses. The excluded category for firm type is Investor-Owned utililty.

(4) Own Bidders: 1000MWh increase in sales ➔ 86 percentage point increase in Pct Achieved
(5) Own Bidders: 1000MWh increase in sales ➔ 97 percentage point increase in Pct Achieved

Learning?

Table 9: Evolution of Performance and Learning

	All Firms	Top 6 Firms	Non Top 6 Firms
Days Since Market Began	0.00031	0.00033	0.00028
	(0.00010)**	(0.00029)	(0.00009)**
Volume Optimal Output (GWh)	0.16	0.25	0.09
	(0.06)**	(0.10)*	(0.06)
Off-Peak Season	0.01361	-0.04437	0.03164
	(0.01892)	(0.03799)	(0.01885)
Constant	0.02330	0.21053	-0.01441
	(0.03030)	(0.07503)**	(0.02886)
Observations	9765	2103	7662
R-squared	0.25	0.18	0.11

Notes: Model includes firm fixed effects. The dependent variable is the *PercentAchieved* for firm i on day t. Parameters are estimated by OLS. White standard errors in parentheses.

* significant at 5%

** significant at 1%

Conclusions

- Electricity markets are a great “field” setting to understand firm behavior under uncertainty and private information
- Stakes appear to matter in strategic sophistication
- Both sophistication (“market power”) and lack of sophistication (“avoid the market”) contribute to inefficiency in this market
- Equilibrium bidding models
  - For large firms, models closely predict actual bidding
  - For small firms/new markets, models less accurate
- Market design
  - If strategic complexity imposes large participation costs, may wish to choose mechanisms with dominant strategy equilibrium (e.g. Vickrey auction)