Strategic Interaction Between Wholesale and Ancillary Service Markets

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Outline

1. Motivation

Big Picture

- Reliability of electricity markets requires the instantaneous balancing of supply and demand;
- The procurement of the wholesale electricity market and ancillary services (AS) is vital in achieving this objective;
- Important design feature whether ancillary service markets clear simultaneously or sequential with wholesale markets;
- Simultaneous timing adopted in a number of US markets (PJM, CAISO, ERCOT, MISO, and NYISO);
- EU provides numerous examples where AS and wholesale markets clear sequentially (Germany, Spain, France, and Italy).

1. Motivation

The implications of AS-wholesale market competition

- The existing literature has focused largely on technical aspects of AS markets;
- Electricity markets are often concentrated and subject to market power concerns;
- The literature has largely abstracted away from market power implications of AS-wholesale market competition and instead focused only on wholesale market power issues.

1. Motivation

Main Goal and Contributions

- We propose a model to study **the strategic implications of simultaneous versus sequential timing** when firms compete in the ancillary services and wholesale electricity markets;
- Sequential market clearing has been an important channel through which firms can employ strategic commitment in other settings;
- Our analysis evaluates the strategic commitment effect in the multi-market AS and wholesale electricity market competition.
- We employ data from Alberta's electricity markets to demonstrate the quantitative implications of our theoretical model;

1. Motivation

Summary of our findings

- Under sequential timing, firms facing increasing marginal cost curves reduce AS output and lower marginal costs in the wholesale market;
- The **strategic commitment effect has** a small impact on wholesale market outcomes but **a large impact on the the ancillary services market (higher market-clearing price)**.

2. Theoretical Model

- Cournot competition in wholesale and ancillary service markets;
- AS provision impacts the cost of providing wholesale output because it precludes the use of a portion (or all) of a generation unit's available capacity in the wholesale market.
- This linkage between the output choices impacts strategic behavior and equilibrium outcomes in both markets;
- Increased output in (AS or wholesale) market will increase the marginal cost of supplying the other market.

2. Theoretical Model

Cost Function

- Cost function of firm i is given by:

$$C_i(q_i, x_i) = \kappa\,(q_i + \eta x_i) + \frac{1}{2}\,\gamma\,(q_i + \eta x_i)^2, \quad \text{for } \; i = 1, 2 \qquad (1)$$

- x_i and q_i are linked through marginal costs. The greater is x_i, the greater the marginal cost of q_i, and vice versa;
- The magnitude of this connection depends on γ, κ and η;
- $\eta \in (0, 1]$;
- Greater values of γ correspond to a more steeply-sloped marginal cost curve;

2. Theoretical Model

Profit Function

- Firms earn revenues from AS sales as well as wholesale market output;
- Firm i's profits, $i = 1, 2$, are specified as follows:

$$\pi_i(q_i, q_j, x_i, x_j) = P(q_i, q_j)\, q_i + P^{AS}(x_i, x_j)\, x_i - C_i(q_i, x_i) \qquad (2)$$

- We consider two variations in model timing to reflect different market design regimes used in practice.

2. Theoretical Model

Simultaneous Market-Clearing

- Firms choose their outputs in both markets simultaneously, which corresponds to regimes employing a joint-clearing co-optimization approach;

$$\pi_i = (a - bq_i - bq_j)\, q_i + (A - Bx_i - Bx_j)\, x_i - \kappa(q_i + \eta x_i) - \frac{1}{2}\gamma(q_i + \eta x_i)^2$$

2. Theoretical Model

Simultaneous Market-Clearing (PSNE)

- The (symmetric) Nash equilibrium yields the following AS and wholesale quantities for each firm:

$$x_{simultaneous} = \frac{(3b + \gamma) A - 3b \eta \kappa - a \eta \gamma}{9 B b + \gamma (3B + 3b \eta^2)} \tag{3}$$

$$q_{simultaneous} = \frac{(3B + \eta^2 \gamma) a - 3B \kappa - A \eta \gamma}{9 B b + \gamma (3B + 3b \eta^2)}. \tag{4}$$

- As the demand intercept in the wholesale market (a), increases, the firm's output in the wholesale market will increase;
- This will raise the marginal cost of supplying output into the AS market, reducing the firm's quantity in that market.

2. Theoretical Model

Sequential Market-Clearing

- AS quantities are chosen before wholesale market quantities;
- This timing allows firms to choose their AS market outputs strategically to influence wholesale market outcomes;
- Conditional on x_1 and x_2, the second stage Nash equilibrium in the wholesale market is given by:

$$q_1(x_1, x_2) = \frac{(a-\kappa)(\gamma+b) + b\,\eta\,\gamma\,x_2 - \eta\,\gamma\,x_1\,(2b+\gamma)}{(3b+\gamma)(b+\gamma)} \tag{5}$$

$$q_2(x_1, x_2) = \frac{(a-\kappa)(\gamma+b) + b\,\eta\,\gamma\,x_1 - \eta\,\gamma\,x_2\,(2b+\gamma)}{(3b+\gamma)(b+\gamma)}. \tag{6}$$

2. Theoretical Model

Direct Effect and Strategic Effect

- Next consider the first stage choices of x_1 and x_2;
- The first-stage F.O.C. for firm i can be written as:

$$\frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i}{\partial q_j} \frac{\partial q_j(x_i, x_j)}{\partial x_i} = 0.$$

- $\frac{\partial \pi_i}{\partial x_i}$ reflects the *direct effect*;

2. Theoretical Model

Direct Effect and Strategic Effect

- *Strategic effect* that occurs through the effect of x_i on q_j in the 2nd stage:

$$\frac{\partial \pi_i}{\partial q_j} \frac{\partial\, q_j(x_i, x_j)}{\partial\, x_i} = -\left(b\, q_i\right) \frac{b\, \eta\, \gamma}{(3b+\gamma)\,(b+\gamma)} < 0.$$

- Increasing firm i's AS output increases its 2nd stage wholesale marginal cost;
- Wholesale equilibrium output decreases, and (its rival's) equilibrium wholesale output increases;
- Increase in firm i's rival's output reduces its profit. This effect leads firm i to choose a lower AS market output.

3. Analytical Results

Compared to the simultaneous move game, the sequential move game has:

- Lower AS output;
- Higher Wholesale Output

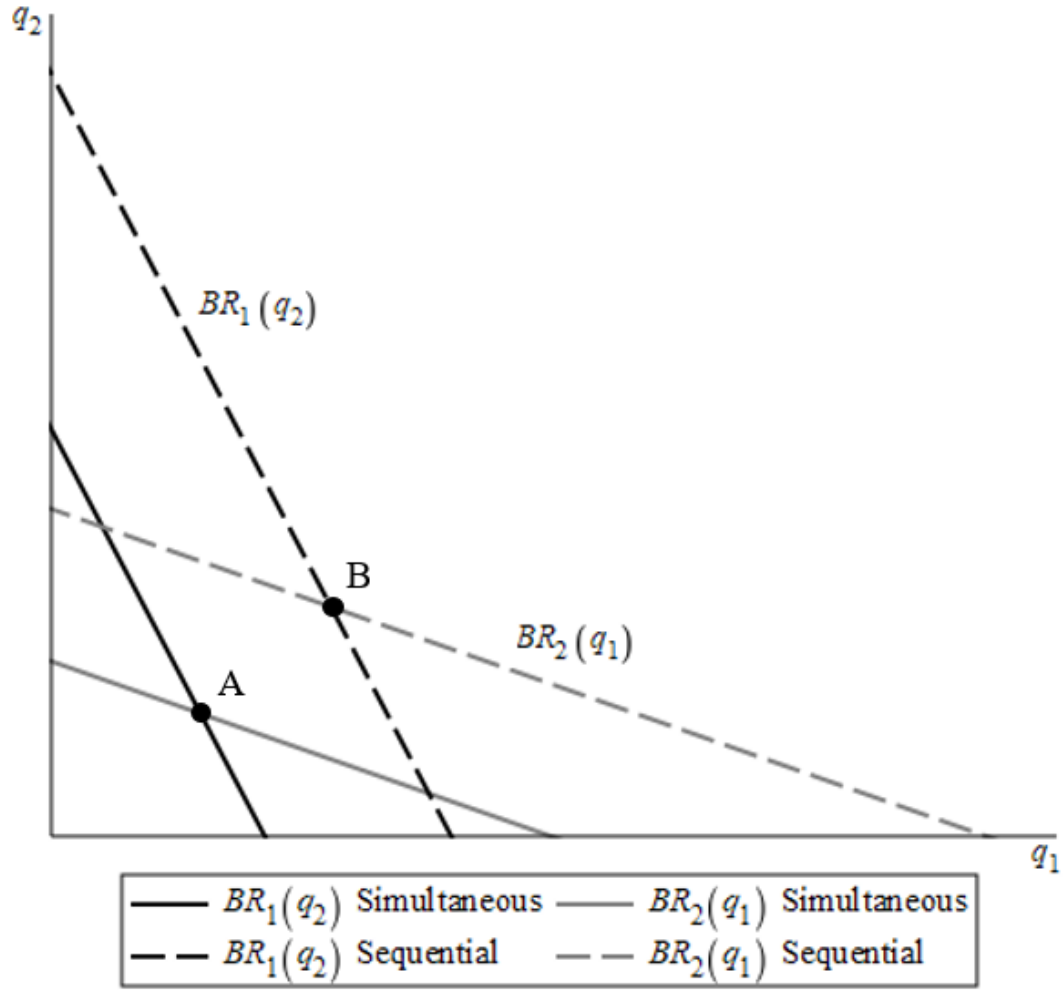
3. Analytical Results

- The impact of AS output on wholesale market outcomes can be readily observed by investigating the second-stage wholesale output best-response function:

$$BR_i(q_j) = \frac{a - \kappa - b\,q_j - \eta\,\gamma\,x_i}{2b + \gamma}.$$

- A decrease in x_i shifts firm i's best response function outward indicating it wants to produce more output for any output level chosen by its rival;

3. Analytical Results



- The points A and B at the intersections denote the equilibria in the simultaneous and sequential move game, respectively.

4. Empirical Analysis

Alberta's electricity market

- Objective: to illustrate the quantitative implications of our model in a setting that reflects key features of real-world electricity markets;
- We extend our theoretical model to capture a number of important features of Alberta's electricity market;
- We use hourly generation unit-level data from January 1, 2020 to December 31, 2020

4. Empirical Analysis

Summary Statistics

Table: Summary Statistics

Variable	Units	Mean	Std. Dev	Min	Max
Wholesale Demand	MWh	9,619.98	873.06	7,200.29	12.165,89
Wholesale Price	$/MWh	46.72	92.14	0.00	999.99
AS Quantity	MWh	636.96	91.82	456.00	892.00
AS Price	$/MWh	13.03	66.35	0.36	891.92
Import Supply	MWh	451.54	285.71	0.00	1,119.00
Import Capacity	MWh	824.97	225.94	153.00	1,198.00
Wind Output	MWh	1,750.35	36.18	11,517.00	1,791.00

- There is considerable variation in wholesale demand and prices;
- AS market is small and the price demanded by firms to supply the AS product is lower.

4. Empirical Analysis

Alberta's Wholesale Market

- Hourly uniform-price procurement auction;
- Firms compete by submitting up to seven price-quantity offer blocks for each generation unit in their portfolio;
- There is a single province-wide wholesale price;
- "Energy-only" market, firms rely solely on revenues from generating electricity in wholesale and AS markets to recover their fixed and variable costs;
- The exercise of market power is explicitly permitted, with no bid mitigation.

4. Empirical Analysis

Alberta's Wholesale Market Structure in 2020

- Electricity market moderately concentrated with the five largest firms controlling 64% of the province's generation capacity;
- Remaining capacity is offered by a large fringe of small firms;
- 47% of installed generation was natural gas based, followed by coal with 33% of installed capacity, wind (11%), hydroelectic generation (5%), and biogas/biomass (3%).

4. Empirical Analysis

Alberta's Ancillary Services Market

- Alberta Electric System Operator (AESO) procures three type of operating reserves (regulating, spinning, and supplemental), in both active and standby forms;
- Regulating reserves address small minute-to-minute demand and supply differentials;
- Spinning and supplemental reserves (together, contingency reserves) are designed to address larger disruptions, such as the failure of large generators;
- Standby operating reserves are called upon when active reserves are unable to produce, which occurs rarely in practice.

4. Empirical Analysis

Alberta's Ancillary Services Market in 2020

- The active AS market is highly concentrated;
- TransAlta provided the highest percentage of all three types of active operating reserves, by MWhs: 69%, 63%, and 48% of regulating, spinning, and supplemental reserves, respectively;
- The second highest market shares in each category were ENMAX (24%) in regulating reserves, the Balancing Pool (16%) in spinning reserves, and Heartland Generation (11%) in supplemental reserves.

4. Empirical Analysis

Symmetric Firms

Table: Symmetric Firms – Heartland Parameters

Panel (a)	$\%\Delta\overline{X}$	$\%\Delta\overline{P}_{AS}$	$\%\Delta\overline{TPC}_{AS}$
$\overline{\eta}$	**-31.09**	**33.19**	**32.85**
Panel (b)	$\%\Delta\overline{Q}$	$\%\Delta\overline{P}_{WS}$	$\%\Delta\overline{TPC}_{WS}$
$\overline{\eta}$	**0.03**	**-0.09**	**-0.09**

- $\overline{\eta} = 1$ serve as an upper bound on the strategic effect that committing to AS output has on wholesale market outcomes;
- Moving from simultaneous to sequential timing reduces the average total AS output produced by -31.09%;
- The average AS price increases by 33.19%;
- The average total AS procurement costs increases by of 32.85%.

4. Empirical Analysis

Symmetric Firms

- The change in market timing can have a large impact on AS market outcomes;
- Small changes in AS output, has a substantial impact on the market-clearing price and total procurement cost in the AS market (**strategic effect**);
- These large changes are facilitated by the highly inelastic residual demand function in the AS market;
- The effects of sequential timing on wholesale quantities and prices are small, both in absolute and percentage terms;
- The smaller wholesale market effects are driven in part by the more elastic fringe supply function.

5. Conclusion and Policy Implications

- A strategic incentive arises in the setting where the AS market clears prior to the wholesale market;
- Firms reduce their AS output in this setting because it allows them to commit to competing more aggressively in the subsequent wholesale market;
- This strategic incentive leads to a higher AS market-clearing price, but puts downward pressure on the wholesale price;
- Were policymakers to consider the AS market independently, the large percentage increases in AS procurement costs might lead to policy changes that are less justified when considering the total effect across both markets.