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

Frank A. Wolak
Director, Program on Energy Sustainable Development
Professor, Department of Economics
Stanford University
wolak@stanford.edu
http://www.stanford.edu/~wolak

Motivation

- Re-structuring fundamentally changes role of transmission network
  - Before—Transmission network improves performance of *imperfectly regulated vertically-integrated utility*
    - Increases ability of utility to substitute *high cost* supply near load center with *low cost* supply from distant resources
  - After—Transmission network improves performance of *imperfectly competitive wholesale market*
    - Increases number of firms able to compete to supply electricity at each location in transmission network
    - Increases amount of *low-priced* energy that can displace *high-priced* energy at load centers
- Conclusion--Optimal transmission network configuration different for vertically-integrated regime versus wholesale market regime
  - Owners of productive assets face different incentives under each regime

Motivation

- 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
  - Suppliers take this into account in formulating their expected profit-maximizing offer curves
- 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)
  - Goal of paper is to measure consumer benefits from this change in strategic behavior due to expanded transmission network—"Competitiveness benefits"

Goals of Research

- Quantify magnitude of competitiveness benefits of proposed expansion of Heywood transmission interconnection between South Australia and Victoria
- The new capacity assumed to be
  - Summer 570 MW both directions
  - Non-summer 650 MW both directions
- Sample period January 1, 2008 to December 31, 2010
- Empirical results find sizeable competitiveness benefits from proposed Heywood transmission expansion
  - Wholesale energy purchase cost reductions from reducing 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
- General methodology can be applied to any ownership structure, pricing mechanism, existing network, configuration, and proposed upgrade

Outline of Presentation

- Review basic features of price-setting process in Australian Wholesale Electricity Market
- 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 *Upgraded* Residual Demand Curve
- Estimate statistical model relating supplier's half-hourly offer price to its half-hourly actual ability to exercise unilateral market power after controlling differences in costs

Outline of Presentation

- Use statistical model to compute counterfactual offer price and offer curve assuming supplier faces increased competition caused by proposed upgrade
  - "Reduced perceived congestion" measure of competition that supplier faces
- Compute two counterfactual market-clearing prices
  - Using reduced perceived congestion offer curves for five strategic suppliers using *actual transmission capacity*
    - Difference between actual price and this counterfactual price measures competitiveness consumer benefits of upgrade
  - Using reduced perceived congestion offer curves for five strategic suppliers using *upgraded transmission* capacity
    - Difference between actual price and this counterfactual price measures total (competitiveness + upgrade) consumer benefits of upgrade

Outline of Presentation

- Compute predicted market-clearing prices using actual offers of all suppliers and actual transmission network
  - Predicted prices closely track actual market-clearing prices over sample period
- Use these three prices to compute aggregate measures of each component of total benefits transmission upgrade
  - Roughly one-third of estimated aggregate consumers benefits of upgrade are the result competitiveness benefits
  - Reduced perceived congestion results in offer curves closer to marginal cost curve, which reduces frequency of extreme price differences across Victoria and South Australia
- Conclusion—Competitiveness consumer benefits of transmission expansions particularly important in energy-only market with a high offer cap like Australia
  - Many transmission expansion can pay for themselves through reduced wholesale energy purchase costs
    - Consumers pay for wholesale energy, transmission, distribution and retailing services

Key Features of Australia Wholesale Electricity Market

Market Structure in Australia

Installed Capacity by Prime Mover

Prime Mover	Capacity in MW	Capacity Share (%)
Coal	26666	56%
Hydro	7510	16%
OCGT	6114	13%
CCGT	2601	5%
Steam	2411	5%
Wind	1502	3%
Biomass	877	2%
NG Cogeneration	263	1%
Renewables	31	0%
Totals	47975	100%

Capacity Owned and Capacity Share of Five Largest Firms in Victoria and South Australia

Owner	Capacity in MW	Capacity Share (%)
Hazelwood Power	1640	3%
Loy Yang A	2180	5%
NRG Flinders Operating Services Pty Ltd	950	2%
TXU Pty Ltd	1280	3%
Yallourn Energy	1480	3%
Totals	7530	16%

Price Determination in Australia

- Australia uses a zonal-pricing model
  - Market only explicitly prices congestion across state boundaries
  - Price-setting model “effectively assumes” infinite transmission capacity within each state
  - Five interconnected states--QLD, NSW, VIC, TAS, and SA
- Price-setting process simultaneously minimizes the as-offered cost of serving 5-minute demands in each Australian state during each 5-minute interval
  - Solution yields state-level 5-minute prices
  - Arithmetic average of six 5-minute prices during a half-hour period for each state is half-hourly price for that state
- To perform upgrade analysis, must have model of price-setting process for Australia market
  - Requires data on half-hourly offer curves of generation unit owners, 5-minute demands, and 5-minutes maximum flows in each direction on all transmission interfaces

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

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
  - Increase the extent of competition that each supplier faces by flattening distribution of residual demand curves that firm faces
  - This is source of competitiveness benefits of transmission expansions

Measuring Ability versus Incentive to Exercise Unilateral Market Power

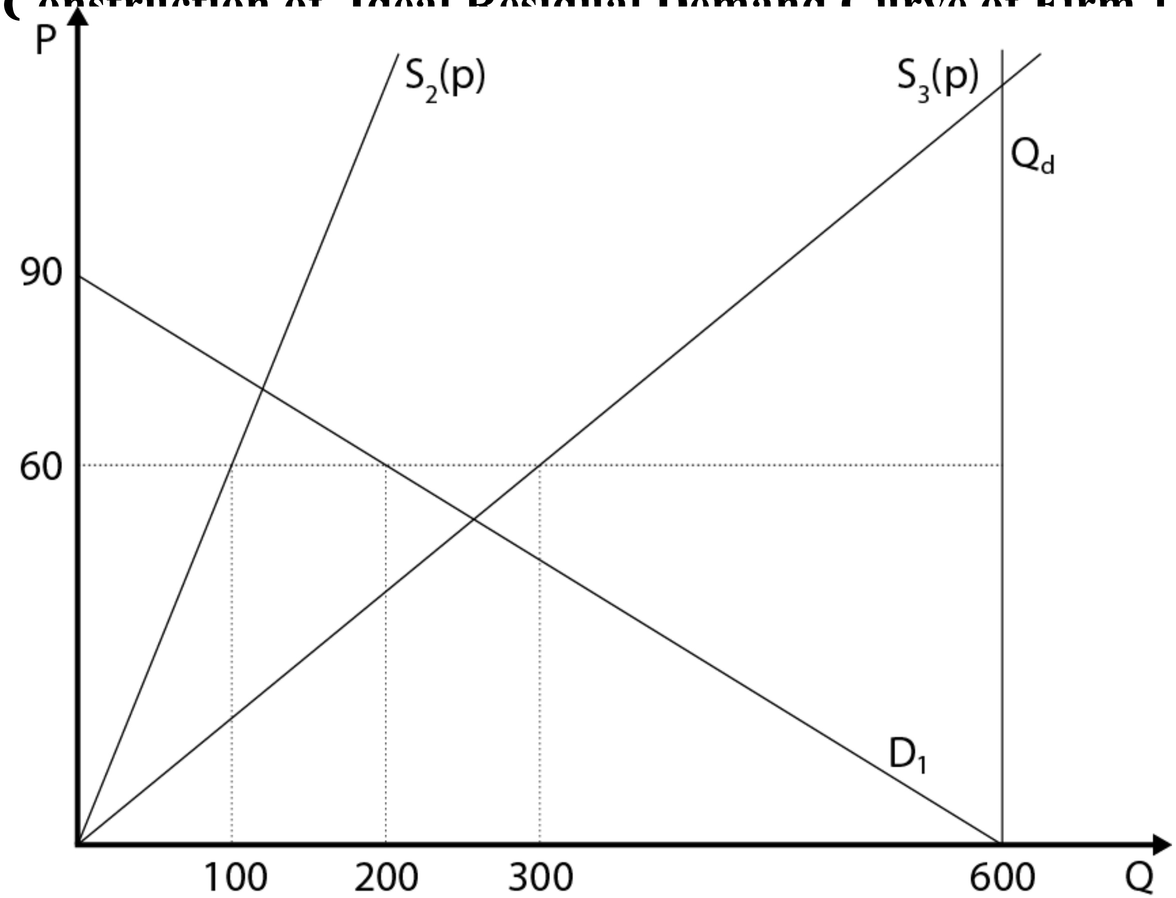
- ***The residual demand curve*** is the essential input for ***measuring firm-level ability*** to exercise unilateral market power
- ***Fixed-price forward market obligations*** are an essential input for measuring ***firm-level incentive*** to exercise unilateral market power
  – These are confidential in Australia, 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 likely to have greater incentive to sign more fixed-price forward market obligations which further increase competitiveness of short-term market outcomes for reasons described above

Two Residual Demand Curves

- Feasible Residual Demand Curve—Residual demand curve based on offers of other firms that can actually compete to supply energy with Firm A because of existing transmission network
- Upgraded Residual Demand Curve—Residual demand curve based on offers of other firms that can compete to supply energy with Firm A because of upgraded transmission network
- Feasible 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

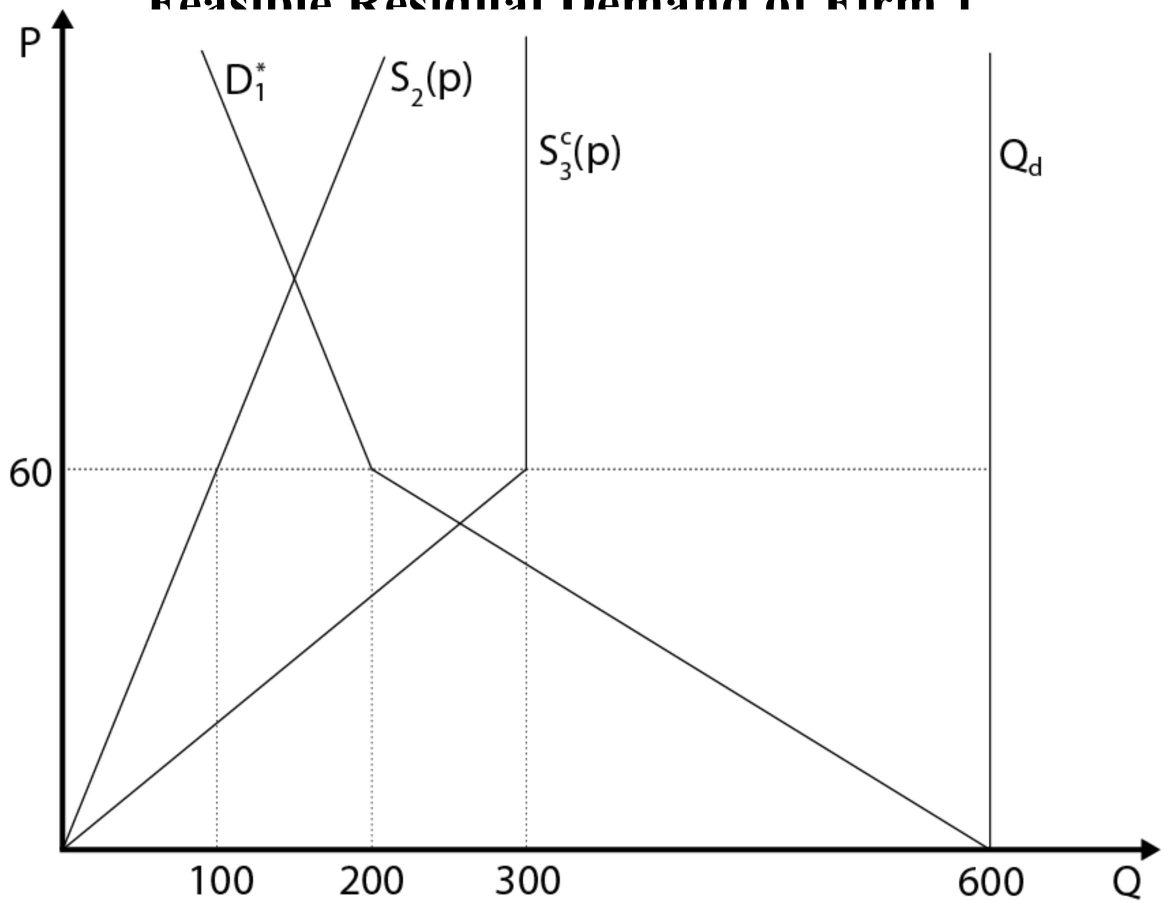
Construction of Ideal Residual Demand Curve of Firm 1

Construction of Ideal Residual Demand Curve of Firm 1



Feasible Residual Demand of Firm 1 with Transmission Constraints

Feasible Residual Demand of Firm 1



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

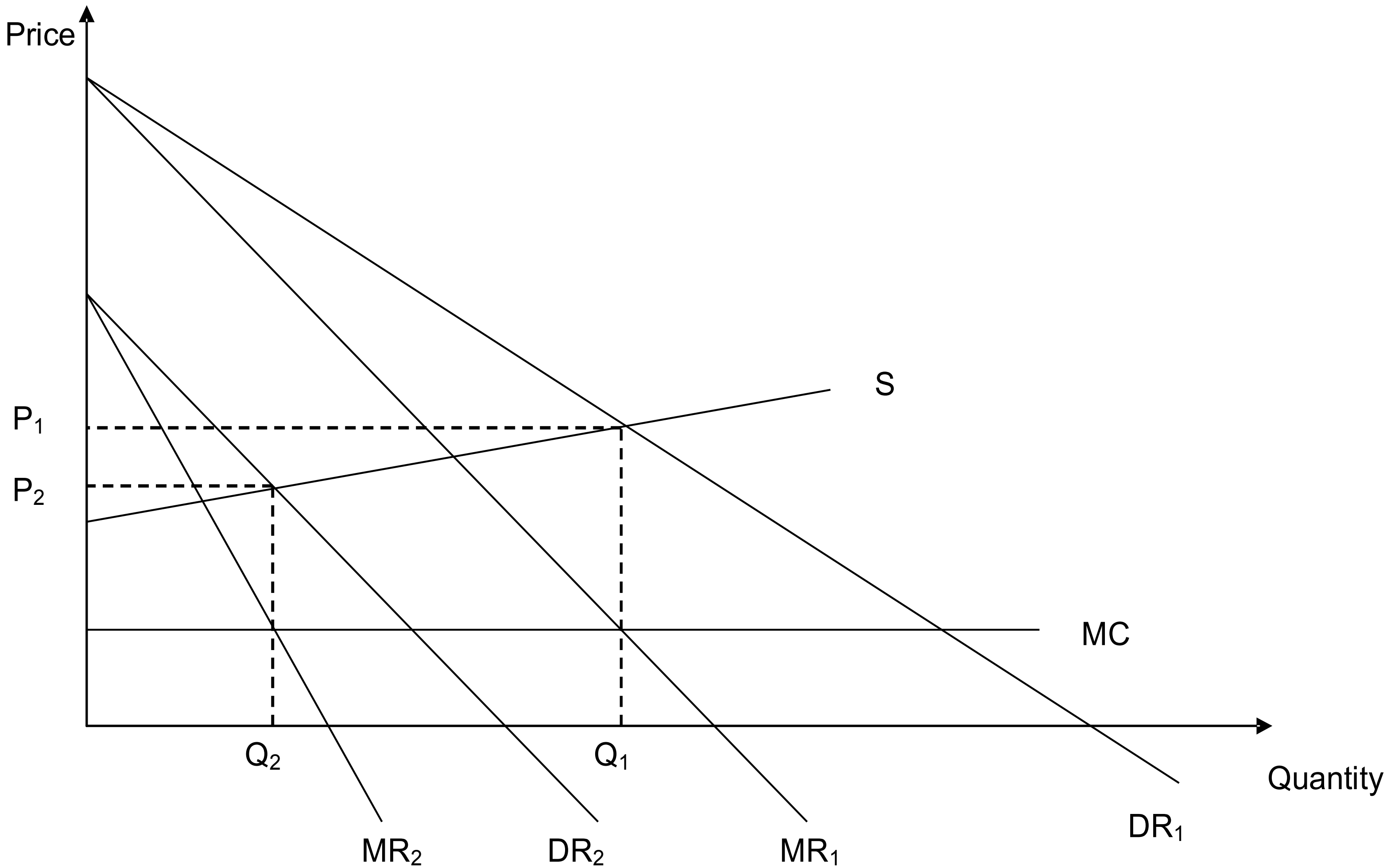
Supplier behaves like a profit-maximizing monopolist given its residual demand curve

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

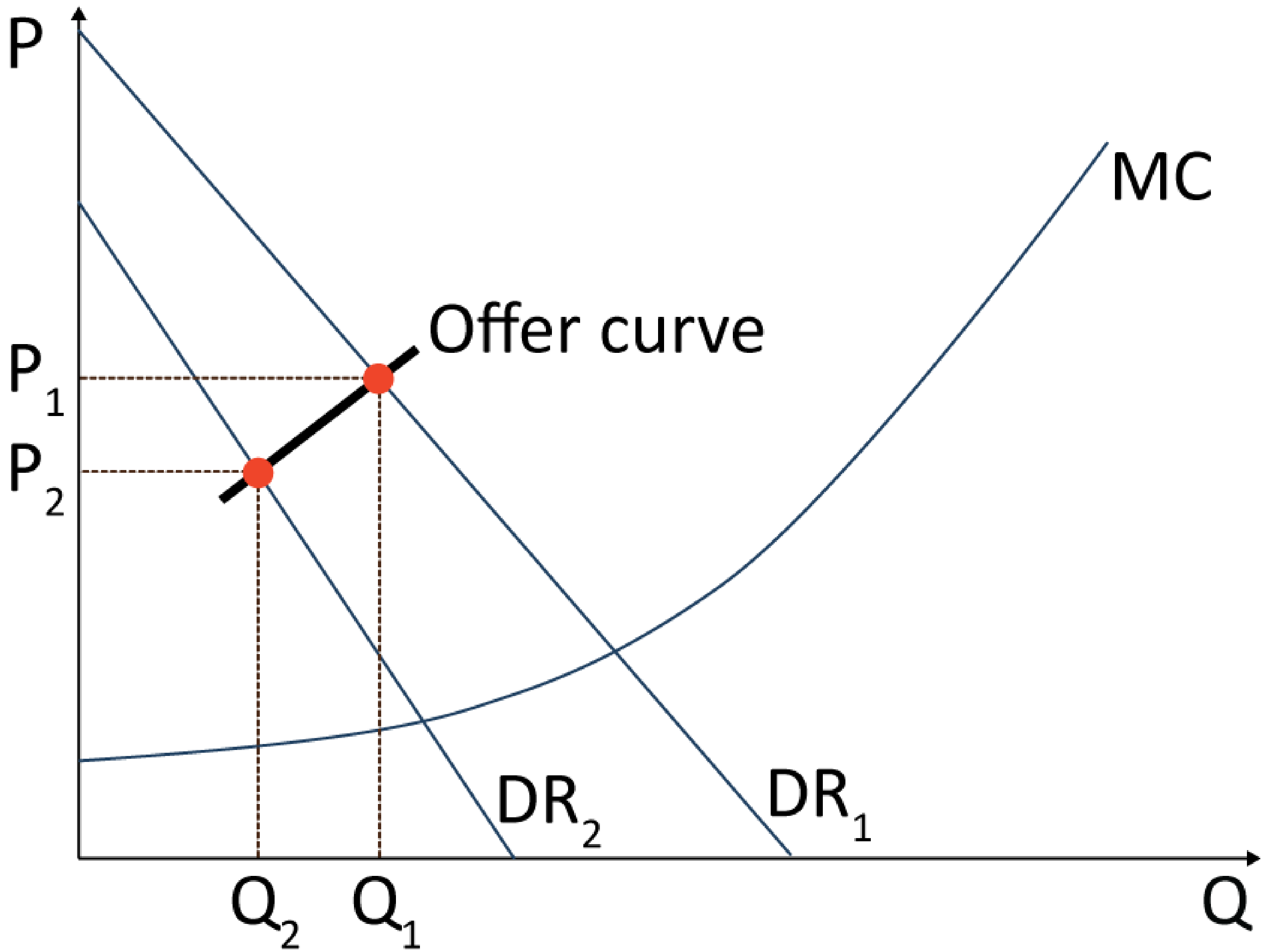
Simplified Model of Expected Profit Maximizing Offer Behavior

- 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

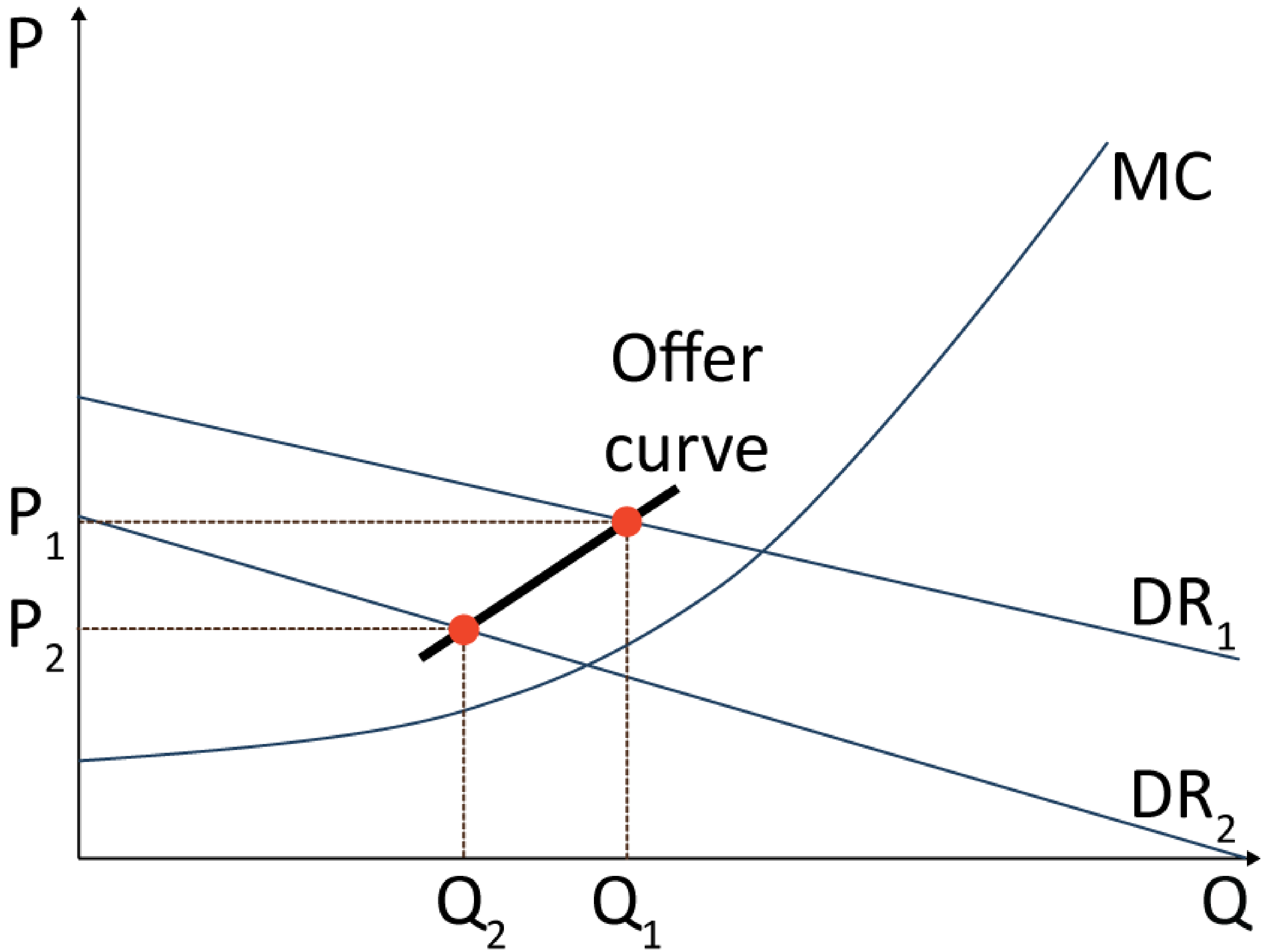
Expected profit-maximizing offer curve for two residual demand realizations



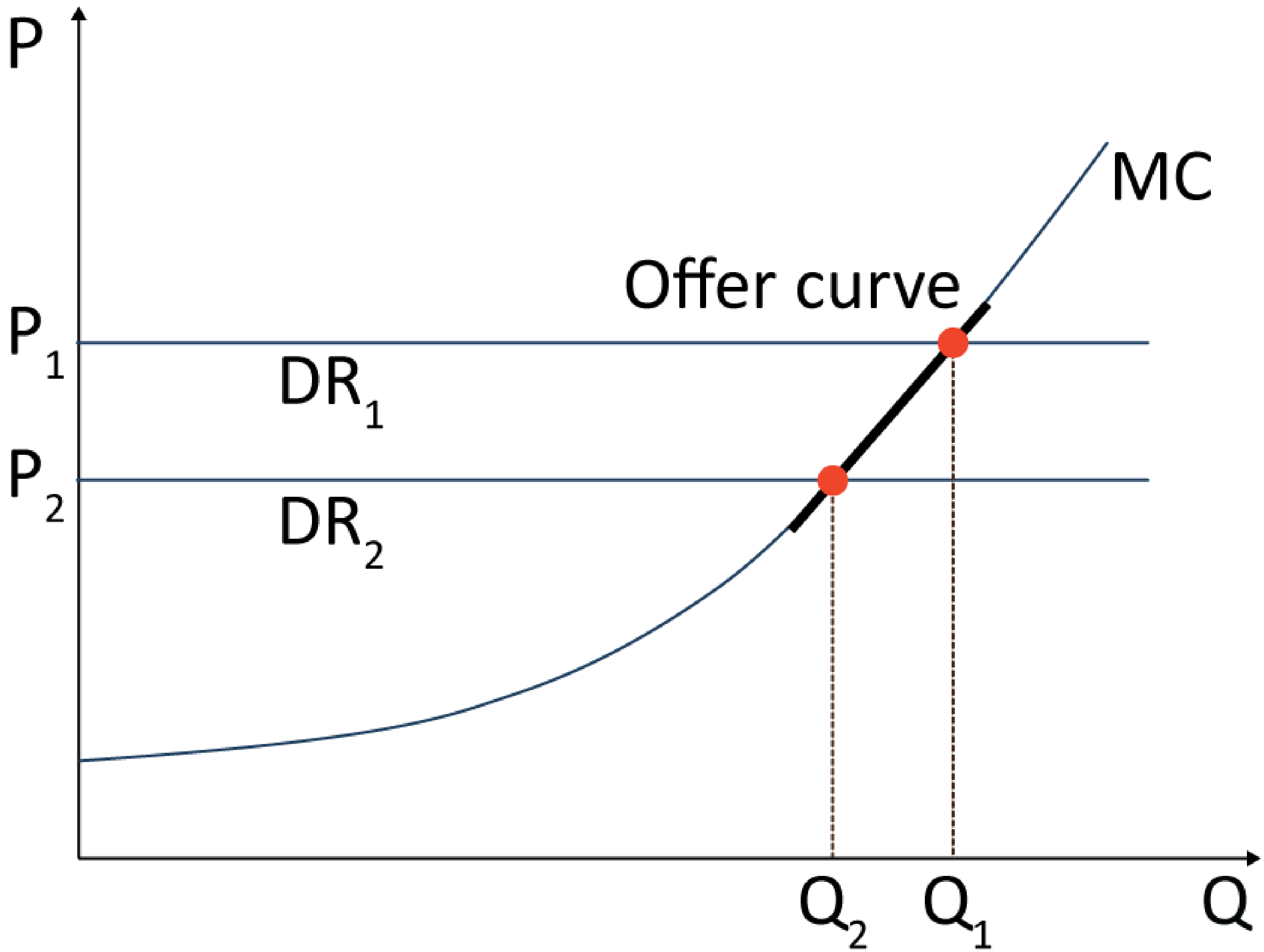
Derivation of offer curve with steeper residual demands



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 is index of ability of supplier to exercise unilateral market power

    $= -(DR(p)/DR'(p))$
  - η is ex post observable
    - Measures $/MWh price increase that results from a 0.01 proportional reduction (1 percent reduction) in quantity sold by firm
- Implication of theory—Higher values of η imply a greater ability to exercise unilateral market power
  - Wolak (2003) provided empirical support for this prediction in CA
  - McRae and Wolak (2009) finds evidence for prediction in NZ
  - Wolak (2010) finds evidence for prediction in Colombia

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

- Estimating η for a supplier in the Australian market is complicated by the fact that the transmission-constrained residual demand curve can only be computed numerically
- Numerically compute η as $/MWh price increase in Australian state were Firm A's units are located as result of a one percent reduction in half-hourly quantity sold by Firm A
- Three step process
  - For each 5-minute period, use actual offers, actual demand, and solve for predicted 5-minute prices and generation unit-level dispatch levels
  - Take total predicted generation unit-level outputs of Firm A in that 5-minute interval and subtract this from demand in that supplier's zone and re-solve for state-level prices with this reduced level of demand excluding this supplier's offers
- Call these prices p(high,s,j) for state s and 5-minute period j
- Compute p(high,s) as average of six 5-minute values of p(high,s,j)
  - Take 0.9 times total predicted generation unit-level outputs of Firm A in that 5-minute interval and subtract this from demand in that supplier's zone and re-solve for state-level prices with this reduced level of demand excluding this supplier's offers
- Call these prices p(low,s,j) for state s and 5-minute period j
- Compute p(low,s) as average of six 5-minute values of p(low,s,j)

Measure *Ability* to Exercise Market Power in Australian Wholesale Electricity Market

- Compute $\eta = -(DR(p)/DR'(p))$ as

$$-\{(p(high,s) – p(low,s))/(0.1*Q(actual))\}*Q(actual)$$
$$= -(1/100)*\{(p(high,s) – p(low,s))/0.1$$

  for Firm A located in state s, \$/MWh price increase from a 0.01 proportionate (one percent) reduction in firm's half-hourly output, where Q(actual) is the actual half-hourly output of Firm A

- To compute η(Feasible), use actual transmission capacity of inter-connections
- To compute η(Upgrade), use upgraded transmission capacity for all inter-connections
  - Single transmission interconnection considered in this analysis, but multiple upgrades can be considered at once

Half-hourly Averages of η(Feasible) and η(Upgrade) for 2008, 2009 and 2010 for large VIC and SA firms

Half-hours 0:00-11:30

	Loy Yang A		Hazelwood Power		Yallourn Energy		NRG Flinders Operating Services		TXU Pty Ltd	
Half-hour	Pre-Upgrade	Post-Upgrade	Pre-Upgrade	Post-Upgrade	Pre-Upgrade	Post-Upgrade	Pre-Upgrade	Post-Upgrade	Pre-Upgrade	Post-Upgrade
0:00	339.46	155.117	247.694	90.93	218.93	75.228	63.902	45.521	88.2	42.436
0:30	289.02	96.807	191.034	62.464	135.806	53.099	45.246	22.257	37.95	17.467
1:00	285.15	93.682	224.895	34.321	134.232	25.87	45.561	15.181	30.77	10.843
1:30	302.67	112.886	186.493	58.17	191.491	50.922	56.238	35.495	49.39	28.091
2:00	215.62	112.2	165.479	54.756	143.136	45.418	60.713	25.068	41.61	23.994
2:30	198.24	46.236	137.295	27.499	124.387	22.468	37.974	11.609	12.09	3.711
3:00	70.11	40.658	29.977	24.146	27.953	23.647	35.239	9.89	9.37	2.766
3:30	47.28	38.517	27.342	22.407	30.719	25.319	32.92	8.592	7.26	2.482
4:00	42.87	36.314	25.417	21.702	29.817	25.743	33.698	8.099	4.93	1.91
4:30	40.08	34.344	26.786	22.407	27.263	23.425	30.868	9.47	4.09	1.73
5:00	44.32	38.74	27.794	23.466	26.877	22.256	33.471	10.403	4.22	2.038
5:30	64.33	53.761	34.846	27.399	29.862	24.317	34.805	12.274	7.07	3.365
6:00	65.19	53.637	34.295	27.037	30.349	25.41	33.801	12.952	28.63	4.77
6:30	157.39	69.977	88.715	46.859	70.271	43.366	35.071	18.134	28.72	16.254
7:00	335.99	204.043	253.3	136.453	231.428	126.35	83.112	63.457	108.96	88.575
7:30	126.49	40.141	84.128	24.311	57.977	22.598	28.308	12.579	58.78	14.299
8:00	175.65	53.038	126.915	29.871	69.172	25.817	30.825	14.673	49.75	19.92
8:30	323.39	201.327	216.061	130.973	166.753	97.665	68.078	53.375	138.31	96.034
9:00	350.54	211.543	145.265	52.838	128.275	65.747	33.922	23.465	132.19	31.921
9:30	289.98	238.622	133.102	103.122	117.826	110.994	81.14	68.06	181.61	78.5
10:00	108.7	96.723	50.277	41.054	46.105	37.876	89.137	22.241	347.9	35.486
10:30	425.61	297.359	215.704	201.02	207.31	198.143	183.122	142.191	576.62	141.11
11:00	446.22	211.32	337.563	152.186	267.934	151.452	227.974	117.774	262.95	87.393
11:30	556.5	407.766	445.676	245.241	398.251	235.867	202.325	157.108	389.42	171.351

Note that mean of η(Feasible) > mean of η(Upgrade)

Half-hourly Averages of η(Feasible) and η(Upgrade) for 2008, 2009 and 2010 for large VIC and SA firms

Half-hours 12:00-23:30

	Loy Yang A		Hazelwood Power		Yallourn Energy		NRG Flinders Operating Services		TXU Pty Ltd	
Half-hour	Pre-Upgrade	Post-Upgrade	Pre-Upgrade	Post-Upgrade	Pre-Upgrade	Post-Upgrade	Pre-Upgrade	Post-Upgrade	Pre-Upgrade	Post-Upgrade
12:00	476.79	272.733	321.706	143.816	250.244	134.32	270.715	110.497	404.1	123.169
12:30	476.95	351.306	177	138.777	183.835	146.517	311.551	92.322	523.61	125.553
13:00	836.48	534.049	485.778	281.707	416.786	294.244	363.36	188.5	750.03	230.666
13:30	996.63	675.459	678.984	402.501	637.793	381.997	400.482	173.374	965.99	118.219
14:00	984.98	733.259	612.185	422.739	526.708	420.231	482.401	336.724	1370.53	258.379
14:30	1015.34	683.397	550.078	421.707	602.77	479.687	712.304	285.729	2189.79	290.323
15:00	760.75	538.886	305.677	230.357	382.095	312.557	491.084	128.245	1150.74	118.719
15:30	751.12	482.027	382.555	308.546	394.385	316.451	342.956	186.323	716.86	131.323
16:00	1100.03	711.629	508.154	309.499	577.494	377.217	334.57	156.421	582.38	159.434
16:30	697.21	264.006	493.297	127.918	402.939	152.508	278.664	105.042	415.1	104.385
17:00	562.49	210.541	265.021	136.181	271.482	131.288	425.803	33.699	639.33	37.552
17:30	540.44	296.997	310.672	163.542	315.21	146.149	382.555	107.859	1040.25	188.154
18:00	413.76	287.3	275.382	158.787	249.207	164.282	438.942	66.371	1040.35	73.83
18:30	572.26	471.157	365.104	250.554	342.708	224.522	181.468	139.383	564.23	185.317
19:00	747.17	725.468	422.507	402.136	349.29	333.195	288.713	234.186	702.89	346.487
19:30	405.28	371.427	249.728	218.281	194.564	177.18	225.534	91.527	395.57	153.205
20:00	624.2	501.076	272.654	200.489	222.614	177.814	175.091	94.89	380.68	77.639
20:30	555.17	427.329	451.563	348.517	376.562	291.616	227.835	168.913	461.9	134.568
21:00	369.14	354.666	288.043	258.173	228.367	180.18	281.945	133.69	557.34	121.387
21:30	430.46	198.024	284.178	98.023	277.163	60.018	88.49	43.763	381.75	43.211
22:00	128.52	52.822	79.386	26.056	28.795	22.473	27.587	12.84	299.24	10.155
22:30	188.34	145.691	99.087	91.49	84.584	78.647	95.27	54.097	234.28	54.733
23:00	114.29	107.496	64.66	60.148	55.358	52.357	75.157	31.141	85.96	32.268
23:30	402.12	158.18	273.919	85.261	174.67	56.336	56.843	43.753	70.88	41.927

Note that mean of η(Feasible) > mean of η(Upgrade)

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(Feasible) to of η(Upgrade)
  - $/MWh price increase brought about by 1% reduction in output greater for Feasible Residual Demand Curve versus Upgraded 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 Challenge—Quantify how offer curves of a strategic supplier change if it faces Upgraded Residual Demand curve instead of Feasible Residual Demand curve

Predictive Relationship Between Offer Prices and Shape of Residual Demand Curves

- Simplified model of expected profit-maximizing offer behavior described earlier 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.

Predictive Relationship Between Offer Prices and Shape of Residual Demand Curves

- Regress half-hourly offer price on day-of-sample dummy variables, half-hour-of-day dummy variables, and half-hourly value of η(Feasible)

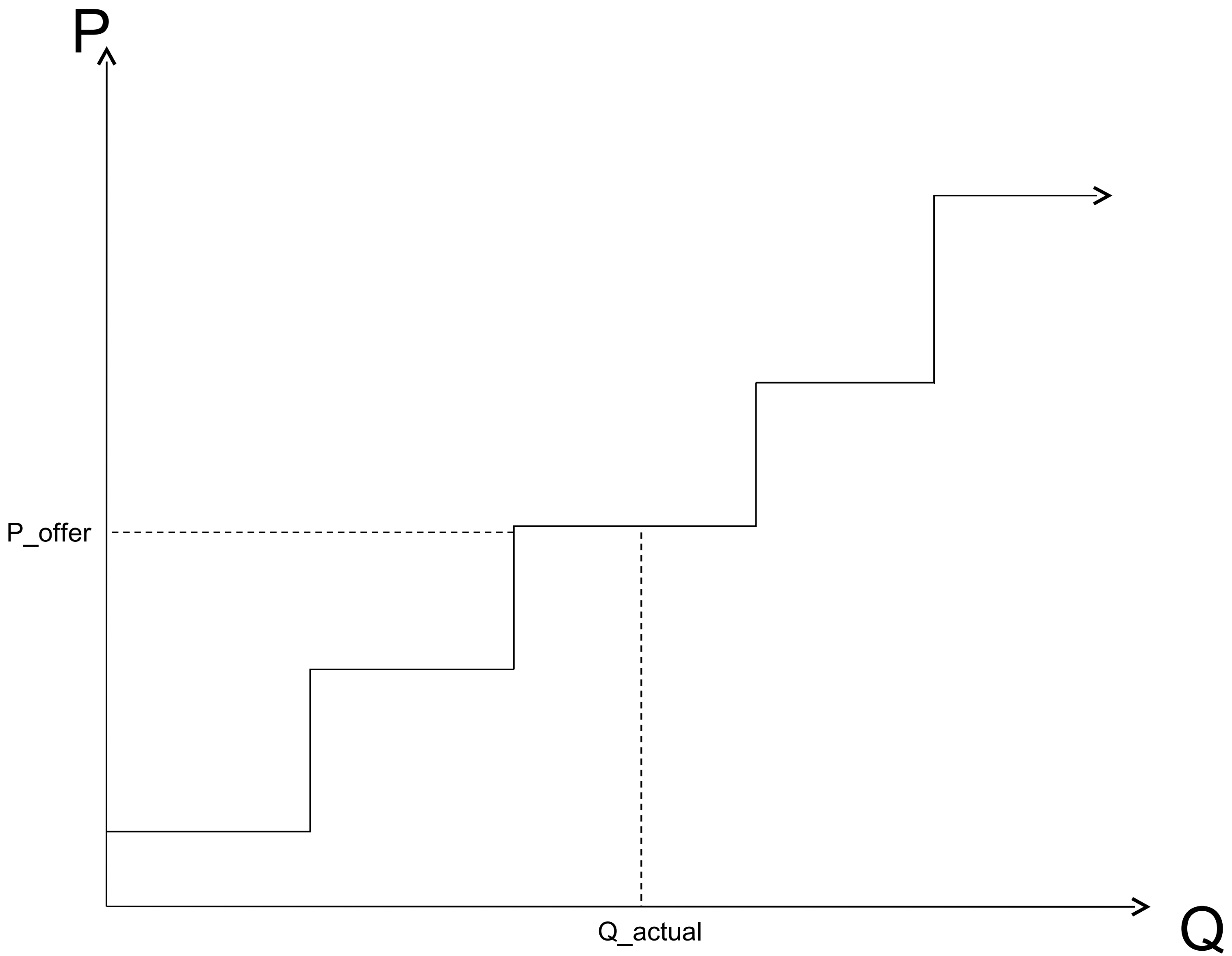
$$P_{jhdm}(\text{offer}) = \alpha_{dhmj} + \tau_{hj} + \beta_j \eta_{jhdm} + \varepsilon_{jhdm}$$

  – 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 half-hour-of-the-day fixed effects for supplier j

  – ε_{jhdm} are mean zero best-linear prediction function errorsP

- Consistent estimate of BLP(P_h(offer)|C_h,η_h) for population joint distribution of offer prices, marginal costs, and inverse elasticities

Definition of Offer Price



Relationship Between Offer Prices and Shape of Residual Demand Curve

Firm	β(Firm)	Standard Error
LYA	0.0951146	0.0117364
HWPS	0.1482320	0.0199135
YWPS	0.1277265	0.0308257
NRG	0.3063703	0.0227238
TXU	0.2242719	0.0104254

- Use estimate of β_j, coefficient on η_j(Feasible) in regression, to compute counterfactual half-hourly offer price using η_j(Upgrade)
- If P_{jhk} is the offer price for bid quantity increment k for supplier j during hour h, then reduced perceived congestion offer price for this bid quantity increment is:

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

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

Half-hourly Standard Deviations of η(Feasible) and η(Upgrade) for 2008, 2009 and 2010 large VIC and SA firms (Half-hours 1-24)

Loy Yang A

Standard Deviation	
Pre-Upgrade	Post-Upgrade
4308.24	1791.74
5187.14	956.8
5381.77	1362.96
3867.67	1149.73
2437.39	1174.81
2987.68	68.1
705.19	61.69
99.71	61.51
72.56	61.84
64.56	57.08
71.29	65.79
108.75	88.97
100.09	85.27
2091.17	881.72
3386.48	2456.11
1812.92	132.88
2413.05	211.22
5172.11	4536.9
5775.51	5138.16
4332.97	4210.53
863.12	851.43
5514.42	4302.97
5924	2652.74
6699.51	5515.17

Hazelwood Power

Standard Deviation	
Pre-Upgrade	Post-Upgrade
3597.34	1267.16
4095.85	779.29
4536.37	120.85
3125.52	623.15
2206.96	524.01
2420.57	40.58
64.7	36.46
60.58	35.96
42.13	36.12
43.25	38.07
43.99	38.31
61.43	38.51
54.63	42.11
1203.26	536.09
2646.25	1904.64
1187.73	93.58
1963.58	111.46
3631.64	3108.82
1638.91	615.07
1925.82	1785.65
267.08	241.93
3104.24	3094.55
5067.76	2049.1
6033.2	3274.71

Yallourn Energy

Standard Deviation	
Pre-Upgrade	Post-Upgrade
3421.66	1247.8
2664.05	779.06
2637.08	112.56
3586.48	621.84
2136.11	511.65
2300.49	35.86
61.14	41.06
69.2	47.81
53.88	50.32
50.73	46.51
59.98	44.34
62.91	41.41
53.56	44.65
854.85	477.03
2406.88	1788.85
843.74	91.21
729.72	89.03
2670.55	2206.67
1793.19	1164.13
2515.84	2515.08
240.32	217.54
3075.29	3073.43
3863.76	2080.32
5354.65	3319.36

NRG Flinders

Standard Deviation	
Pre-Upgrade	Post-Upgrade
701.09	677.78
124.33	101.63
122.48	39.01
560.94	544.96
742.74	348
84.79	21.97
82.05	25.7
81.24	21.59
84.02	18.13
77.13	23.65
79.83	24.88
99.59	24.39
74.78	29.2
190.14	183.68
1010.86	1008.58
92.72	75.32
83.82	52.61
1181.16	1179.43
218.94	198.42
1584.24	1583.65
1852.07	149.46
2628.49	2425.43
3614.47	1774.5
2730.14	2261.17

TXU Pty. Ltd.

Standard Deviation	
Pre-Upgrade	Post-Upgrade
752.6	605.54
267.82	126.49
240.34	68.78
408.28	324.57
617.31	448.76
88.49	18.15
68.08	12.49
39.13	12.56
20.32	8.46
16.24	6.7
19.11	11.85
34.71	11.94
262.86	18.33
284.11	235.54
1390.98	1380.91
546.82	80.74
298.97	86.32
2358	2330.26
1076.09	183.83
1596.89	1392.72
5756.28	215.33
9319.36	2685.85
3218.25	1202
4379.85	2372.84

Note that Standard Deviation (SD) of η(Feasible) >> SD of η(Upgrade)

Half-hourly Standard Deviations of η(Feasible) and η(Upgrade) for 2008, 2009 and 2010 large VIC and SA firms (Half-hours 25-48)

Loy Yang A

Standard Deviation	
Pre-Upgrade	Post-Upgrade
6610.28	3666.82
5406.22	4531.51
9780.21	7258.89
9673.28	8221.33
9692.13	7497.32
9859.61	7992.35
8222.24	6520.18
8080.73	5864.62
10451.42	7906.7
7607.5	3368.22
6246.7	2206.32
5150.28	3446.67
4046.71	3008.06
6161.94	5216.08
7230.73	7080.32
3919.99	3765.37
6709.09	5555.53
6560.49	5238.65
4916.08	4716.59
4848.67	2404.24
1624.01	159.16
2156.95	2032.03
1559.68	1559.63
4687.28	1686.36

Hazelwood Power

Standard Deviation	
Pre-Upgrade	Post-Upgrade
5124.37	2060.21
2006.48	1802.67
6752.37	4940.05
7002.29	5306.85
7044.59	5164.73
6456.27	5915.05
3233.27	2688.02
4325.08	4096.73
5042.88	3487.79
5916.72	1904.78
3397.63	1699.88
3225.8	1963.44
2726.61	1755.37
4576.48	3219.41
4881.83	4816.9
2692.45	2486.45
3147.01	2463.58
5364.13	4430.85
4303.48	3698.87
3757.74	1492.39
1125.11	81.62
1395.71	1393.68
882.96	882.67
3637.94	965.75

Yallourn Energy

Standard Deviation	
Pre-Upgrade	Post-Upgrade
3465.74	1935.72
2187.85	2008.42
6250.38	5338.99
7137.72	5653.54
5595.76	5223.12
7413.43	6723.92
4359.22	3719.07
4935.8	4727.34
5722.71	4398.76
4087.18	2078.2
3569.2	1665.23
3544.72	1721.45
2650.9	1830.61
4157.46	2778.85
3912.66	3881.83
1965.71	1891.93
2549.43	2233.64
4539.25	3825.26
3589.51	2509.39
3856.03	734.2
100.62	72.53
1274.89	1274.15
881.86	881.7
2930.89	635.88

NRG Flinders

Standard Deviation	
Pre-Upgrade	Post-Upgrade
701.09	677.78
124.33	101.63
122.48	39.01
560.94	544.96
742.74	348
84.79	21.97
82.05	25.7
81.24	21.59
84.02	18.13
77.13	23.65
79.83	24.88
99.59	24.39
74.78	29.2
190.14	183.68
1010.86	1008.58
92.72	75.32
83.82	52.61
1181.16	1179.43
218.94	198.42
1584.24	1583.65
1852.07	149.46
2628.49	2425.43
3614.47	1774.5
2730.14	2261.17

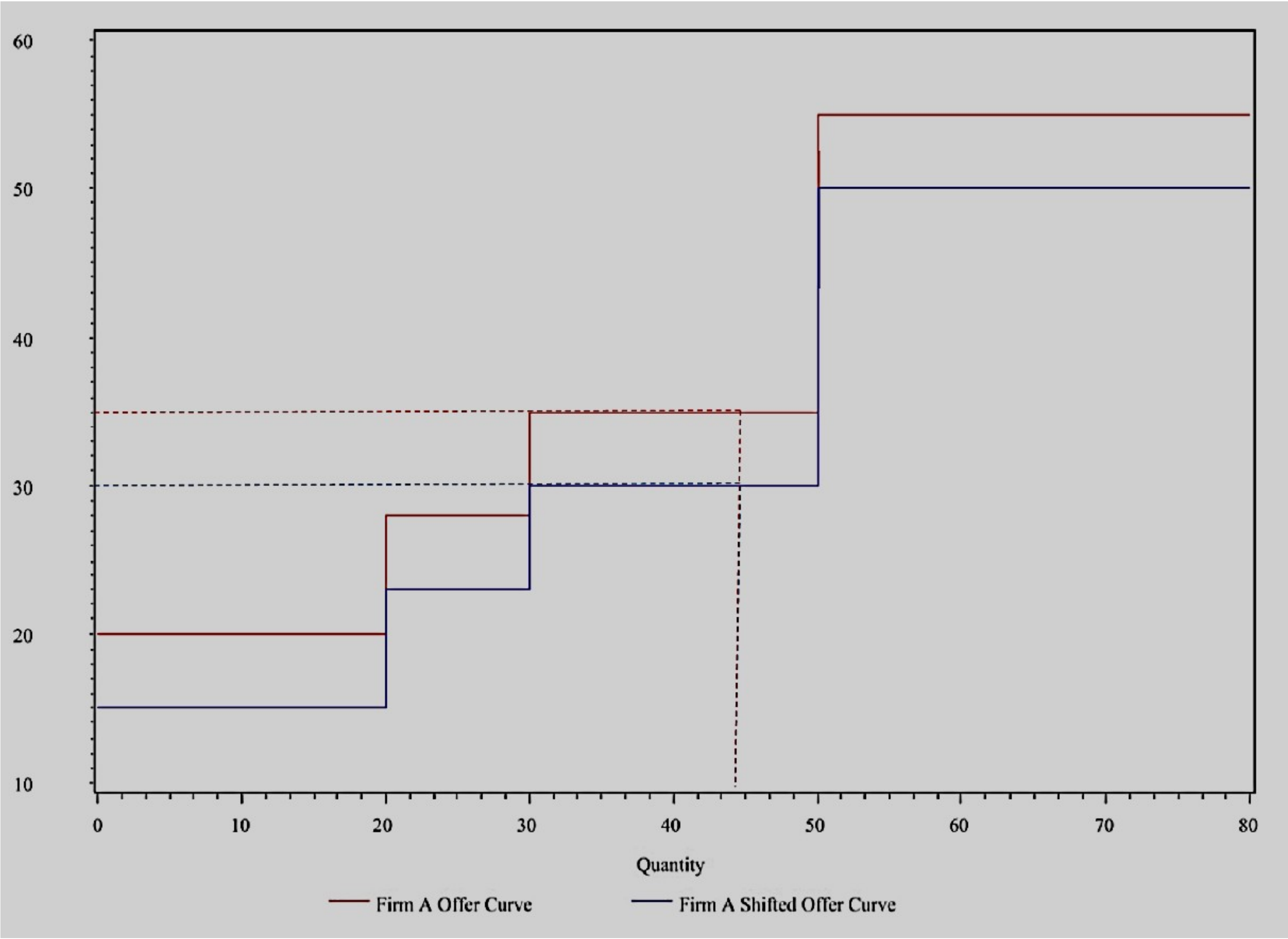
TXU Pty. Ltd.

Standard Deviation	
Pre-Upgrade	Post-Upgrade
752.6	605.54
267.82	126.49
240.34	68.78
408.28	324.57
617.31	448.76
88.49	18.15
68.08	12.49
39.13	12.56
20.32	8.46
16.24	6.7
19.11	11.85
34.71	11.94
262.86	18.33
284.11	235.54
1390.98	1380.91
546.82	80.74
298.97	86.32
2358	2330.26
1076.09	183.83
1596.89	1392.72
5756.28	215.33
9319.36	2685.85
3218.25	1202
4379.85	2372.84

Note that Standard Deviation (SD) of η(Feasible) >> SD of η(Upgrade)

Actual Network and Upgraded Network Offer Curves

Actual Network (Red) and Upgraded Network (Green) Prices Offer Curves for Strategic Supplier in VIC and SA



Quantifying Competitiveness for Benefits Australian Wholesale Market

- Compute three market-clearing prices using actual or reduced congestion offer curves for strategic suppliers and original offer curves for other suppliers, with and without transmission upgrade
  - Predicted Network price--PP_h
    - Solve 5-minute dispatch model with *actual offer curves* for all suppliers using *actual transmission network*
  - Perceived Reduced Congestion Network price--PC_h^F
    - Solve 5-minute dispatch model with *reduced congestion offer curves* for strategic suppliers and actual offer curves for all others using *actual transmission network*
  - Upgraded Network price--PC_h^U
    - Solve 5-minute dispatch model with *reduced congestion offer curves* for strategic suppliers and actual offer curves for all others using *upgraded transmission network*

Quantifying Competitiveness Benefits

- PP_h = Predicted price using actual offers for all suppliers and actual configuration of transmission network
- PC_h^F = Feasible counterfactual price using perceived reduced congestion offer curves for strategic suppliers with actual transmission network
- PC_h^U = Upgraded counterfactual price using perceived reduced congestion offer curves and upgraded transmission network
- QD_h = Quantity demanded
- Absolute consumer benefits (change in wholesale energy costs) in Australian dollars

$$\Delta R_h^F = (PP_h - PC_h^F)QD_h \text{ and } \Delta R_h^I = (PP_h - PC_h^U)QD_h,$$

- Relative consumer benefits (change in wholesale energy costs as percent of total wholesale energy costs) over time horizon H

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

Quantifying Competitiveness for Benefits Australian Wholesale Market

- Difference between Predicted price and Perceived Reduced Congestion price is pure competitiveness benefits of upgrade
- Difference between Predicted price and Upgraded Network Price is combined competitiveness and increased transmission capacity benefits of upgrade
- Difference between Perceived Reduced Congestion price and Upgraded Network price is pure increased transmission capacity benefits of upgrade with reduced perceived congestion offers

Quantifying Competitiveness Benefits

Annual Revenue Differences for Predicted (PP), Feasible Perceived Reduced Congestion Counterfactual (PC^F), and Upgraded Counterfactual (PC^U) Prices in Millions of Australia Dollars

Year	Region	$(PP - PC^F)QD$	$(PP - PC^U)QD$	$(PC^F - PC^U)QD$
2008	NSW	2.08	18.70	16.62
	QLD	0.71	9.78	9.06
	SA	105.25	-234.78	-340.02
	TAS	0.52	3.59	3.06
	VIC	74.18	1204.44	1130.26
	Totals	**182.74**	**1001.72**	**818.98**
2009	NSW	30.29	60.91	30.62
	QLD	8.35	41.79	33.44
	SA	63.64	171.74	108.09
	TAS	0.98	5.22	4.24
	VIC	55.08	27.02	-28.06
	Totals	**158.35**	**306.67**	**148.32**
2010	NSW	2.77	9.73	6.96
	QLD	1.03	4.03	2.99
	SA	55.64	-1.27	-56.91
	TAS	0.48	1.51	1.03
	VIC	89.54	216.77	127.23
	Totals	**149.46**	**230.77**	**81.31**

Quantifying Competitiveness Benefits

Annual Revenue Differences for Predicted (PP), Feasible Perceived Reduced Congestion Counterfactual (PC^F), and Upgraded Counterfactual ((PC^U) Prices as a fraction of Predicted Total Wholesale Market Revenues

Year	Region	$(PP - PC^F)QD$ as a fraction of predicted total wholesale energy revenues	$(PP - PC^U)QD$ as a fraction of predicted total wholesale energy revenues	$(PC^F - PC^U)QD$ as a fraction of predicted total wholesale energy revenues
2008	NSW	0.000	0.002	0.002
	QLD	0.000	0.002	0.002
	SA	0.039	-0.086	-0.125
	TAS	0.001	0.006	0.005
	VIC	0.007	0.108	0.101
	Totals	0.007	0.038	0.031
2009	NSW	0.003	0.006	0.003
	QLD	0.004	0.018	0.014
	SA	0.052	0.140	0.088
	TAS	0.002	0.009	0.008
	VIC	0.016	0.008	-0.008
	Totals	0.009	0.017	0.008
2010	NSW	0.001	0.002	0.002
	QLD	0.001	0.003	0.002
	SA	0.111	-0.003	-0.113
	TAS	0.001	0.004	0.003
	VIC	0.046	0.110	0.065
	Totals	0.017	0.027	0.010

Conclusions from Analysis

- Competitiveness benefits vary significantly across years
  - Major benefits come during periods when suppliers have the greatest ability to exercise unilateral market power
  - High offer price cap in Australia market makes competitiveness benefits of upgrades larger
- Annual consumer competitiveness benefits of Heywood upgrade are between $182 to $142 million
- Annual total (competitiveness + upgrade) consumers benefits of Heywood upgrade are between $1 billion and $230 million
- Across three years of sample, competitiveness benefits are 1 percent of predicted total wholesale energy purchase costs
- Across three years of sample, total consumer (competitiveness + upgrade) benefits are 3 percent of total wholesale energy purchase costs

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 $\ln(P_h/PC_h^F)$ and $\ln(P_h/PC_h^I)$ on ln(system-wide wind output) and ln(system-wide demand) and hour-of-day fixed effects for VIC and SA (where wind units are located)
  - In both cases, coefficient on log of hourly wind output is negative and precisely estimated, indicating the lower levels of wind output predict higher levels of hourly "competitiveness benefits"
  - Coefficient on log of hourly system demand is positive, indicating higher competitiveness benefits at higher levels of system demand
- Results suggest that both more volatile demand and wind output both increase competitiveness benefits of increased transmission capacity
  - Increasingly important source of benefits of upgrades with greater renewable energy share

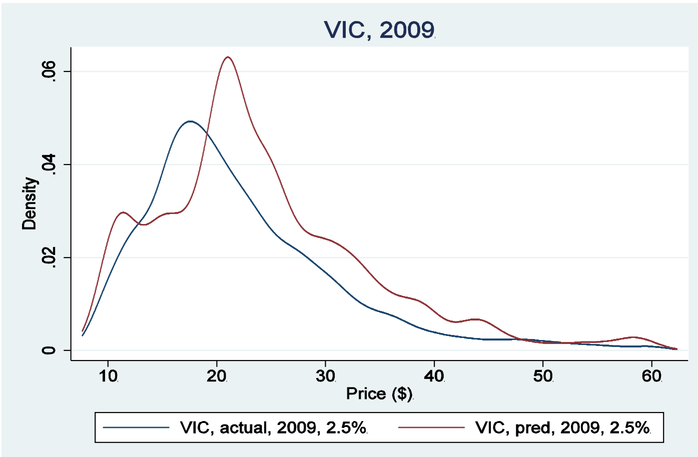
Conclusions

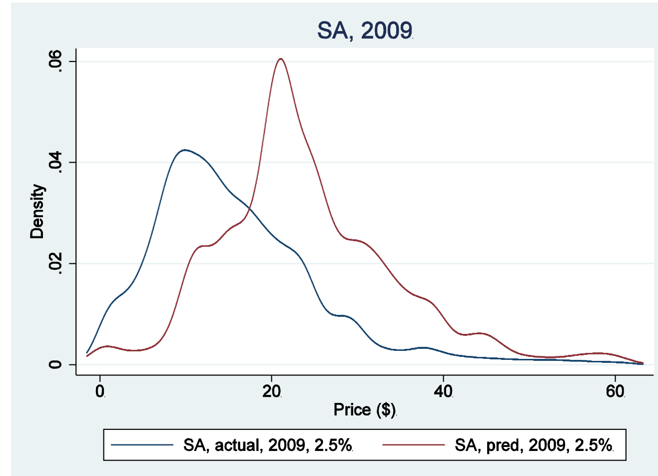
- Transmission expansions increase competition suppliers face, which causes a strategic supplier to submit an offer curve closer to its marginal cost curve
  - This yields market prices closer to competitive benchmark levels
- Competitiveness benefits of transmission expansions in Australian market can be substantial
  - Offer cap of $AU 13,100/MWh increases magnitude of benefits
  - Many transmission expansion can pay for themselves through reduced wholesale energy purchase costs
- 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
    - See Wolak (2011) “Measuring the Competitiveness Benefits of a Transmission Investment Policy: The Case of the Alberta Electricity Market” on web-site
- Methodology can be applied to any bid-based wholesale electricity market and any combination of proposed transmission upgrades
  - Need to know market model, configuration of transmission before and after upgrade, offer curves, and market demand and prices

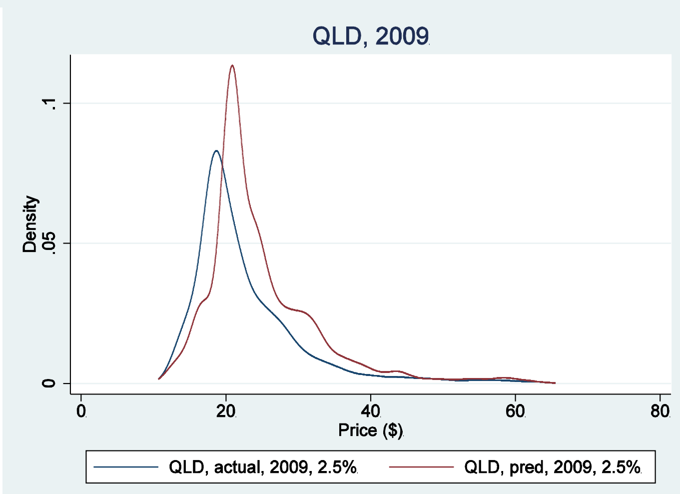
Frank A. Wolak
Department of Economics
Stanford University
Stanford, CA 94305-6072
wolak@zia.stanford.edu

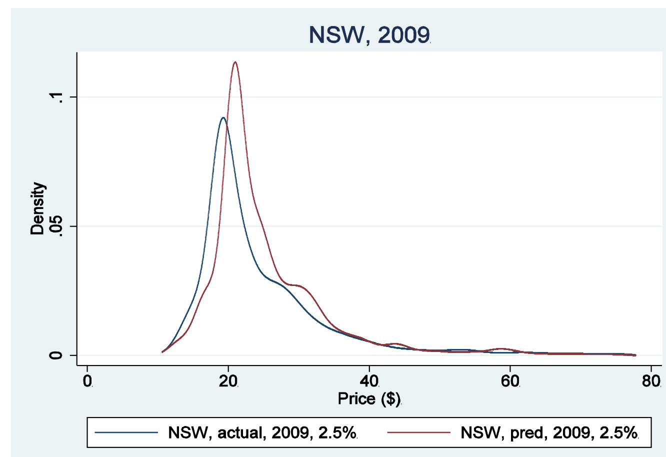
Related papers available from
http://www.stanford.edu/~wolak

Predicted versus Actual Prices



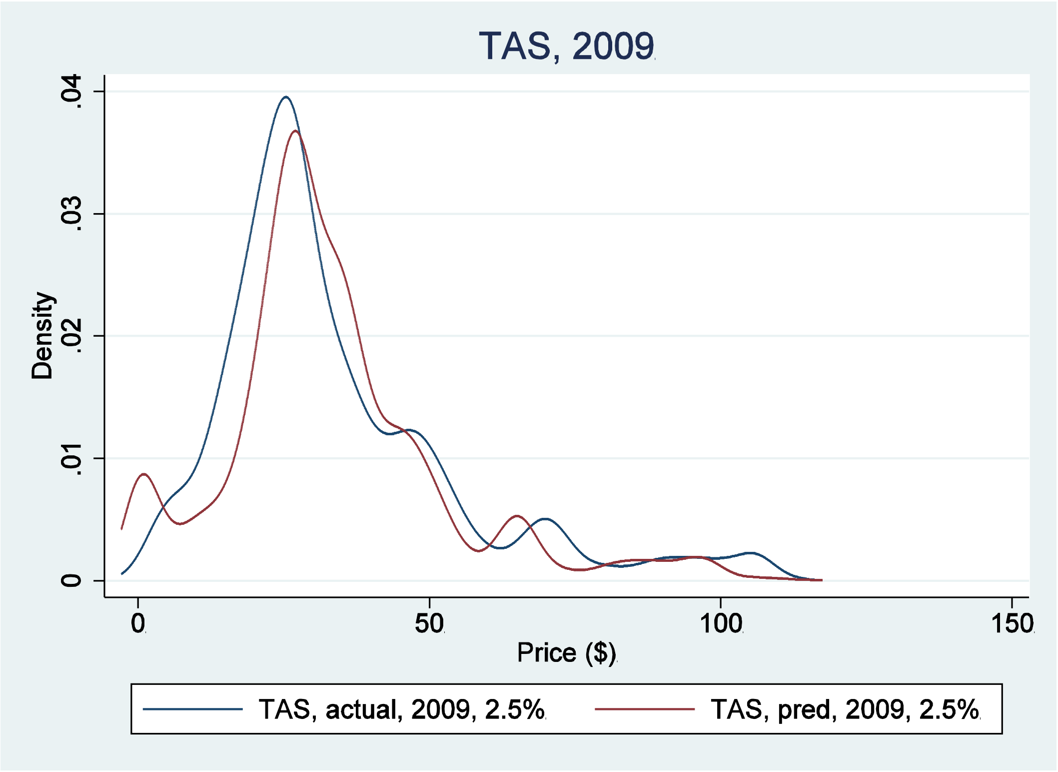






Except for a few extreme half-hours dispatch model is able to predict actual prices well

Predicted versus Actual Prices



Except for a few extreme half-hours dispatch model is able to predict actual prices well

Joint Density of Offer Prices and Shape of Residual Demand Curve

- What does offer price regression estimate?
- During sample period, there is a joint density of (P_{hn} ,η_{hn}^F) given day of sample and hour-of-day for each supplier
- From $f(P_{hn}, \eta_{hn}^F | d,h)$ can derive $BLP(P_{hn}|\eta_{hn}^F,d,h) = a(d,m) + b(h) + c^* \eta_{hn}^F$, the best linear predictor function of the offer price given the inverse elasticity for day of sample d and hour of day h
- OLS yields consistent estimate of the parameters of this function that given best prediction of offer price given inverse elasticity for population joint density
- Important note—This relationship is not causal for reasons discussed in Wolak (2003) and (2007), but is a valid predictive relationship given existence of $f(P_{hn}, \eta_{hn}^F | d,h)$