Imperfect Markets versus Imperfect Regulation in US Electricity Generation

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Context

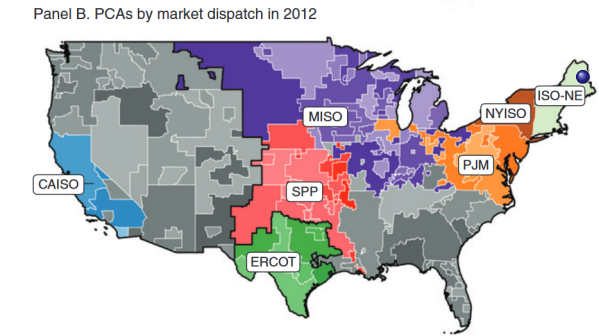
US electricity grid consists of power-control-areas (PCAs).

- Before: monopoly or balancing authority controls transmission line.
- Treatment: local PCA cedes controls of transmission to independent system operator and then participants wholesale electricity market where price is determined by a centralized auction.
  60% of US installed power capacity has been market-based dispatch by 2012.

Research Question

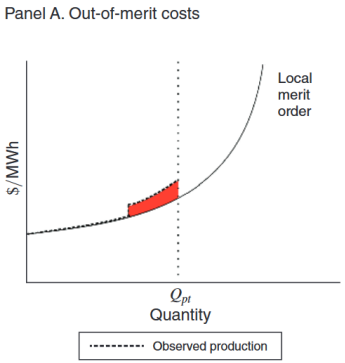
- Compare costs & benefits between **"Regulation"** and **"Market"** in US electricity Market. **Market efficiency** vs. **Market power**
  - Generation costs
  - Trade gains
- DID, Treatment: market liberalization (11 events).

Identification Challenge



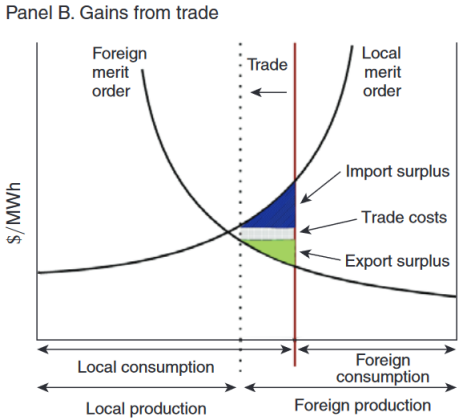
- PCAs are not segmented. $\Rightarrow$ trade leads to biased estimates.
- Decompose generation cost:
  - Out-of-merit order costs
  - Gains from trade

Out-of-merit Order



- Q_{pt}: generation of PCA p in hour t.
- Observed Costs: $C_{pt}(Q_{pt}) = \sum_{i=0}^{N_{pt}} c_{pt}(i) q_{pt}(i)$.
- Merit Order Costs: $C^*_{pt}(Q_{pt}) = \sum_{i=0}^{Q_{pt}} c_{pt}(i)$.
- Out-of-Merit costs: a unit is used to meet demand but while there is cheaper alternative. $O_{pt}(Q_{pt}) = C_{pt}(Q_{pt}) - C^*_{pt}(Q_{pt})$.

Gains from Trade



- L_{pt}: load of PCA p in hour t.
- $G^*_{pt}(L_{pt}, Q_{pt}) = C^*_{pt}(L_{pt}) - C^*_{pt}(Q_{pt}) + c_{pt}(i = Q_{pt}) * [(Q_{pt} - L_{pt}]$.
- Gray area: transmission costs

Production Cost Decomposition

$$\sum_p C_{pt}(Q_{pt}) = \sum_p O_{pt}(Q_{pt}) - \sum_p G^*_{pt}(L_{pt} + Q_{pt}) + \sum_p C^*_{pt}(L_{pt}) + \sum_p [c_{pt}(i = Q_{pt}) - c_t(i = Q_t)] * [Q_{pt} - L_{pt}] \quad (1)$$

Data

- Hourly unit-level generation and load from 1999-2012, for 98 PCAs.
- Fuel costs
- Capacities
- Heat efficiency
- Out-of-merit calculated by original data

Methodology

Difference-in-difference (DD):

$$y_{pt} = \tau D_{pt} + \gamma_{pm} + \delta_{tr} + \lambda_{pm} Log(L_{pt}) + \kappa_{pm} Log[C^*_{pt}(L_{pt})] + \eta \chi_{pt} + \varepsilon_{pt} \qquad (2)$$

y_{pt}

- log(gains from trade)
- log(out-of-merit costs)
- log(trade volume)
- log(MWh out-of-merit)

Randomization

TABLE 1—SUMMARY STATISTICS FOR POWER CONTROL AREAS BY EVENTUAL MARKET ADOPTION

	1999			2012		
	Adopt markets	No markets	Difference of means	Adopt markets	No markets	Difference of means
Quantities (*GWh*)						
Load	10.98	9.94	1.03	11.83	10.94	0.90
	[8.72]	[7.45]	(0.90)	[9.24]	[8.20]	(0.98)
Generation	10.50	10.49	0.01	11.08	11.63	−0.54
	[8.59]	[7.93]	(0.94)	[8.98]	[8.90]	(1.02)
Net trade volume	1.27	1.49	−0.23	1.76	1.49	0.28
	[1.31]	[2.03]	(0.13)	[1.79]	[2.17]	(0.16)
Out-of-merit Generation	2.43	2.07	0.37	2.69	3.04	−0.36
	[1.98]	[1.87]	(0.22)	[2.10]	[2.60]	(0.28)
Observations	525,600	332,880	1,719,312	527,040	333,792	1,719,312
Costs (*thousands of US$*)						
Observed	136.55	116.72	19.83	192.38	202.68	−10.30
	[122.39]	[102.32]	(12.09)	[170.39]	[178.21]	(19.57)
Out-of-merit Costs	29.63	19.24	10.38	37.30	41.92	−4.62
	[38.55]	[19.54]	(3.40)	[44.47]	[40.00]	(4.65)
Gains from trade	2.56	3.84	−1.27	8.74	6.45	2.29
	[10.36]	[10.46]	(0.57)	[54.80]	[30.43]	(2.44)

Result I

Panel B. log(gains from trade)				
Market dispatch	0.448	0.461	0.470	0.437
	(0.071)	(0.072)	(0.066)	(0.065)
First neighbor				0.032
Market dispatch				(0.079)
Second neighbor				0.011
Market dispatch				(0.072)
$log(L_{pt})$		Yes	Yes	Yes
$log\left(C^{*}_{pt}(L_{pt})\right)$			Yes	Yes
Clusters	16,412	16,412	16,412	16,412
PCAs	98	98	98	98
R^2	0.501	0.559	0.582	0.583
Observations	8,475,828	8,475,828	8,475,828	8,475,828
Panel C. log(out-of-merit costs)				
Market dispatch	−0.130	−0.114	−0.155	−0.180
	(0.029)	(0.028)	(0.025)	(0.026)
First neighbor				−0.008
Market dispatch				(0.032)
Second neighbor				−0.009
Market dispatch				(0.025)
log(load)		Yes	Yes	Yes
log(load merit cost)			Yes	Yes
Clusters	16,437	16,437	16,437	16,437
PCAs	98	98	98	98
R^2	0.862	0.870	0.879	0.880
Observations	11,618,837	11618,837	11,618,837	11,618,837

- gains from trade: 55% increase = 44 log points
- out-of-merit costs reduction: 16% = 18 log points
- $log(y) - log(x) = \tau \Rightarrow \frac{y-x}{x} = e^{\tau} - 1$

Result II

- trade volume: 25% increase
- out-of-merit production reduction: 5%

TABLE 3—IMPACT OF MARKET DISPATCH ON QUANTITIES

	(1)	(2)	(3)	(4)
Panel A. log(trade volume)				
Market dispatch	0.168	0.149	0.211	0.226
	(0.033)	(0.033)	(0.031)	(0.031)
First neighbor				0.044
Market dispatch				(0.036)
Second neighbor				0.009
Market dispatch				(0.032)
$log(L_{pt})$		Yes	Yes	Yes
$log(C^*_{pt}(L_{pt}))$			Yes	Yes
Clusters	16,464	16,464	16,464	16,464
PCAs	98	98	98	98
R^2	0.537	0.568	0.584	0.585
Observations	12,004,719	12,004,719	12,004,719	12,004,719
Panel B. log(MWh out-of-merit)				
Market dispatch	−0.072	−0.073	−0.054	−0.055
	(0.013)	(0.013)	(0.013)	(0.014)
First neighbor				−0.023
Market dispatch				(0.016)
Second neighbor				0.026
Market dispatch				(0.013)
$log(L_{pt})$		Yes	Yes	Yes
$log(C^*_{pt}(L_{pt}))$			Yes	Yes
Clusters	16,440	16,440	16,440	16,440
PCAs	98	98	98	98
R^2	0.890	0.896	0.901	0.901

Wrap-up

- This papers quantifies the effect of adopting market-based dispatch compared to monopolistic dispatch with regulation.
- Results support market liberalization:
  - 16% reduction in out-of merit costs,
  - increasing gains from trade by 55%,
  - a reduction in production costs of between \$3 and \$5 billion per year $\approx 5\%$ total variable cost reduction.

Reference

Cicala, S. (2022). Imperfect markets versus imperfect regulation in US electricity generation. American Economic Review, 112(2), 409-441.