The Role of Financial Market Participants in Improving Wholesale Electricity Market Performance

Convergence Bidding in California

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Public Perception of Financial Market Participants

- Buys something he has no intention of consuming and sells something he does not or cannot produce
- Profits from buying low and selling high over time and space
- Can also sell first and buy back later–Short sales
- Financial participants are often called "arbitrageurs" or "speculators", because they engage in "risky arbitrage"
- Financial participants take money away from producers that make product and consumers that purchase product
- *Note that in wholesale electricity markets there are few riskless profit opportunities for financial participants*

Recent Publicity for Financial Participants in the US-1

The New York Times | http://nyti.ms/1v0XD5r

ENERGY & ENVIRONMENT | NYT NOW

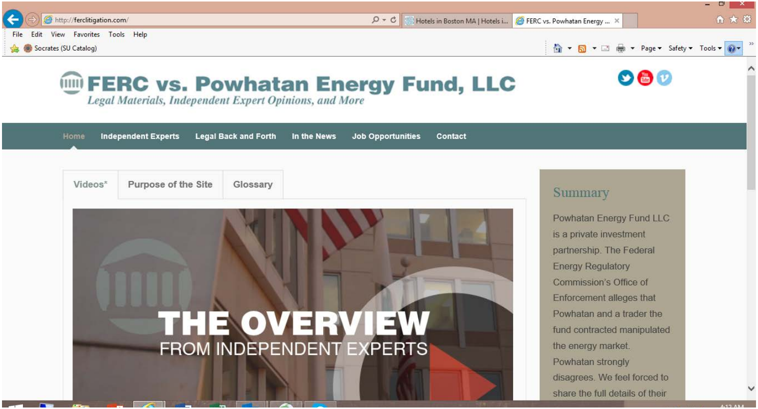
Traders Profit as Power Grid Is Overworked

By JULIE CRESWELL and ROBERT GEBELOFF AUG. 14, 2014

PORT JEFFERSON, N.Y. — By 10 a.m. the heat was closing in on the North Shore of Long Island. But 300 miles down the seaboard, at an obscure investment company near Washington, the forecast pointed to something else: profit.

As the temperatures climbed toward the 90s here and air-conditioners turned on, the electric grid struggled to meet the demand. By midafternoon, the wholesale price of electricity had jumped nearly 550 percent.

Recent Publicity for Financial Participants in the US-2



What Did Financial Participants Do to Deserve This?

- Financial participants, generation unit owners, retailers are all attempting to maximize expected profits by taking any legal action that increases profits
- Desire of all market participants, including financial participants, to earn higher profits is like gravity
  - Cannot deny the existence of laws of gravity, but must respect these laws in the design of buildings, aircrafts, etc.
- Energy market designers/regulators must respect "laws of economics"
  - If a profitable action exists, it will be exploited as long as it remains profitable
- Regulator cannot deny the existence of this "law" in the design of a wholesale electricity market

Implications for Market Design and Regulatory Oversight

- Many undesirable market outcomes can be traced to a failure to respect laws of economics, not nefarious behavior by some market participants
- In poorly designed market, financial participants exploiting profitable opportunities can significantly increase costs to consumers
- in well-designed market, financial participants exploiting profitable opportunities can reduce cost of supplying consumers and increase system reliability
- In both instances, financial participants are behaving according to the "laws of economics" with no intent to harm market efficiency
  - This talk will present one example

Example of Efficiency Benefits of Financial Participants

- All US wholesale electricity markets are multi-settlement, locational marginal pricing (LMP) markets
  - Day-ahead buy or sell firm financial commitments to deliver or consume electricity each hour of the following day
  - In real-time, buy or sell energy every 5-minutes
  - Both day-ahead and real-time markets set prices at thousands of locations or nodes in the control area
- On February 1, 2011, California ISO introduced explicit virtual bidding or convergence bidding, a purely financial product for trading differences between day-ahead and real-time prices at a location
- Discuss empirical evidence from Jha and Wolak (2014) that introduction of this purely financial product improved efficiency of market and increased system reliability

Background on Trading in Forward and Spot in Commodity Markets

- In markets with risk neutral traders, we expect that $E_t[p^S_{t+k} - p^F_{t,t+k}] = 0$, where
  - p^S_{t+k} = spot price at time t+k
  - $p^F_{t,t+k}$ = forward price at time t for delivery at time $t + k$
  - $E_t(.)$ = expectation conditional on information available at time t
- All commodity markets have non-trivial trading costs that invalidate this relationship. Profitable trading implies that $|E_t[p^S_{t+k,t+k} - p^F_{t,t+k}]| > c$, where c = round-trip cost associated with trading price differences across the two markets
- Develop test of null hypothesis that a profitable trading strategy exists in financial markets with transactions costs

Trading and Forward and Spot in Commodity Markets

- Assess impact of introduction of virtual bidding on c ("implicit trading cost" described above), variance of real-time prices, variance of difference between day-ahead and real-time prices, autocorrelation of daily price difference vector
- Assess impact of introduction of virtual bidding on efficiency of market outcomes in wholesale electricity market and greenhouse gas emissions intensity of electricity sector
- Background on operation of US wholesale electricity markets necessary to explain why expected profit-maximizing actions of financial participants using explicit virtual bidding (EVB) has potential to improve efficiency of wholesale market outcomes

Background on US Wholesale Electricity Markets–LMP

- In day-ahead market, ISO uses generation unit-specific offer curves to solve for generation unit-level output levels for all 24 hours of following day
- Output levels found that minimize "as-bid cost" to serve demand at all locations in transmission network subject to expected real-time transmission network configuration and other operating constraints
- Locational marginal price (LMP) at a node is increase in optimized value of this objective function associated with increasing demand at that node by 1 MWh.
  - Resulting outputs levels and LMPs are firm financial forward market commitments.

Background on US Wholesale Electricity Markets–LMP

- Between day-ahead and real-time market, suppliers can revise their offer curves
- LMP process is re-run in real time to determine locational prices and real-time output levels every 5-minutes using most up-to-date information on transmission network and operating constraints.
- LMPs and output levels that result from minimizing as-bid cost to meet demand at all locations in transmission network during 5-minute interval are also firm financial commitments
  - Average of 5-minute LMPs during hour is hourly real-time LMP.
  - Hourly real-time prices are substantially more volatile than day-ahead prices because of limited flexibility in electricity generation units and transmission network in real-time versus day-ahead time frame

Background on US Wholesale Electricity Markets–Multi-Settlement

- Supplier receives revenue from day-ahead forward market sales regardless of real-time output of its generation unit. Sell 40 MWh at a price of $25/MWh receive $1,000 for sales.
- Any deviation from day-ahead generation or load schedule is cleared in real-time market.
  - If supplier only produces 30 MWh, it must purchase 10 MWh of day-ahead commitment from real-time market
- Same logic applies to a load-serving entity. Buy 100 MWh in day-ahead for $40/MWh and pay $4,000 regardless of real-time consumption.
  - If load-serving entity consumes 110 MWh, must buy additional 10 MWh at real-time price.

Trading Day-Ahead and Real-Time Price Differences before Explicit Virtual Bidding

- A supplier that thinks $P_{DA} < P_{RT}$ will sell less than anticipated real-time production in day-ahead market and sell remaining output in real-time market
  - Reduces supply in day-ahead market and increases supply in real-time market, which causes day-ahead price to rise and real-time price to fall
- A load-serving entity that thinks $P_{DA} > P_{RT}$ will buy less than anticipated real-time consumption in day-ahead market and purchase remaining consumption in real-time market
  - Reduces demand in day-ahead market and increases demand in real-time market, which causes day-ahead price to fall and real-time price to increase
- This "implicit virtual bidding" can create significant system reliability consequences and increase the costs of meeting system demand

What is Explicit Virtual or Convergence Bidding?

- Virtual bids are identified as such to ISO and can be submitted at nodal level
- Incremental (INC) virtual bid is a purely financial transaction that is treated just like an energy offer curve in the day-ahead market. Amount sold in day-ahead market must be purchased in the real-time market as a price-taker
  - Profit from day-ahead sale of 1 MWh INC bid is $P_{DA} - P_{RT}$
- Decremental (DEC) virtual bid is a purely financial transactions that is treated just like an demand bid curve in day-ahead market. Amount purchased in day-ahead market must be sold in real-time market as a price-taker.
  - Profit from accepted 1 MWh DEC bid is $P_{RT} - P_{DA}$
- All market participants can use EVB to profit from expected price differences.

Why Should Explicit Virtual Bidding Reduce Trading Costs and Improve Price Convergence?

- Generation unit owners have limited range of MWh over which they can implicit virtual bid–from minimum operating level to maximum operating level of generation unit.
  - Firms can only implicitly virtual bid where own generation units.
- Load-serving entities can only bid within range of expected demand level.
  - Load serving entities can only submit physical demand bids in day-ahead market for their entire service area.
  - ISO allocates this aggregate demand bid curve to nodes in service territory of load-serving entity
  - Prevents "implicit virtual bidding" at load nodes

Why Should Explicit Virtual Bidding Improve Market Performance and Reduce GHG Emissions Intensity?

- If all expected nodal price differences are zero, no reason to take costly actions to exploit them
- There are many low-variable cost, long-start units that may not be started in day-ahead market
  - If long-start units are not committed in day-ahead market they are less likely to run in real-time
  - More expensive short-start unit likely to have to operate instead and set a higher real-time price
- Can submit a DEC virtual bid to increase day-ahead demand and cause unit to be taken in day-ahead market
  - Lower prices potentially set in both day-ahead and real-time markets because long-start unit operates
- Conclusion–Besides reducing price differences between day-ahead and real-time market, EVB can reduce actual cost to serve system demand

Anticipated Benefit of Convergence Bidding in Multi-Settlement Markets

- Reduce implicit trading cost necessary to earn profits trading day-ahead versus real-time price differences
- Suppliers will have an incentive to schedule their expected real-time output in day-ahead market because $E(P_{DA} - P_{RT}) = 0$.
- Load-serving entities have an incentive to schedule real-time expected demand in day-ahead market

Anticipated Benefits of Convergence Bidding in Multi-Settlement Markets

- Reduce the total operating costs of meeting demand in real-time
  - Virtual bidders that correctly anticipate that more real-time demand or supply is needed than was scheduled in the day-ahead market at a given location in transmission network will profit from their virtual bids.
  - Creates incentive for day-ahead market to produce least cost mix of generation unit-level schedules to meet real-time nodal demands which should also reduce volatility in real-time prices and volatility of difference between day-ahead and real-time prices
- We examine validity of these two hypotheses–improved price convergence and market efficiency–for California wholesale electricity market

Outline of Remainder of Talk

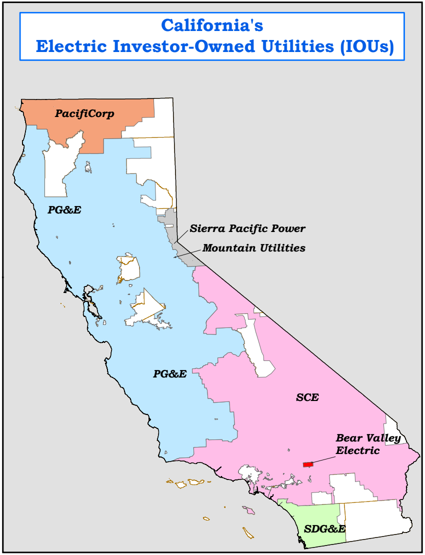
- Data Description
- Formulation of Hypothesis Tests for the Existence of a Profitable Trading Strategy
- Trading Costs Implied by these Tests
- Market Performance Measures: Before and After Explicit Virtual Bidding (EVB)
- Conclusions on Role of Purely Financial Trading

Data Overview

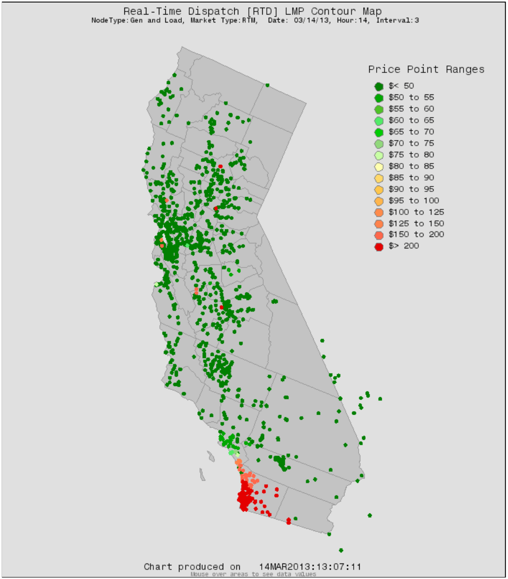
- Hourly prices from California's day-ahead and real-time markets from 4/1/2009 - 12/31/2012.
  - California switched to nodal pricing market on 4/1/2009
- Present detailed empirical results at the Load Aggregation Point (LAP) level and then summary of nodal-level results.
- There are three large load-serving entities in California: Pacific Gas and Electric (PGE), Southern California Edison (SCE), and San Diego Gas and Electric (SDGE). They bid their demand in at the LAP level and pay the LAP price for their withdrawals
  - The LAP price is calculated as a nodal load-weighted average of LMPs in each firm's service territory.
- All generation units are paid or pay their nodal price.
- Many more nodes (about 5,000) than generation units (about 400) in California.

▸ Summary Statistics

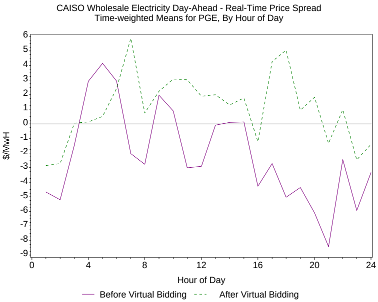
California's Load-Serving Entity Territories

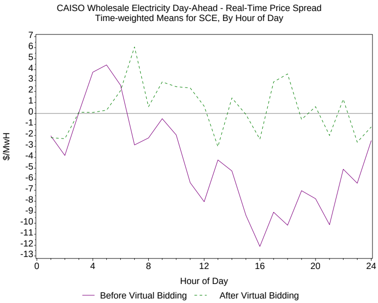


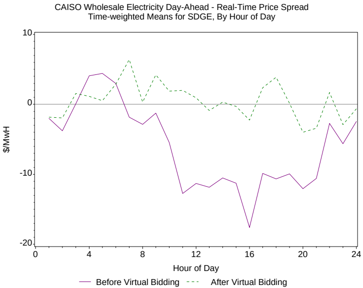
The Location of California's Pricing Nodes



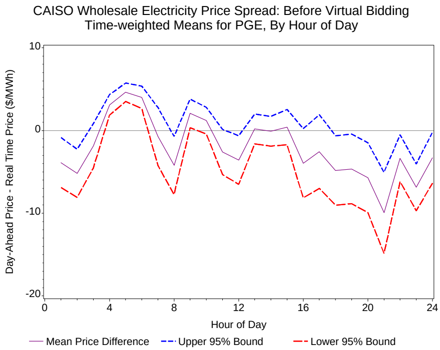
Average Hourly Price Differences: Before and After EVB

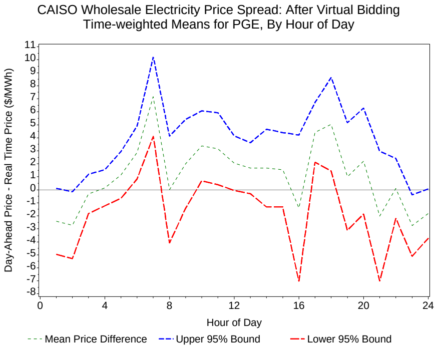




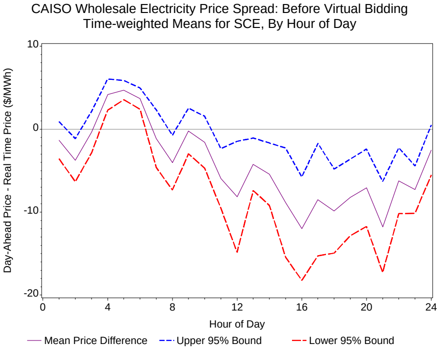


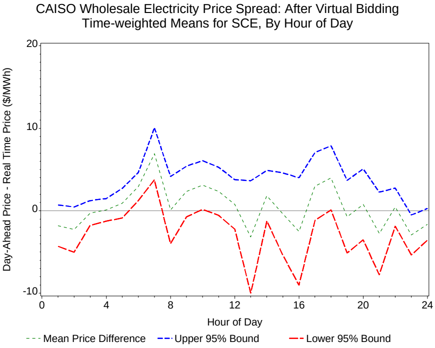
Average Hourly Price Differences with 95 % C.I: PGE



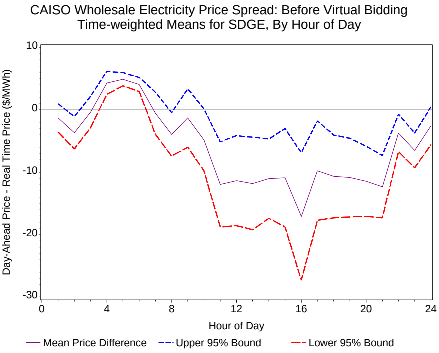


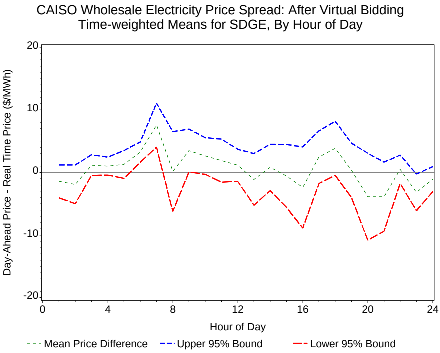
Average Hourly Price Differences with 95 % C.I: SCE





Average Hourly Price Differences with 95 % C.I: SDGE





Joint Null of Zero Expected Price Differences

Table: Test Statistics for Joint Test of Zero Mean Price Differences

	Before EVB	After EVB
PG&E	141.738	88.158
SCE	140.140	105.127
SDG&E	157.742	86.084

- The upper $\alpha = 0.05$ critical value for the $\chi^2(24)$ distribution is 36.415.
- Both sets of test statistics are smaller after explicit virtual bidding (EVB).
- *Note: Non-zero trading costs could be reason for rejection of null hypothesis of zero mean*

The Trader's Problem with Transactions Costs

- Consider a trader that has access to 24 financial assets $X(h) = P(h)^{RT} - P(h)^{DA}$ for $h = 1, 2, ..., 24$ with $X = (X(1), X(2), ..., X(24))'$ with mean vector μ and contemporaneous covariance matrix Λ.
  - As mentioned previously, each asset is:
    Buy (sell) MWhs in hour h in the day-ahead market and sell (buy) back same number of MWhs in the real-time market.

- A profitable trading strategy exists if a trader can make a expected profits from trading these assets, including per-unit trading costs c
  - Expected trading profits exist if $a'\mu - c\sum_{i=1}^{24}|a_i| \; > \; 0$ for some $a \in R^{24}$.
  - Trading charge is assessed on absolute values of portfolio weights, a_i $(i = 1, 2, ...24)$, because trader can buy or sell day-ahead price minus real-time price, which implies the normalization $\sum_{i=1}^{24}|a_i| \; = \; 1$.

Test for the Existence of a Profitable Trading Strategy

- Let $\overline{X}$ be the 24 x 1 vector of estimates of elements of μ using T days of data.
- Let $a^*(\mu)$ equal the expected profit-maximizing portfolio weights and $\phi(\mu) \equiv a^*(\mu)`\mu$, the optimized value of the objective function for each value of μ.
- Hypothesis test is $H : \phi(\mu) - c > 0$ versus $H : \phi(\mu) - c \leq 0$, a profitable trading strategy exists against alternative that it does not.

Test for the Existence of Profitable Trading Strategy

- Test of null hypothesis of the existence of a profitable trading strategy can be re-written as:
  - $H : \phi(\mu) \; > \; c$ versus $H : \phi(\mu) \; \leq \; c$.
- Problem complicated by fact that $\phi(\mu)$ is not differentiable in μ, so δ-method is not applicable. However, $\phi(\mu)$ is directionally differentiable in μ
- Fang and Santos (2014) derive a resampling procedure for computing an estimate of the asymptotic distribution of $\sqrt{T}(\phi(\overline{X}) \; - \; \phi(\mu))$
- We employ a numerical derivative-based approach to simulating this distribution developed by Hong and Li (2015)

Computing Estimate of Asymptotic Distribution of $\sqrt{T}(\phi(\overline{X}) - \phi(\mu))$

- Use bootstrap distribution of Z^b to compute an estimate of the distribution of $\phi(\overline{X})$.
- Compute each bootstrap re-sample of $\phi(\overline{X})$ as: $\phi(\overline{X})^b = \phi(\overline{X}) + Z^b/\sqrt{T}$
- Use this distribution to compute two values of c:
  - Smallest value of c that causes rejection of $\alpha = 0.05$ test of $\phi(\mu) > c$
  - Largest value of c that causes rejective of $\alpha = 0.05$ test of $\phi(\mu) < c$.
- First value is c_{lower} and second is c_{upper}.
  - c_{lower} smallest value of trading cost that causes rejection of null hypothesis of the existence of profitable trading strategy
  - c_{upper} is largest value of trading cost that causes rejection of the null hypothesis that no profitable trading strategy exists

Form of Trading Strategies Considered

- We consider very simple trading strategies that require little time or effort on the part of the trader. In this way, the transactions costs that we capture are the most comparable to the explicit market costs associated with trading.

- More complex trading strategies would require dedicated worker to implement, update and execute. Salary of individual and support staff should be included in trading costs to determine profits

- This process is complicated by the fact that these costs are primarily annual fixed costs

- As following analysis demonstrates, there is no empirical evidence of exploitable autocorrelation over days in the vector of price differences

Autocorrelation Past First Lag for Daily Price Differences Before and After EVB

- Because day-ahead prices for following day are only known during the afternoon of current day, there can be unexploitable first-order autocorelation in vector of daily price differences
- Test for zero autocorrelation beyond first-order conditional on existence of non-zero first order autocorrelation
- Let $\Gamma(\tau) = E(X_t - \mu)(X_{t-\tau} - \mu)'$ τ^{th} order autocorrelation matrix
- Test joint null hypothesis $H : \Gamma(2) = 0, \Gamma(3) = 0, ..., \Gamma(L) = 0$
- Test $H : \xi \equiv vec(\Gamma(2), \Gamma(3), ..., \Gamma(L)) = 0$ and compute estimate of asymptotic covariance of $\hat{\xi}$ using moving blocks bootstrap to allow for autocorrelation in X_t
- Test statistic is asymptotically distributed as chi-squared random variable with $24^2 * (L - 1)$ degrees of freedom

Multivariate Test for Autocorrelation Past First Lag for Daily Price Differences

Table: Test Statistics for Autocorrelation ($1 < L \leq 10$) in Daily Price Differences

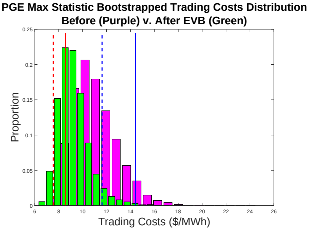
	Before EVB	After EVB
PG&E	2862.2	2767.0
SCE	2789.2	2842.6
SDG&E	3082.1	2700.7

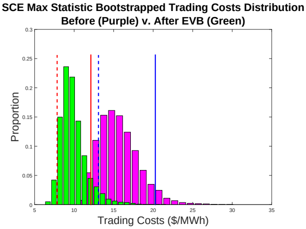
The upper $\alpha = 0.05$ critical value for the $\chi^2(5184)$ for $5184 = 24^2 * 9$ distribution is 5352.6.

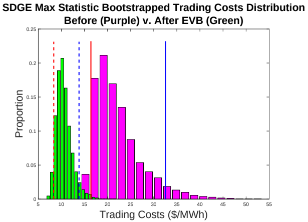
Zonal-Level Implied Trading Costs

		Before EVB	After EVB
c_{lower}	PG&E	8.591	7.531
	SCE	12.112	7.845
	SDG&E	16.453	8.393
c_{upper}	PG&E	14.385	11.684
	SCE	20.185	13.209
	SDG&E	32.391	13.825

Bootstrap Distribution of $\phi(\overline{X})$ Before and After EVB



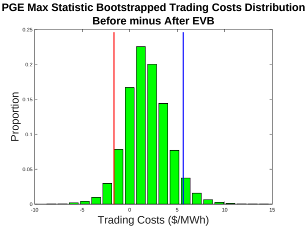


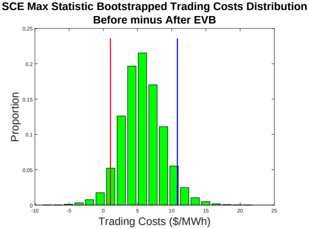


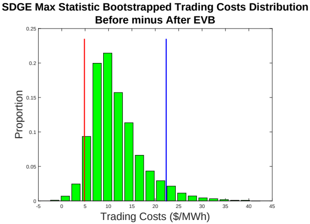
Tests for Changes in Implied Trading Costs Before versus After Implementation of Explicit Virtual Bidding

- If lower 5^{th} percentile of distribution of $c_{pre} - c_{post}$ is greater than zero, then would reject null hypothesis that $c_{pre}^{true} - c_{post}^{true} \leq 0$
- If upper 95^{th} percentile is less than zero, then would reject null hypothesis that $c_{pre}^{true} - c_{post}^{true} \geq 0$
- For SCE and SDG&E, reject null of that $c_{pre}^{true} - c_{post}^{true} \leq 0$ and do not reject $c_{pre}^{true} - c_{post}^{true} \geq 0$
- For PG&E, do not reject either null hypothesis

Bootstrap Distribution of the Difference in Implied Trading Costs with Upper and Lower 5 percent Critical Values







Second Moment Implications of Explicit Virtual Bidding

- Virtual bidders are expected to reduce day-ahead uncertaintly about differences between day-ahead and real-time prices, as well as uncertainty in real-time prices

- Formally, the hypothesis test is $H \ : \Lambda_{pre} - \Lambda_{post} \ \geq \ 0$, the difference between pre-EVB convariance matrix and post-EVB covariance matrix is a positive semi-definite matrix

- Nonlinear multivariate inequality constraints test of Wolak (1989) with null hypothesis that all 24 eigenvalues of $\Lambda_{pre} - \Lambda_{post}$ are greater than or equal to zero

- Estimate of asymptotic covariance matrix of eigenvalues of $\hat{\Lambda}_{pre} \ - \ \hat{\Lambda}_{post}$ using moving blocks boostrap that accounts for potential autocorrelation in vector of daily prices

P-values associated with Volatility Tests

	LAP	Price Difference	Real-Time Price
Pre - Post	PG&E	0.284	0.516
	SCE	0.509	0.697
	SDG&E	0.476	0.647
Post - Pre	PG&E	0.001	0.016
	SCE	0.001	0.034
	SDG&E	0.028	0.165

- Do not reject null hypothesis that all 24 eigenvalues of $\Lambda_{pre} - \Lambda_{post}$ are greater than or equal to zero
- Reject null hypothesis that all 24 eigenvalues of $\Lambda_{post} - \Lambda_{pre}$ are greater than or equal to zero
- Consistent with EVB reducing price volatility

Predictions About Differences in Nodal Level Trading Cost Changes Between Generation Nodes and Non-Generation Nodes Before versus After Implementation of Explicit Virtual Bidding

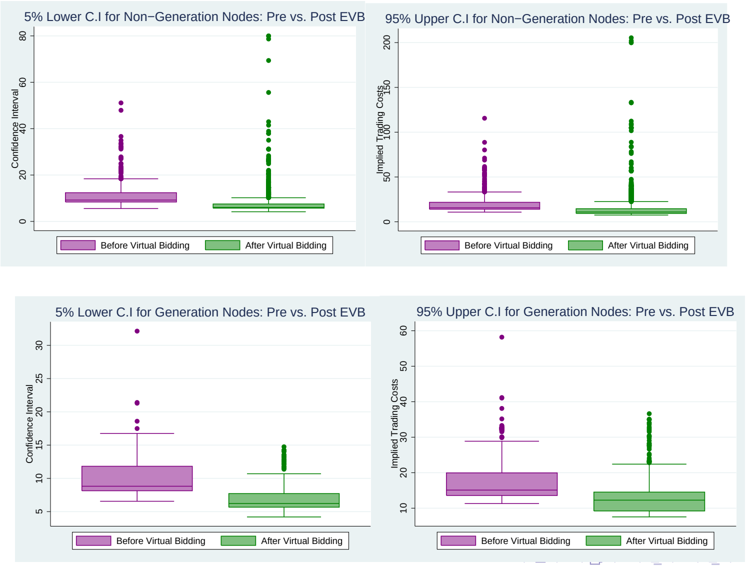
- Average Implied Trading Costs falls for all nodes after introduction of explicit virtual bidding (EVB)—Negative Coefficient on "Post EVB Indicator"
- Average Implied Trading Costs higher for non-generation nodes before EVB—"Gen Node Indicator Negative"
- Average Implied Trading Costs at both types of nodes the same after EVB—"Gen Node x Post EVB Indicator" positive and equal in absolute value to "Gen Node Indicator"

Regression Results Associated with Implied Trading Costs

VARIABLES	(1) 5% Lower Bound	(2) 95% Upper Bound
1(Post EVB)*1(Gen Node)	0.532	1.421
	(0.174)	(0.431)
1(Post EVB)	-3.527	-5.404
	(0.0752)	(0.193)
1(Gen Node)	-0.654	-1.765
	(0.119)	(0.250)
Constant	10.72	19.16
	(0.0538)	(0.118)
Observations	9,791	9,791
R-squared	0.202	0.080

Results implies higher cost to implicit virtual bid at load nodes before EVB and equal cost to virtual bid at all nodes after EVB

Nodal-Level Distribution of c_{lower} and c_{upper}: Before and After EVB



Proportion of Nodes that Reject the Two Null Hypotheses for Differences in Trading Cost Pre- versus Post-EVB

	Total	1(Gen Node)	1(Non-Gen Node)
1(5% Lower Bound$>$ 0)	0.707	0.659	0.711
1(95% Upper Bound$<$0)	0.042	0.076	0.039
Number of Observations	4316	355	3961

- 1(5% Lower Bound$>$0) implies reject null of that $c_{pre}^{true} - c_{post}^{true} \leq 0$ and 1(95% Upper Bound$<$0) implies do not reject $c_{pre}^{true} - c_{post}^{true} \geq 0$
- Results consistent with null hypothesis that implicit trading costs fell at all nodes after implementation of EVB.

Nodal Results–White Noise Tests

Table: Percentage of Tests that Fail to Reject ($\alpha = 0.05$)

	Before EVB	After EVB
Non-Generation Node	0.299	0.912
Generation Node	0.265	0.932

Table: Sample Counts By Cell

	Before EVB	After EVB
Non-Generation Node	4,031	4,386
Generation Node	669	673

- Results consistent with introduction of EVB eliminating "exploitable autocorrelation" in nodal-level vector of daily price differences

Market Efficiency Implications of EVB

- Examine impact of EVB on three measures of market performance:
  - $TOTAL\_VC(t)$: is the total variable cost of all California ISO natural gas-fired generation units (240 of them) in hour t.
  - $TOTAL\_ENERGY(t)$: the total amount of energy consumed in hour t by California ISO natural gas-fired generation units.
  - $STARTS(t)$: total number of California ISO natural gas-fired generation units started in an hour t.
- Controlling nonparametrically for hourly total instate generation, instate renewable portfolio standard (RPS) qualified generation, electricity imports, and daily natural gas prices, conditional means of $STARTS(t)$ is higher after the introduction on EVB, while the conditional means of $TOTAL\_ENERGY(t)$ and $TOTAL\_VC(t)$ are lower after the introduction of EVB.

Notation and Setup

- Let $y_t = W_t'\alpha + X_t'\beta + \theta(Z_t) + \epsilon_t$, with $E(\epsilon_t | X_t, W_t, Z_t) = 0$, where $\theta(Z)$ is an unknown function of the vector Z.

- Three different dependent variables y_t:
  - Dependent variable y_t is one of our three market efficiency measures: $ln(TOTAL\_VC(t))$, $ln(TOTAL\_ENERGY(t))$, or $STARTS(t)$.
  - Non-parametric controls $Z_t =$ hourly instate generation, hourly instate renewable portfolio standard (RPS) qualified generation, hourly electricity imports, and daily delivered natural gas prices in both Northern and Southern California.
  - W_t includes hour-of-day and month-of-year fixed effects.
  - Specifications with X_t as a single indicator which is one if hour of sample t is after the introduction of EVB in 2/1/2011 and X_t as a (24x1) vector with k^{th} element X_{tk}, which equals one if hour t is after 2/1/2011.

Semiparametric Estimator

- We employ Robinson's (1988) two-step (first step uses cross-validation to estimate h) semiparametric estimator:
  1. Find:
     $\begin{bmatrix} h^* & \alpha^* & \beta^* \end{bmatrix} = \underset{\{h,\alpha,\beta\}}{argmin} \sum_{j=1}^{T}[y_j - W_j'\alpha - X_j'\beta - \hat{\theta}_{-j}(Z_j, h)]^2$,
     where $\hat{\theta}_{-j}(Z_j, h) = \frac{\sum_{t=1, t\neq j}^{T}(y_t - W_t'\alpha - X_t'\beta)K((z-Z_t)/h)}{\sum_{t=1}^{T} K((z-Z_t)/h)}$
  2. Run OLS of $[y_t - \hat{\theta}(Z_t, h^*)]$ on W_t and X_t, where
     $\hat{\theta}(Z_j, h) = \frac{\sum_{t=1}^{T}(y_t - W_t'\alpha - X_t'\beta)K((z-Z_t)/h)}{\sum_{t=1}^{T} K((z-Z_t)/h)}$.
- Robinson (1988) derives consistent estimate of variance of asymptotic distribution, which we use to construct standard errors.

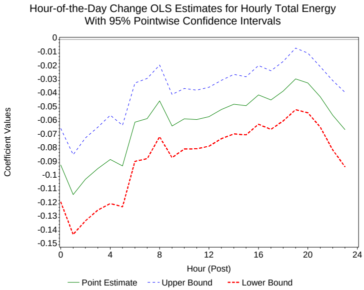
Semiparametric Coefficient Results

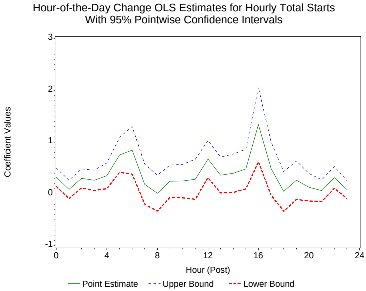
Dependent variable	$ln(TOTAL\_ENERGY(t))$	$STARTS(t)$
β	-0.0615	0.3434
Standard error	0.0101	0.0672

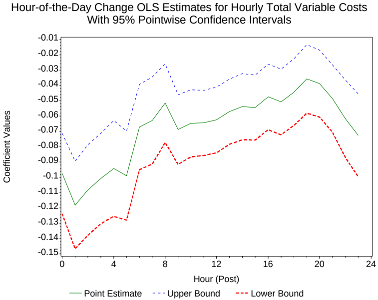
Dependent variable	$ln(TOTAL\_VC(t))$
β	-0.0678
Standard error	0.0100

Implied total annual variable cost savings of approximately $180 million and total annual CO_2 emissions reduction of 1,300,000 Tons.

Hour-of-the-Day Percent Change Estimates







Conclusions

- Derive hypothesis test for the existence of a profitable trading strategy between forward and real-time markets
- Smallest trading costs that rejects null hypothesis of the existence of a profitable trading decreases after EVB at both the LAP and nodal level
- Find evidence consistent with null hypothesis that trading profits fell after the introduction of EVB (Results in paper)
- Cannot reject null hypothesis that variance in real-time prices and variance in difference between day-ahead and real-time prices fell after introduction of EVB
- Evidence of economically sizable market efficiency gains (cost and energy) and environmental benefits from EVB

Questions or Comments?

Related Papers at
http://www.stanford.edu/wolak

Summary Statistics by Service Area and EVB

		Before EVB		After EVB	
Area	Variable	Mean	Std. Dev	Mean	Std. Dev
PGE	DA Price	35.771	12.396	29.774	12.159
	RT Price	37.922	64.614	28.684	57.789
	Price Diff	-2.151	63.504	1.089	56.823
SCE	DA Price	34.890	12.776	29.845	12.857
	RT Price	39.302	83.054	29.384	68.671
	Price Diff	-4.412	81.639	0.461	67.675
SDGE	DA Price	34.776	12.493	30.806	12.508
	RT Price	40.807	106.269	30.298	78.351
	Price Diff	-6.031	105.214	0.508	77.528

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