Measuring the Competitiveness Benefits of a Transmission Investment Policy: The Case of the Alberta Electricity Market

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Motivation for Paper

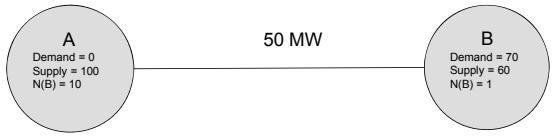
- Re-structuring and role of transmission network
  - Before—Transmission network improves performance of *imperfectly regulated vertically-integrated utility*
  - After—Transmission network improves performance of *imperfectly competitive wholesale market*
- Least-delivered-cost-to-consumers transmission network is not the same under both regimes
  - Transmission network configuration impacts ability of expected profit-maximizing suppliers to impact wholesale prices to increase their profits
- Additional transmission capacity can increase number of hours per year that a strategic supplier faces competition from all suppliers in market
  - This causes more competitive behavior by strategic suppliers (offer curve closer to marginal cost curve)

What is Restructuring?

- Replace explicit regulation with market mechanisms to set prices and determine how electricity is supplied
  - Price-regulated open access to
    - Inter-state transmission network
    - Local distribution network
  - Market mechanism to set prices for wholesale power and determine generation units providing energy
  - Market mechanism to set prices for retail electricity and determine retailers providing energy
- Why should restructured regime yield benefits to consumers relative vertically-integrated regulated monopoly regime?
  - Transmission expansions can increase extent of competition that suppliers face

Motivation for Paper

- Simple theoretical motivation
- More transmission capacity connecting nodes increases potential competition faced by suppliers to serve demand
  - Induces more competitive behavior by supplier at node B
  - Wholesale market prices closer to competitive benchmark levels
  - Consumers can benefit from lower wholesale prices that fund transmission investments without having to increase retail prices
- Wholesale price reduction is “Competitiveness Benefit” of transmission investment
- Two node example (A and B)



Purpose of Paper

- Quantify magnitude of competitiveness benefit for actual wholesale electricity market
  - Alberta wholesale electricity market
  - Sample period January 1, 2009 to December 31, 2011
- Empirical results find sizeable competitiveness benefits of transmission investments that eliminate perception of transmission congestion by strategic suppliers
  - Competitiveness benefits are specific to concentration of generation ownership, pricing mechanism, and configuration of existing transmission network in market
- Methodology can be applied to any ownership structure, pricing mechanism, existing network, configuration, and proposed upgrade

5

Outline of Presentation

- Review basic features of Alberta Wholesale Electricity Market (AWEM)
- How transmission constraints impact behavior of expected profit-maximizing suppliers with the ability to exercise unilateral market power
- Introduce two measures of the *ability* of a supplier to exercise unilateral market power
  - Inverse semi-elasticity of Feasible Residual Demand Curve
  - Inverse semi-elasticity of Ideal Residual Demand Curve
- Estimate empirical model relating a strategic supplier's hourly offer price to its hourly actual ability to exercise unilateral market power

6

Outline of Presentation

- Use empirical model to compute counterfactual offer price and offer curve assuming supplier faces Ideal Residual Demand Curve
  - "No perceived congestion" measure of competition that supplier faces
- Compute two counterfactual market-clearing prices
  - No perceived congestion offer curves for five strategic suppliers using actual amount of congestion faced by all suppliers
    - Upper bound on counterfactual price
  - No perceived congestion offer curves for five strategic suppliers with no actual congestion assumed for all supplier
    - Lower bound on counterfactual price
- Compute upper and lower bounds on competitiveness benefits for using these two counterfactual prices
  - Canadian dollar (CAD) magnitude of benefits
  - Benefits as a percentage of total wholesale energy costs

7

A Brief Primer on the Alberta Wholesale Electricity Market

8

Market Structure in Alberta

Installed Capacity by Prime Mover

Prime Mover	Capacity in MW	Capacity Share (%)
Coal	6,232	46.29
Natural Gas Cogeneration	3,712	27.57
Hydroelectric	879	6.53
Natural Gas Combined Cycle	843	6.26
Wind	777	5.77
Natural Gas Combustion Turbine	753	5.59
Biomass and other renewables	266	1.98
Total Installed Capacity	13,462	100.00

Approximately 85 percent thermal capacity

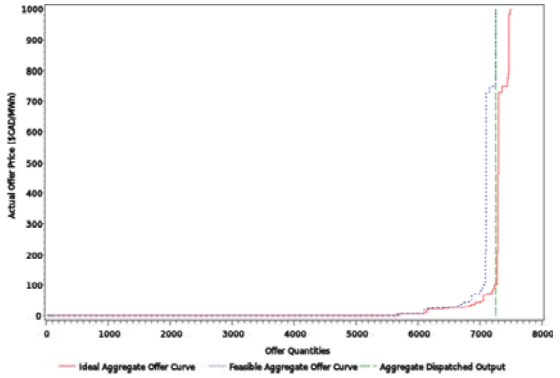
Capacity Owned and Capacity Share of Five Largest Firms

Owner	Capacity (MW)	Share of System (%)
ATCO Power	1,349	16.52
Capital Power	1,507	11.19
ENMAX	1,897	14.09
TransAlta	2,354	17.49
TransCanada	2,580	19.17
Total of Five Largest Firms	9,687	78.46

9

Price Determination in Alberta

Feasible (reflects actual transmission constraints and sets actual price) Aggregate Offer Curve and Ideal Aggregate Offer Curve (no constraints) for Hour 12 of 5/12//2010



10

A Simple Model of Expected Profit-Maximizing Offer Behavior to Measure *Ability* to Exercise Unilateral Market Power

11

Profit-Maximizing Firms Exercise All Available Unilateral Market Power

- A firm exercising all available unilateral market power subject to the market rules is equivalent to
  - The firm maximizing its profits, which is equivalent to
  - *The firm's management serving its fiduciary responsibility to its shareholders by exercising all available unilateral market power*
- Two ways to limit the amount of market power firm a exercises
  - Reduce its ability to exercise unilateral market power
    - Reduce slope of distribution of residual demand curves that it faces
  - Reduce its incentive to exploit its ability to exercise unilateral market power
    - Increase quantity of fixed price forward market obligations to supply energy
- Transmission network investments can reduce ability of suppliers to exercise unilateral market power
  - Reduce slope of distribution of residual demand curves that firm faces
  - This is source of competitiveness benefits of transmission expansions

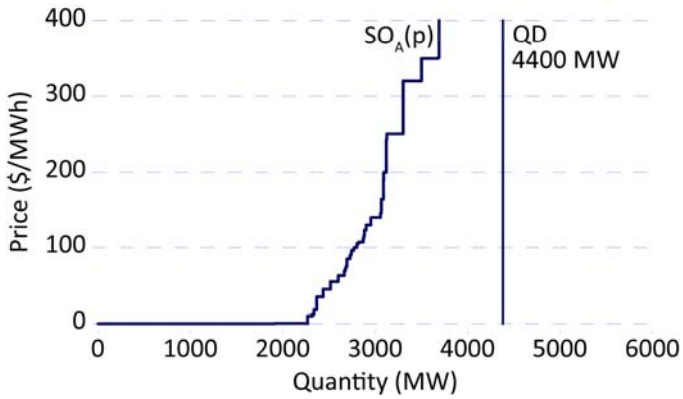
12

Measuring Ability and Incentive to Exercise Unilateral Market Power

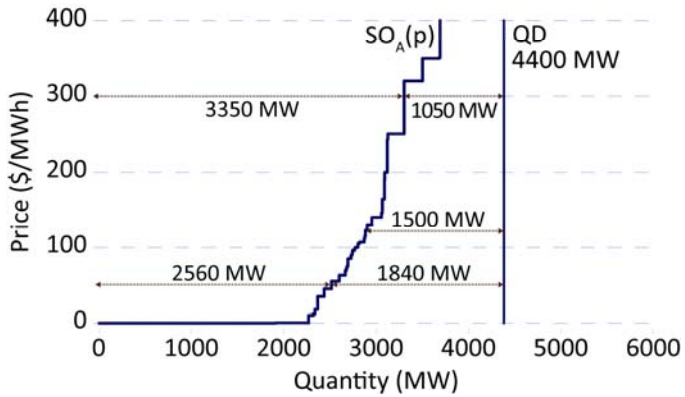
- ***The residual demand curve*** is the essential input for ***measuring firm-level ability*** to exercise unilateral market power
- ***Fixed-price forward market obligations*** are an essential input for measuring ***firm-level incentive*** to exercise unilateral market power
  - These are confidential in Alberta, so analysis is conditional on fixed-price forward market obligations
  - Analysis cannot account for potential incremental forward contracting benefits of transmission upgrades
    - Suppliers facing greater competition more hours of the year have greater incentive to sign more fixed-price forward market obligations which further increase competitiveness of short-term market outcomes for reasons described above

13

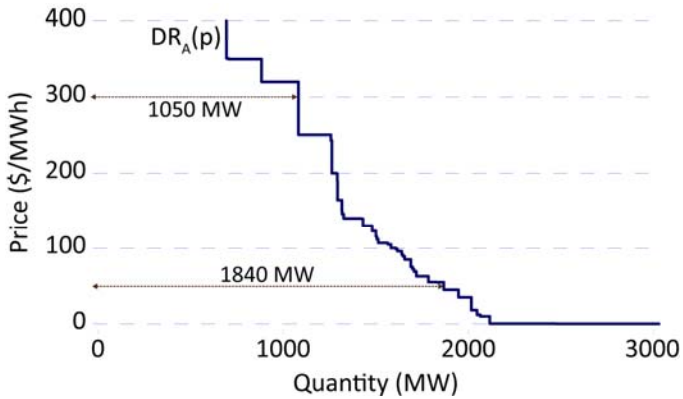
Calculation of residual demand curve from offers of all suppliers except Firm A



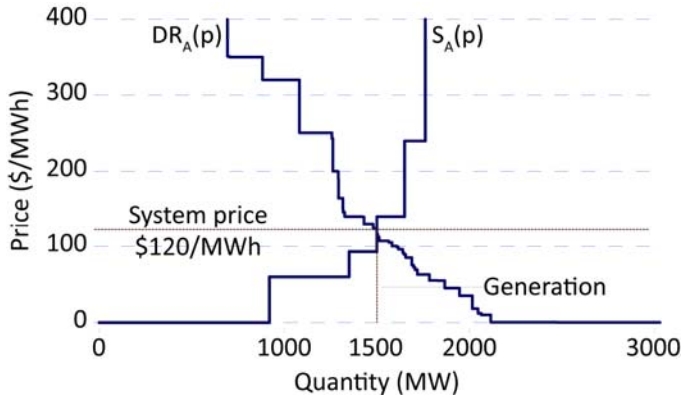
Calculation of residual demand curve for Firm A



Calculation of residual demand curve for Firm A



Residual demand and offer curves for Firm A

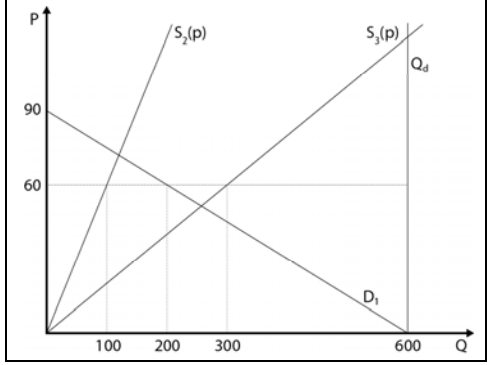


Two Residual Demand Curves

- Feasible (or Actual) Residual Demand Curve—Only use quantity offers of other firms that can actually compete to supply energy with Firm A because of transmission constraints
- Ideal Residual Demand Curve—Use all offers regardless of their actual ability to compete to supply energy with Firm A
- Actual Residual Demand Curve is steeper because transmission network constrains some offers from competing with Firm A
- Conclusion--Transmission constraints imply greater ability of a supplier to exercise unilateral market power

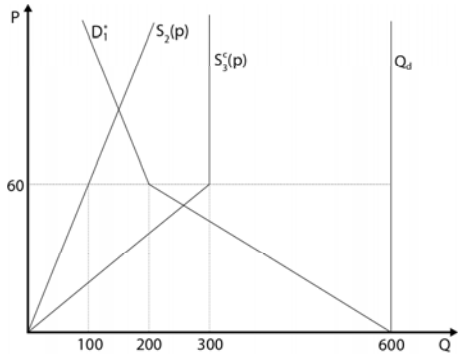
18

Construction of Ideal Residual Demand Curve of Firm 1



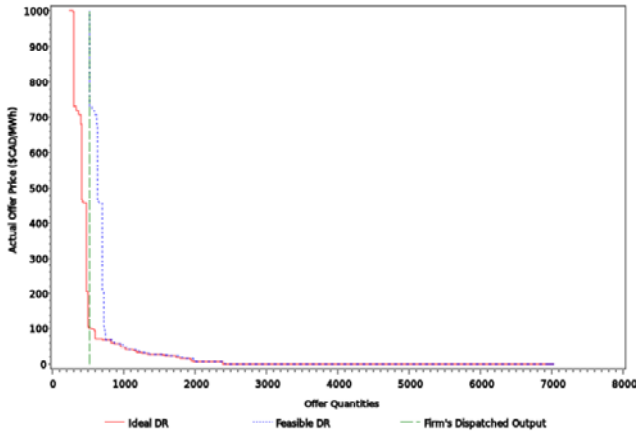
19

Feasible Residual Demand of Firm 1 with Transmission Constraints



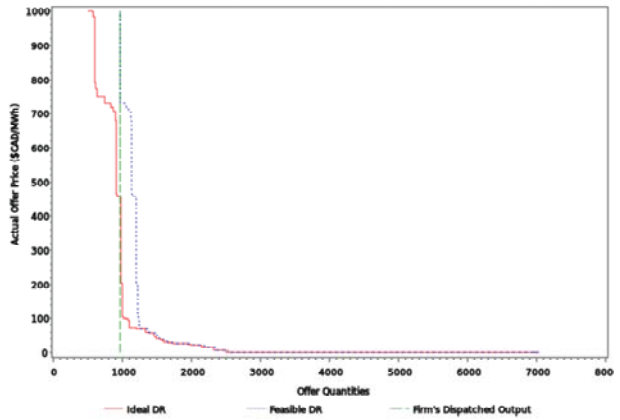
20

Ideal and Feasible Residual Demand Curves for ATCO Power
Hour 13 of 5/16/2010



21

Ideal and Feasible Residual Demand Curves for Capital Power
Hour 13 of 5/16/2010



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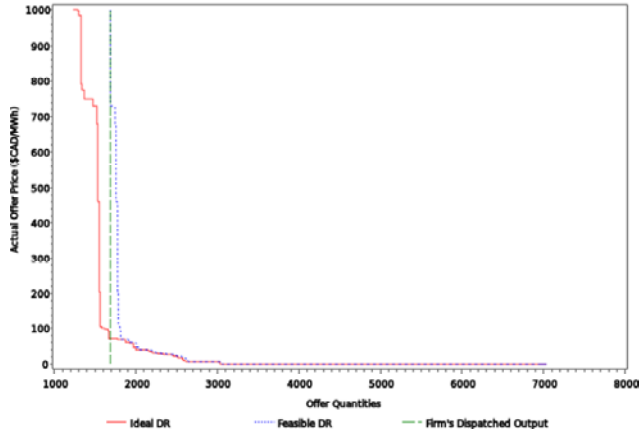
Ideal and Feasible Residual Demand Curves for ENMAX
Hour 13 of 5/16/2010



23

Determinants of Ability

A supplier with no retail load obligations or fixed-price forward contract obligations has variable profits from selling in wholesale market

$$\Pi(p) = DR(p)(p - c)$$

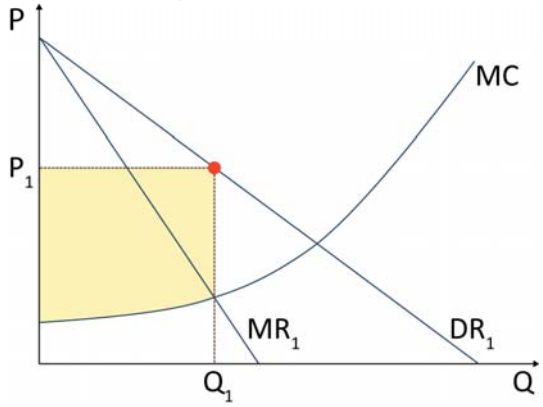
p = wholesale price, c = marginal cost
DR(p) = residual demand curve at p

Supplier behaves like a profit-maximizing monopolist given its residual demand curve

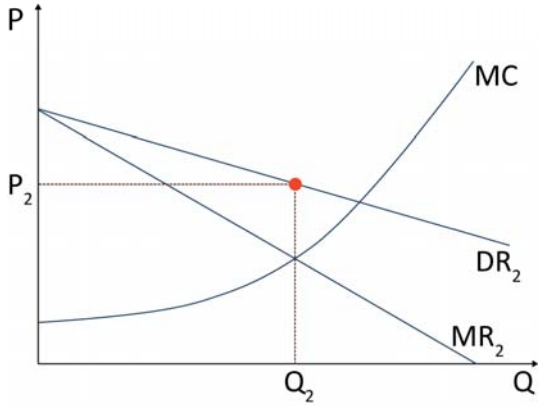
Conclusion—Produce at output level where marginal revenue equals marginal cost (MR = MC)

24

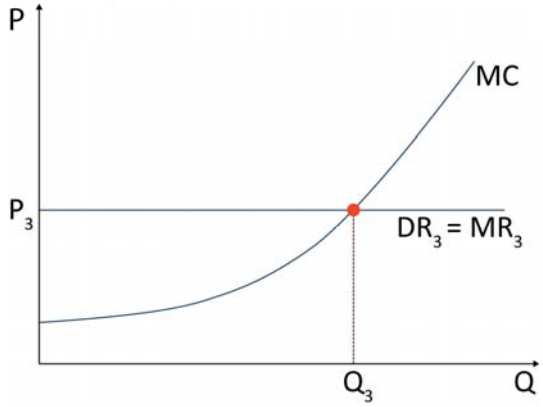
Profit-maximizing choice of price and quantity for differentiable DR



Profit-maximizing choice of price and quantity with elastic residual demand



Profit-maximizing choice with perfectly elastic residual demand

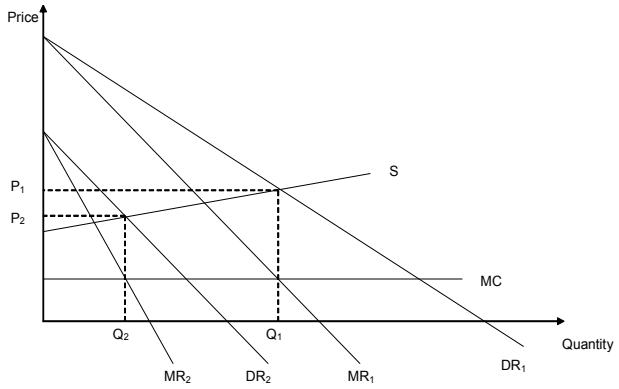


Simplified Model of Expected Profit Maximizing Offer Behavior

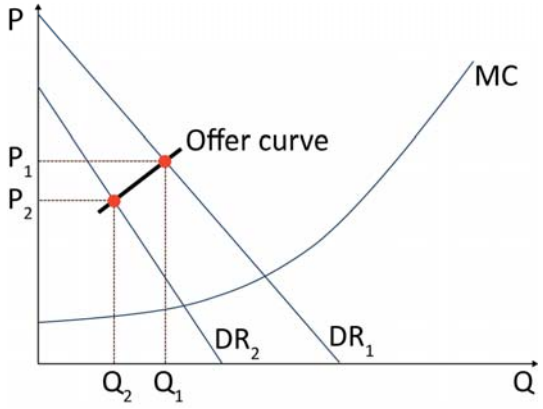
- Supplier does not know residual demand curve it will face when it submits offers
  - Suppliers submits offers simultaneously
- Suppliers knows distribution of residual demand curves that they face
- Implication---Supplier submits offer curve that sets market-clearing price and quantity sold for each residual demand realization to maximize expected profits with respect to distribution of residual demand curve realizations that it faces

28

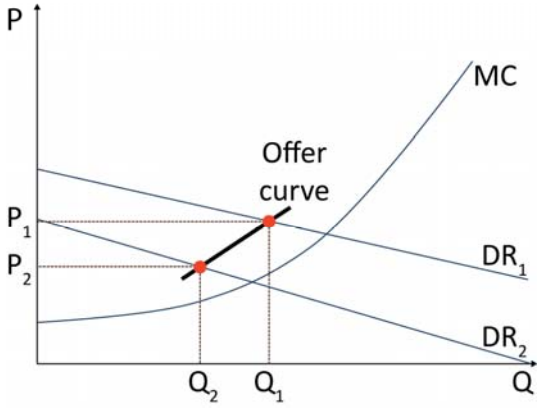
Expected profit-maximizing offer curve for two residual demand realizations



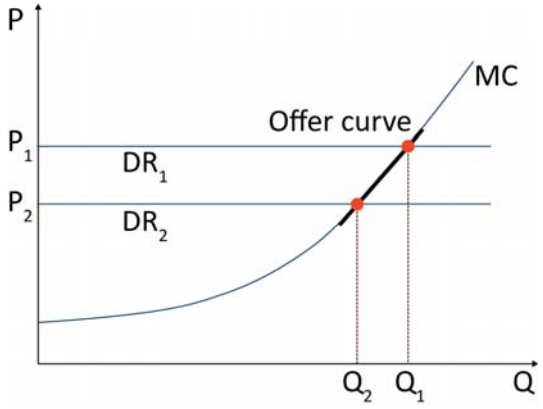
Derivation of offer curve with steeper residual demands



Derivation of offer curve with flatter residual demands



Derivation of offer curve with perfectly elastic residual demands



Measuring *Ability* to Exercise Market Power in Wholesale Electricity Market

- Each firm's residual demand curve can be computed given half-hourly offer curves of all other suppliers
  - DR(p) = Q^d – SO(p)
  - SO(p) aggregate willingness to supply of all other firms = sum of offer curves over all other firms in market
- Residual demand curve is ex post observable
  - η = inverse semi-elasticity of residual demand curve = -(1/100)*(DR(p)/DR'(p))
  - η is ex post observable
    - Measures $/KWh price increase that results from a one percent reduction in quantity sold by firm
- Implication of theory—Higher values of η imply a greater ability to exercise unilateral market power

Hourly Averages of η(Actual) and η(Ideal) for 2009, 2010 and 2011 for three large suppliers

Daily Means of Hourly Feasible and Ideal Inverse Semi-Elasticites for ATCO

Hour	Feasible Inverse Semi-elasticity	Ideal Inverse Semi-elasticity
0	6.3913	4.5223
1	4.5759	3.0814
2	4.1091	2.5671
3	3.1988	1.7622
4	3.7905	2.1794
5	4.0035	2.3963
6	9.2222	6.283
7	29.2169	24.9878
8	21.7098	11.7629
9	41.5394	33.8444
10	41.1473	29.7382
11	50.5034	28.8659
12	29.4344	19.192
13	42.7524	21.8586
14	29.8361	19.1386
15	51.7264	30.8415
16	56.1854	33.2363
17	79.4979	54.4671
18	52.3705	29.9049
19	35.7296	17.0578
20	37.1703	29.5469
21	28.7581	16.9043
22	11.0723	6.3052
23	9.0169	4.5579

Daily Means of Hourly Feasible and Ideal Inverse Semi-Elasticites for Capital Power

Hour	Feasible Inverse Semi-elasticity	Ideal Inverse Semi-elasticity
0	6.9569	4.7097
1	4.8931	3.0866
2	4.5806	2.6925
3	4.427	1.9455
4	5.2092	2.3134
5	4.7518	2.494
6	9.9295	6.5786
7	29.1587	24.9033
8	22.5017	12.8093
9	41.8103	33.5288
10	30.1607	22.3046
11	51.2066	28.7834
12	27.7195	17.8637
13	40.7075	28.6439
14	28.6991	19.2485
15	47.7725	36.331
16	59.0699	30.445
17	65.9477	49.8988
18	69.1007	32.5257
19	31.3424	14.4765
20	57.4056	30.3224
21	26.4011	13.5428
22	10.4818	6.378
23	8.7793	4.76

Daily Means of Feasible and Ideal Hourly Inverse Semi-Elasticities for TransAlta

Hour	Feasible Inverse Semi-elasticity	Ideal Inverse Semi-elasticity
0	13.5245	8.1049
1	8.6496	4.1487
2	13.5271	7.8086
3	9.0608	4.2187
4	10.877	4.2615
5	12.7985	7.0101
6	18.0116	11.7573
7	39.0842	31.6787
8	27.4971	16.1518
9	60.5141	35.5801
10	57.4434	28.3626
11	53.2884	32.6641
12	38.4105	21.6951
13	44.8432	24.5349
14	63.6096	22.1926
15	63.5564	43.7651
16	72.6378	40.3488
17	87.5616	61.5054
18	76.4675	37.6527
19	41.8704	19.8875
20	42.128	32.6894
21	34.3374	15.5131
22	14.2099	7.9596
23	12.8844	6.3362

Note that mean of η(Actual) > mean of η(Ideal)

Transmission Constraints and Supplier Behavior

Transmission Constraints and Residual Demands

- Transmission constraints causes the offers of some generation units to be eliminated from the actual residual demand curve
  - Increases slope of residual demand curve
  - Increases value of residual demand for a given price level
- Increases ability of supplier to exercise unilateral market power
  - Recall earlier comparison of η(Actual) and η(Ideal)
  - $/MWh price increase brought about by 1% reduction in output greater for Feasible Residual Demand Curve versus Ideal Residual Demand Curve
- Conclusion—One benefit of a transmission expansion is facing suppliers with distribution of flatter residual demand curves
  - Suppliers face greater competition and therefore have less ability to exercise unilateral market power
- Research Question—How will offer curves of a strategic supplier change if it faces Ideal (no congestion) Residual Demand curve instead of Feasible (with congestion) Residual Demand curve?

Relationship Between Offer Prices and Shape of Residual Demand Curve

- Simplified model of expected profit-maximizing offer behavior implies

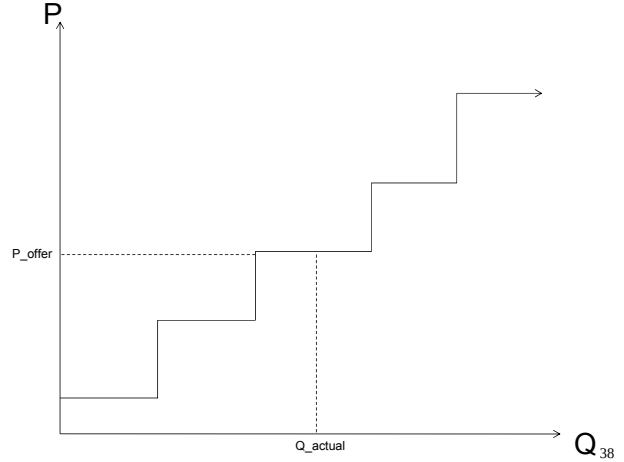
$$P_{hn} = C_{hn} + \beta\eta_{hn}^{F},$$

  - P_{hn} is the offer price of supplier n during hour h
  - C_{hn} is the marginal cost of the most expensive generation unit owned from supplier n that is operating during hour h,
  - η_{hn}^{F} is the inverse semi-elasticity of the Feasible Residual Demand Curve of supplier n during hour h (index of ability to exercise unilateral market power),
  - β is an unknown parameter to be estimated.
- Regress hourly offer price on day-of-sample dummy variables, hour-of-day dummy variables, and hourly value of η(Actual)

$$P_{jhdm}(\text{offer}) = \alpha_{dmj} + \tau_{hj} + \beta_j\eta_{jhdm} + \varepsilon_{jhdm}$$

  - To control for differences in C_{hn} across days and hours of sample
    - α_{dmj} and γ_{dmj} are day-of-month d and month of sample m fixed effects
    - τ_{hj} and are hour-of-the-day fixed effects for supplier j
  - ε_{jhdm} are mean zero and constant variance regression errors

Definition of Offer Price



Relationship Between Offer Prices and Shape of Residual Demand Curve

Table 4: Coefficient Estimates of β_j in Regression (3.8) for Supplier j

	Coefficient Estimate	Standard Error
$\beta_{TransAlta}$	0.0552976	0.002048
$\beta_{TransCanada}$	0.0546614	0.00137
β_{ENMAX}	0.0423829	0.001491
$\beta_{Capital\ Power}$	0.0574105	0.001564
$\beta_{ATCO\ Power}$	0.097143	0.002224

Note: Each line of the table corresponds to a different regression with 1,095 day-of-sample and 24 hour-of-day fixed effects included in each regression.

- Use estimate of β_j, coefficient on η_j(Feasible) in regression, to compute counterfactual hourly offer price using η_j(Ideal)
- If P_{jhk} is the offer price for bid quantity increment k for supplier j during hour h, then no perceived congestion offer price for this bid quantity increment is:

$$P_{jhk}^{NC} = P_{jhk} - \beta_j(\eta_{hn}^{F} - \eta_{hn}^{I})$$

- Repeating this process for all bid quantity increments yields a new vector of offer price and quantity increment pairs for all five strategic suppliers

Hourly Standard Deviations of η(Actual) and η(Ideal) for 2009, 2010 and 2011 for three large suppliers

Table 5(a): Daily Standard Deviations of Hourly Feasible and Ideal Inverse Semi-Elasticities for ATCO

Hour	Feasible Inverse Semi-Elasticity	Ideal Inverse Semi-Elasticity
0	41.581	40.743
1	13.322	14.893
2	13.31	12.571
3	9.364	7.605
4	10.295	7.981
5	10.924	9.633
6	40.067	35.372
7	292.143	290.078
8	132.398	60.35
9	345.616	311.174
10	253.786	235.329
11	292.137	184.427
12	98.242	74.311
13	274.736	102.382
14	134.156	97.913
15	359.722	215.827
16	271.348	206.488
17	456.979	408.841
18	280.885	227.529
19	254.419	71.31
20	235.152	226.993
21	162.497	110.504
22	48.755	32.261
23	44.892	18.773

Table 5(b): Daily Standard Deviations of Feasible and Ideal Hourly Inverse Semi-Elasticities for Capital Power

Hour	Feasible Inverse Semi-elasticity	Ideal Inverse Semi-Elasticity
0	42.075	41.232
1	15.016	14.058
2	15.484	12.636
3	29.114	7.747
4	29.606	7.938
5	13.884	9.509
6	40.304	35.644
7	291.856	289.94
8	133.435	64.155
9	342.833	310.167
10	119.003	106.736
11	283.955	170.37
12	93.317	72.353
13	254.823	235.151
14	134.195	98.2
15	316.323	302.876
16	337.785	202.272
17	522.559	288.61
18	611.637	289.342
19	158.011	59.6
20	469.176	234.132
21	136.791	60.309
22	34.966	32.301
23	30.378	18.867

Table 5(c): Daily Standard Deviations of Feasible and Ideal Hourly Inverse Semi-Elasticities for TransAlta

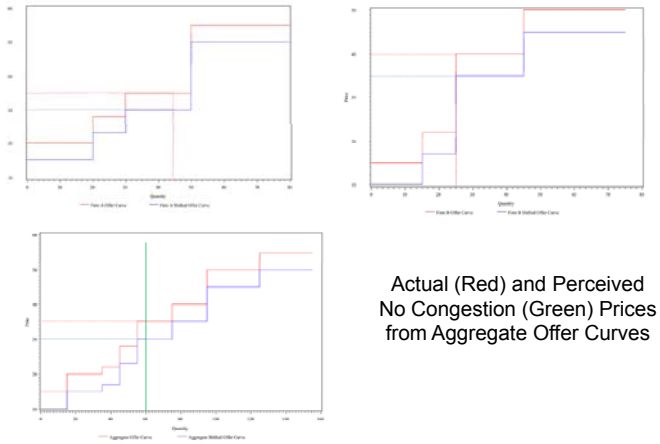
Hour	Feasible Inverse Semi-elasticity	Ideal Inverse Semi-elasticity
0	65.209	59.51
1	26.255	53.503
2	125.547	116.741
3	43.99	17.537
4	54.178	19.225
5	61.63	51.984
6	79.64	71.81
7	320.28	313.171
8	140.397	73.597
9	497.988	311.275
10	405.63	133.104
11	291.225	204.085
12	167.336	84.217
13	250.864	88.981
14	774.835	96.418
15	362.656	320.241
16	429.677	321.408
17	400.863	335.92
18	630.742	345.018
19	253.976	91.804
20	312.371	305.789
21	174.459	77.193
22	37.217	31.736
23	34.718	17.451

Note that Standard Deviation (SD) of η(Actual) > SD of η(Ideal)

Quantifying Benefits of Alberta's Transmission Policy

- Construct no-perceived-congestion offer curves using counterfactual offer prices and original quantities for five strategic suppliers
- Compute counterfactual market-clearing prices using these offer curves for strategic suppliers and original offer curves for other suppliers
  - Actual Realized Congestion price
    - Only accept offers from units that actually supplied energy for at most the amount of energy they actually supplied
  - No Congestion price
    - Accept lowest-priced offers from all units
      - No offers are not accepted because of congestion

Actual and No Perceived Congestion Offer Curves



Actual (Red) and Perceived No Congestion (Green) Prices from Aggregate Offer Curves

Quantifying Competitiveness Benefits

- PC_h^F = Feasible counterfactual price using no perceived congestion offer curves for strategic suppliers with actual amount of congestion
  - Only offers with positive quantities accepted in actual market were included in aggregate offer curve to meet actual demand
- PC_h^I = Ideal counterfactual price using no congestion offer curves and no realized congestion
- Absolute consumer benefits (change in wholesale energy costs) in Canadian Dollars

  $\Delta R_h^F = (P_h - PC_h^F)QD_h$ and $\Delta R_h^I = (P_h - PC_h^I)QD_h$,
- Relative consumer benefits (change in wholesale energy costs as percent of total wholesale energy costs) over time horizon H

$$\Delta RR_h^F = 100 * \frac{\sum_{h=1}^{H}(P_h - PC_h^F)QD_h}{\sum_{h=1}^{H} P_h * QD_h} \text{ and } \Delta RR_h^I = 100 * \frac{\sum_{h=1}^{H}(P_h - PC_h^I)QD_h}{\sum_{h=1}^{H} P_h * QD_h},$$

Quantifying Competitiveness Benefits

Annual and Sample Average Hourly Revenue Differences for Ideal and Feasible Counterfactual Prices in CAD and as Percentage of Annual Wholesale Energy Costs

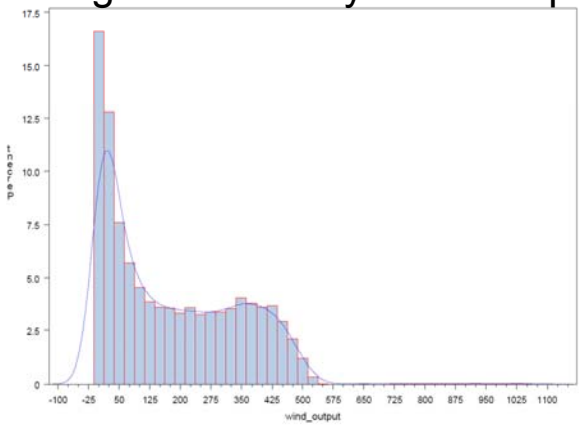
Year	Ideal Price Cost Difference	Feasible Price Cost Difference	Wholesale Energy Costs	Ideal Cost Difference as a Percent of Wholesale Revenues	Feasible Price Cost Difference as a Percent of Wholesale Revenues
2009	61,912.99	2,734.43	398,345.3	15.54254	0.686447
2010	81,648.03	2,080.56	426,525.7	19.14258	0.487792
2011	102,963.6	5,043.68	653,753	15.74962	0.771496
Sample	79,590.19	3,066.67	472,816.4	16.83321	0.648596

- Substantial Competitiveness Benefits even if perception of facing no congestion does not turn out to be the case
  - $80 million over 3-year, 2009 to 2011, period
- Extremely large Competitiveness Benefits if perception of facing no congestion turns out to be the case
  - $2 billion over 3-year 2009 to 2011, period

Increasing Intermittent Resources

- Intermittency of wind and solar generation is likely to create more opportunities for thermal suppliers to reduce size of market over which they face competition
- Low wind conditions likely to lead to increased opportunities for thermal suppliers to raise market prices
  - Face higher residual demand at each price level
- Regress hourly values of $(P_h - PC_h^F)$ and $(P_h - PC_h^I)$ on hourly system-wide wind output and hourly system-wide demand and hour-of-day fixed effects
  - In both cases coefficient on hourly wind output is negative and precisely estimated, indicating the lower levels of wind output predict higher levels of "competitiveness benefits"
  - Coefficient on hourly system demand is positive and precisely estimated, indicating higher competitiveness benefits at higher levels of system demand
- Results suggest that both more volatile demand and more wind capacity both increase competitiveness benefits
  - Increasingly important source of benefits of upgrades with greater renewable energy share

Histogram of Hourly Wind Output



Conclusions

- Transmission expansions increase competition suppliers face, which causes a strategic supplier to submit an offer curve closer to its marginal cost curve
  - This yields market prices closer to competitive benchmark levels
- Competitiveness benefits of transmission expansions in Alberta market can be substantial
- Methodology can be applied to any bid-based wholesale electricity market
  - Existing network configuration
  - Proposed transmission network upgrade
  - Method used to manage congestion (nodal and zonal pricing)
- Failure to account for competitiveness benefits of transmission upgrades can unnecessarily increase wholesale electricity prices paid by electricity consumers
  - Likely to be even greater source of benefits for a wholesale electricity market with larger share of intermittent resources

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