Financial Arbitrage and Efficient Dispatch in Wholesale Electricity Markets

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Virtual bids are a special class of bid included in the design of all U.S. electricity wholesale markets in order to improve auction results.

- Lower system costs by preventing physical generation and load from exercising market power in the day-ahead
- Increase liquidity and information to the market by opening the market to financial speculators without any ties to physical generation or load
- Increase system reliability by preventing physical generation and load from implicitly virtual bidding

Does virtual bidding work as advertised? Do financial arbitrageurs lower system costs?
Background on RTO Markets

2/3 of U.S. load now part of an RTO/ISO

- Standard market design since 2000
- Centralized economic auction and physical dispatch provides efficiency, stability, and reliability
- Open access transmission system and large number of market participants provide competition and lowers system costs
Background on RTO Markets

Day-Ahead Market

- Single auction for a full 24 hours of generation
- Demand bids 24 hourly \((p,q)\) schedules
- Supply offers 24 hourly \((p,q)\) schedules (except PJM)
- RTO clears offers against bids, solves least-cost optimal power flow subject to physical constraints and reliability needs, every hour
- Result is 24 separate hourly prices at all nodes throughout the system

Real-Time Market

- 24 separate auctions, each for 1 hour of generation
- Demand does not bid, ISO forecast is used
- Supply offers new \((p,q)\) schedules for deviations, every hour
- RTO clears offers against bids, solves least-cost optimal power flow subject to physical constraints and reliability needs, every 5 minutes
- Result is a second set of 24 separate hourly prices at all nodes throughout the system, computed as the simple average of the 5-minute prices
Background on Virtuals

- Financial product that allows participants to speculate on differences between forward and spot prices
- 1 MWh of virtual supply nets $p^{DA} - p^{RT}$
- 1 MWh of virtual demand nets $p^{RT} - p^{DA}$
- Open to financial speculators without any ties to physical generation or load
- Virtual supply and demand is taken into account in the day-ahead auction
  - Treated same as physical generation offer or physical load bid
  - Can displace real physical generation or add to load demand in forward market
  - Affects how power flows through the system
  - Affects $p^{DA}$
- In theory, a liquid virtual market forces prices to converge such that $p^{DA} = E[p^{RT}]$
Virtuals profit from, and theoretically reduce, the DART spread, defined as $p^{DA} - p^{RT}$.

### Convergence of Zonal Energy Prices

Table 3 evaluates price convergence at the zonal level by reporting the percentage difference between the average day-ahead price and the average real-time price in select zones, as well as the average absolute value of the difference between hourly day-ahead and real-time prices from 2011 to 2013.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Avg. Diff % (DA - RT)</th>
<th>Avg. Absolute Diff %</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>1.4%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Central</td>
<td>1.1%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Capital</td>
<td>2.6%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Hudson Valley</td>
<td>0.9%</td>
<td>0.9%</td>
</tr>
<tr>
<td>New York City</td>
<td>1.8%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Long Island</td>
<td>0.9%</td>
<td>1.7%</td>
</tr>
</tbody>
</table>
Literature Review

Finance: Forward Risk Premium

- Bessembinder and Lemmon (2002)

Industrial Organization: Market Power and Strategic Bidding

- Borenstein, Bushnell, Knittel, and Wolfram (2008)

Econometric/Empirical: Before-and-After Studies

- Birge, Hortacsu, Mercadal, and Pavlin (2013)
- ISO Annual Market Monitor Reports
The Fault with Virtual Bidding

Received Theory

- Each market is a complete solution
- The day-ahead is a purely financial cash-settled forward market
- Day-ahead and real-time markets are successive runs of the same market design
  - The only difference is new information
  - Given same supply and demand, both auctions will produce the same dispatch and prices

Reality

- Day-ahead and real-time optimizations are different
  - Day-ahead market solves a simplified representation of the transmission system and various other constraints
  - Real-time market is better resolved, but takes the day-ahead unit commitment as the starting point
  - No time to run optimization from scratch, must assume day-ahead schedules and find optimal response to deviations
  - In real-time, added dimension of operator discretion and strictly binding physical constraints
Consequences of differences between day-ahead and real-time market optimizations

- Price convergence is a measure of how good the day-ahead approximation is
- Even with no market power issues, no withholding, no implicit convergence bidding or other strategic bidding behavior from generators and load, and perfect foresight from the RTO and market participants in the day-ahead: $p^{DA} \neq p^{RT}$ so $DART \neq 0$
- Virtuals can profit from a DART spread that is partially or entirely due to modeling differences between markets, not strategic bidding from physical market participants (the problem they were designed to solve)
- In some of these cases, virtuals can be purely parasitic
The Fault with Virtual Bidding

Example 1: CAISO Hour-Ahead Arbitrage (2011)

- In 2011, CAISO implemented virtual bidding
- Participants could bid virtuals at the interties
- Surrounding balancing authorities required real-time imports/exports in/out of California to be scheduled an hour ahead of time
- Real-time leg of virtual payout settled against a forecasted "Hour-Ahead" price (HA).
  - 1 MWh of virtual supply at intertie node nets $p^{DA} - p^{HA}$
  - 1 MWh of virtual demand at intertie node nets $p^{HA} - p^{DA}$
- Participants noticed that on average $p^{HA} < p^{RT}$
- Arbitrage opportunity: pair a virtual supply offer at an intertie node with a virtual demand bid at an internal node
- Virtual supply at intertie node nets $p^{DA} - p^{HA}$
- Virtual demand at internal node nets $p^{RT} - p^{DA}$
- If no congestion between nodes, strategy nets $p^{RT} - p^{HA}$
Example 1: CAISO Hour-Ahead Arbitrage (2011)

CAISO Division of Market Monitoring Annual Report for 2010 (2011), Figure 3.7.
Example 1: CAISO Hour-Ahead Arbitrage (2011)

CAISO Division of Market Monitoring Annual Report for 2011 (2012), Figure 4.4.
Offsetting virtual positions by the same participant have accounted for the bulk of all offsetting virtual positions occurring since the start of convergence bidding. Almost all of these offsetting positions consisted of virtual imports that offset internal virtual demand.

There was a sharp drop in offsetting positions in mid-April. This decrease corresponds to two events. At this time, the ISO expressed concern about the volume of offsetting virtual demand and imports bids and initiated a stakeholder process to address this issue. In addition, systematic predictable differences in day-ahead, hour-ahead and real-time prices began to decrease.

The use of offsetting virtual positions by individual market participants increased slightly in June and July, but continued to decline until the suspension of the interchanges in late November.

As shown in Figure 4.5, substantial amounts of offsetting virtual positions also occurred when different market participants placed virtual demand bids within the ISO that were offset by virtual import bids placed by different participants. These offsetting virtual bids can result from the market activity of different participants independently responding to differences between day-ahead prices and prices in the hour-ahead and real-time markets. However, the impact of these offsetting bids on overall market outcomes is the same: these offsetting bids do not add any net supply or demand to the day-ahead market, but can exacerbate real-time imbalance offset charges when hour-ahead prices diverge from real-time prices.
Why was $p^{HA} < p^{RT}$?

- CAISO has infrequent but severe price spikes in the real-time.
- These price spikes are often not due to congestion, but ramping issues affecting the energy price (system power balance constraint violated).
- Ramping issues tend to occur intra-hour over a few 5-minute intervals due to unanticipated load "jumps".
- These spikes therefore don’t occur in the hour-ahead.
- Spikes are priced-in to the real-time price, the simple average of the 12 5-minute interval prices.
- On average $p^{HA} < p^{RT}$.
Virtuals don’t help

- Virtuals extract rents due to the difference between hour-ahead and real-time prices.
- Offsetting virtual supply and demand does not commit extra generation in the day-ahead, thus doesn’t help eliminate the real-time spikes that are causing arbitrage opportunity.
- Virtuals do not provide any new information to the RTO.
- Excessive virtuals clearing at the intertie nodes prevent the RTO from estimating RT physical imports, reducing system stability and reliability.
- These virtuals are purely parasitic.
- CAISO banned virtuals at the intertie nodes in November 2011.
Example 2: CAISO Targeting Price Spikes (2011-2012)

- CAISO has infrequent but severe price spikes in the real-time.
- In a typical hour $p^{DA} > p^{RT}$
- However, in the rare hours when a spike occurs $p^{DA} << p^{RT}$
- On average $p^{DA} < p^{RT}$
- Virtual demand is profitable, on average
## Example 2: CAISO Targeting Price Spikes (2011-2012)

<table>
<thead>
<tr>
<th>Year</th>
<th>Count of Hours</th>
<th>Spike</th>
<th>No Spike</th>
<th>All Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>62</td>
<td>6,538</td>
<td>6,600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% of hours</td>
<td>0.94%</td>
<td>99.06%</td>
<td>100.00%</td>
</tr>
<tr>
<td></td>
<td>DA/RT spread</td>
<td>$ (349.06)</td>
<td>$ 1.18</td>
<td>$ (2.21)</td>
</tr>
<tr>
<td>2010</td>
<td>87</td>
<td>8,673</td>
<td>8,760</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% of hours</td>
<td>0.99%</td>
<td>99.01%</td>
<td>100.00%</td>
</tr>
<tr>
<td></td>
<td>DA/RT spread</td>
<td>$ (343.68)</td>
<td>$ (0.65)</td>
<td>$ (4.06)</td>
</tr>
<tr>
<td>2011</td>
<td>65</td>
<td>8,695</td>
<td>8,760</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% of hours</td>
<td>0.74%</td>
<td>99.26%</td>
<td>100.00%</td>
</tr>
<tr>
<td></td>
<td>DA/RT spread</td>
<td>$ (341.80)</td>
<td>$ 2.32</td>
<td>$ (0.23)</td>
</tr>
<tr>
<td>2012</td>
<td>70</td>
<td>8,714</td>
<td>8,784</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% of hours</td>
<td>0.80%</td>
<td>99.20%</td>
<td>100.00%</td>
</tr>
<tr>
<td></td>
<td>DA/RT spread</td>
<td>$ (365.55)</td>
<td>$ 2.11</td>
<td>$ (0.82)</td>
</tr>
<tr>
<td>2013</td>
<td>47</td>
<td>8,713</td>
<td>8,760</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% of hours</td>
<td>0.54%</td>
<td>99.46%</td>
<td>100.00%</td>
</tr>
<tr>
<td></td>
<td>DA/RT spread</td>
<td>$ (335.67)</td>
<td>$ 3.98</td>
<td>$ 2.16</td>
</tr>
<tr>
<td>2009-2013</td>
<td>331</td>
<td>41,333</td>
<td>41,664</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% of hours</td>
<td>0.79%</td>
<td>99.21%</td>
<td>100.00%</td>
</tr>
<tr>
<td></td>
<td>DA/RT spread</td>
<td>$ (347.81)</td>
<td>$ 1.82</td>
<td>$ (0.97)</td>
</tr>
</tbody>
</table>

Source: Data are from OASIS. Calculations are author's.
Example 2: CAISO Targeting Price Spikes (2011-2012)

<table>
<thead>
<tr>
<th>Hour</th>
<th>DA Schedule</th>
<th>Assumed Ramping</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>30,000</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>40,000</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>50,000</td>
<td></td>
</tr>
</tbody>
</table>
Example 2: CAISO Targeting Price Spikes (2011-2012)

- DA Schedule
- Assumed ramping
- RT Load

Load (MW)

Steep 5-min Interval Ramp

5-min interval
Example 2: CAISO Targeting Price Spikes (2011-2012)

- DA Schedule
- Assumed ramping
- RT Load
- DA Schedule with Virtual Demand

<table>
<thead>
<tr>
<th>Hour</th>
<th>Load (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>30,000</td>
</tr>
<tr>
<td>16</td>
<td>40,000</td>
</tr>
<tr>
<td>17</td>
<td>50,000</td>
</tr>
</tbody>
</table>

- Assumed ramping virtual demand: 22/30
Example 2: CAISO Targeting Price Spikes (2011-2012)

Virtuals don’t help

- Virtuals extract rents due to the difference between day-ahead and real-time prices
- Difficult to predict when spikes will occur so participants bid virtual demand in a large number of hours, targeting average positive profits
- Virtual demand commits additional units, increases the day-ahead price, which means improved convergence, on average. An apparent improvement.
- However, this turns out not to be welfare improving
  - 99% of the time this is a mistake since $p^{DA} > p^{RT}$, the extra physical supply scheduled is not needed and increases day-ahead systems costs
  - 1% of the time this is also a mistake because not specifically committing fast-ramping units. Price still spikes in the real-time

- These virtuals are parasitic

- CAISO implemented a "flexible ramping constraint" in 2012, and ramping product in 2014
The Fault with Virtual Bidding

Example 3: PJM Commitment of CTs (2012)

- Historically, in PJM, steam units were base-load and cleared the day-ahead market ahead of combustion turbines (CTs) with higher heat rates.
- Over time, as natural gas prices dropped, CTs began displacing steam units in the day-ahead market clearing.
- Steam units provided free services:
  - Black start: steam units are located near load pockets where black start capacity is needed.
  - Voltage support: steam units are better able to provide voltage support and reactive services to keep the grid balanced.
- 2012: CTs offering lower prices than steam units in day-ahead auction.
- The day-ahead algorithm does not consider black-start and voltage support.
- In the real-time, PJM operators have to turn down CTs and commit more expensive steam units, increasing real-time price and out of market make-whole payments.
Example 3: PJM Commitment of CTs (2012)
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Example 3: PJM Commitment of CTs (2012)

Revised Dispatch in Real-Time

PJM West

PJM East

Load

Coal

Load
Example 3: PJM Commitment of CTs (2012)

Virutals don’t help

- DART spread partially driven by modeling shortfalls of the day-ahead algorithm
- Potential for virutals to extract rents
- Virutals would not be helpful, and could end up committing even more CTs in the day-ahead
- PJM implemented out-of-merit steam unit commitment in day-ahead in late 2012
The Fault with Virtual Bidding