The Changing (and Exciting!) Economics of Electricity Markets

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ARE 264

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The U.S. Electricity Market is Big (by any measure)

- $+$ 150 million utility customers (87% are residential).
- In 2019, net generation of electricity from utility-scale generators in the United States was about 4.1 trillion kilowatthours (kWh) with an additional 0.02 trillion kWh generated by distributed, small-scale solar PV 'prosumers'.
- Revenues from the sale of electricity exceeded $400 billion annually.
- Electricity sector CO_2 emissions account for 26% of the total U.S. energy-related CO2 emissions).

A number of factors are transforming electricity markets

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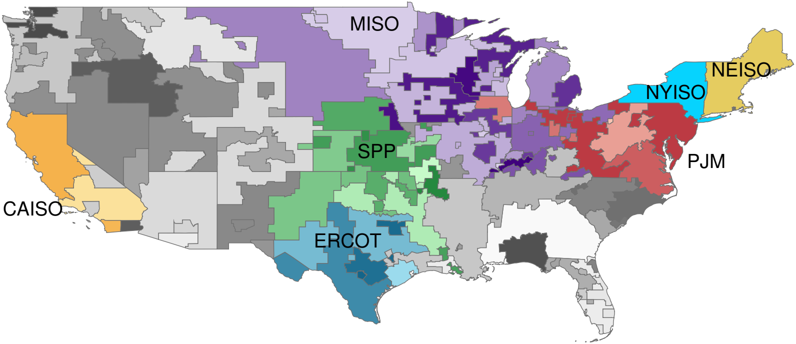
Industry restructuring

(b) PCAs by Market Dispatch in 2012

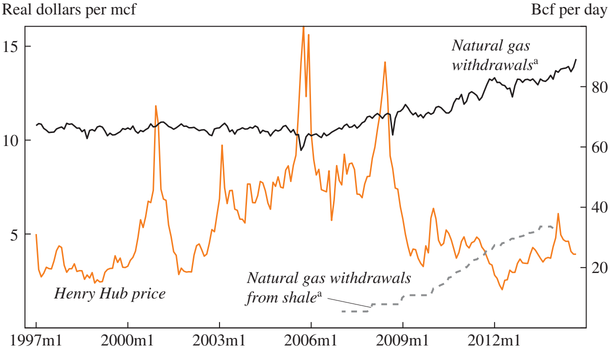


Source: Cicala, 2017

Electricity sector restructuring transformed electricity markets in the 1990s and 2000s.

Shale Gas Boom!

Figure 1. U.S. Natural Gas Production and Price, 1997–2015



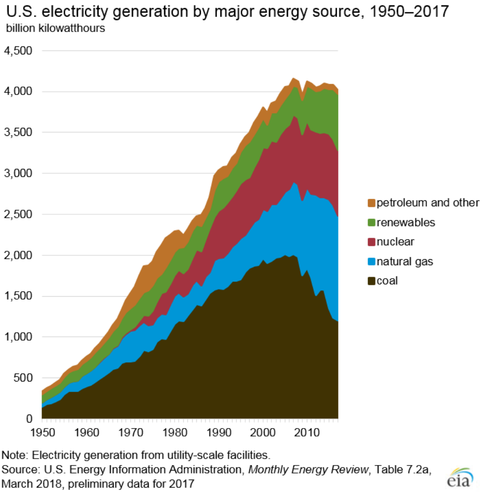
Source: EIA.

a. Gross withdrawals include not only marketed production, but also natural gas used to repressure wells, vented and flared gas, and nonhydrocarbon gases removed.

Source: Hausman and Kellogg, 2017

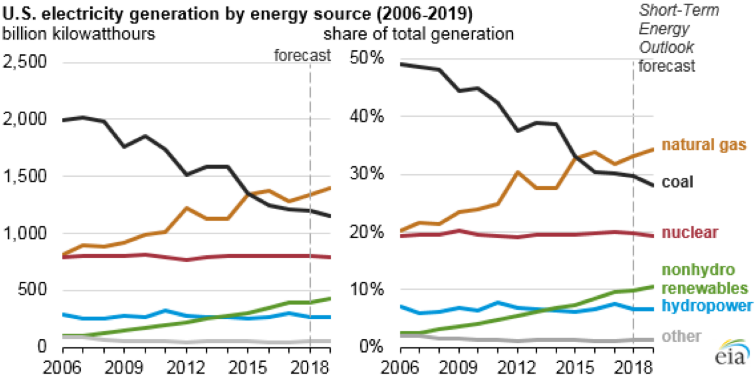
With sustained growth in extraction, domestic natural gas prices have fallen substantially. This has had big implications on electricity generation.

The Fall of Coal

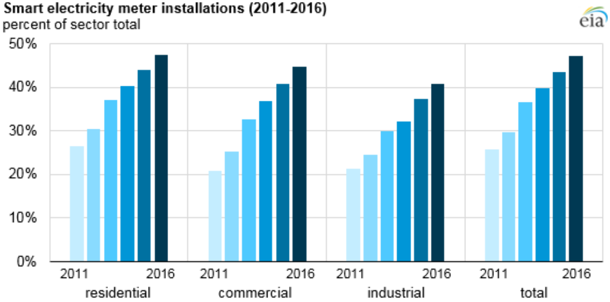


Source: EIA 2018.

The Rise of Renewables



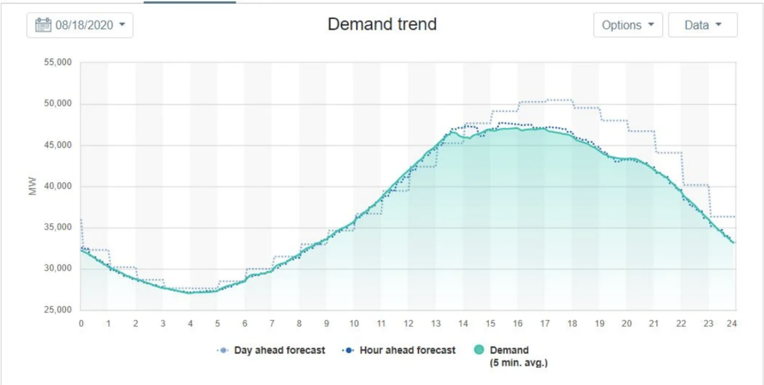
A Smarter Grid



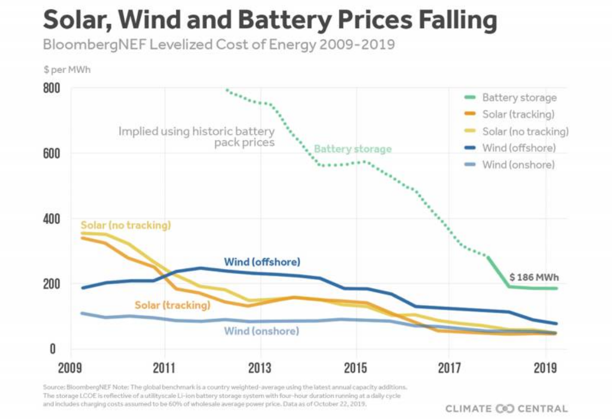
Source: EIA, 2017

Increasing penetration of smart meters/AMI.

Increasing role of demand response



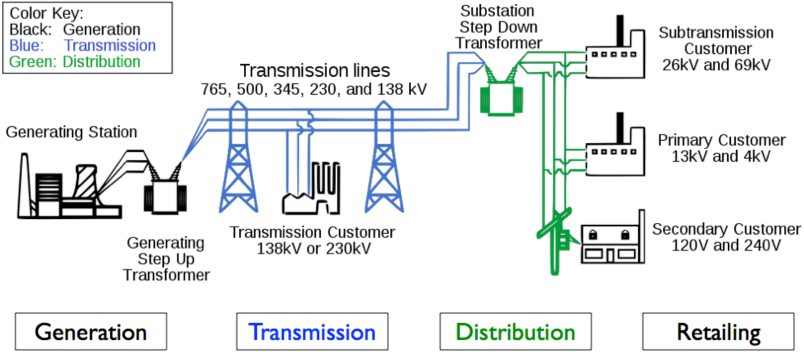
Plummeting Storage Costs



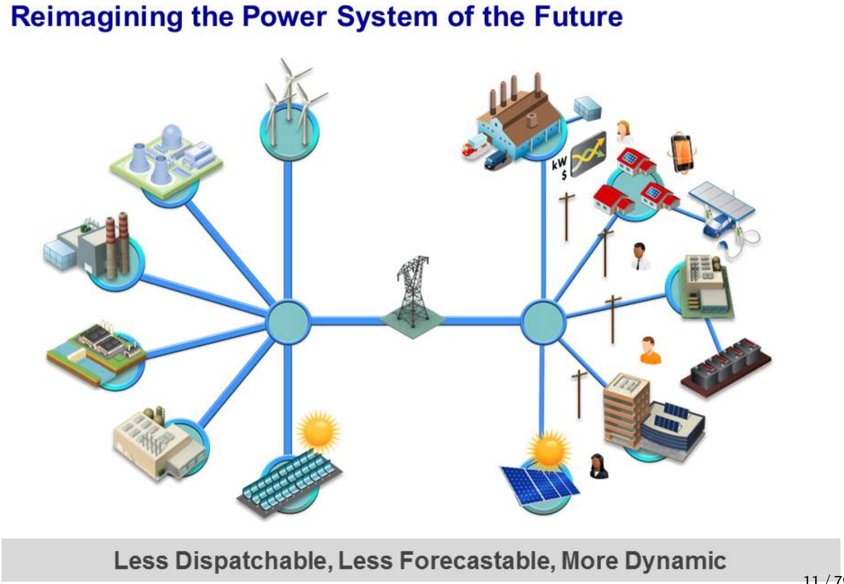
Source: The Economist 2017

The falling costs of storage have the potential to be transformative.

Electricity sector 1.0



Fundamental transformation of electricity markets as we know (and model!) them...



This seems complicated. Why study electricity markets?

1. The economics of electricity markets are compelling and substantive.
2. Rich, detailed, public data: Hourly production, hourly emissions, sub-hourly market prices, input costs, high-frequency consumer data, etc.
3. Electricity markets matter! Big questions about the regulatory, policy, and market reforms that willl guide the evolution of electricity markets over the next decade.
4. The most promising path to deep decarbonization runs through the power sector. If you want to understand the economics of decarbonization, you need to understand electricity markets.

How do we study electricity markets?

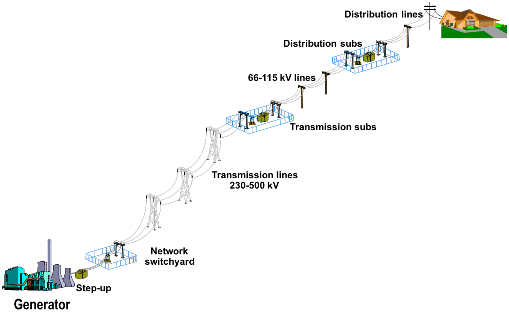
Many methods used:

- Field experiments
- Quasi-experiments: panel data/DID/IV
- Computational/calibrated models
- Structural estimation

Section 1

Electricity Sector Restructuring

Electricity Market Basics



- The U.S. electricity sector was historically comprised of Investor Owned Utilities (IOUs), government-owned utilities, and non-profit cooperatives.
- All were vertically integrated (generation, transmission, distribution) and served exclusively operated territories.

Old model: Vertically integrated and regulated natural monopoly

- Under rate-of-return regulation, vertically integrated regulated monopolies recover operating costs and earn a rate of return on capital investment.
- Balancing authorities determine which power plants meet demand using engineering-based dispatch algorithms.
- This regulatory environment guarantees cost recovery and resource adequacy.. but weak incentives to invest and operate efficiently..

Electricity sector restructuring

Regulatory restructuring has transformed the U.S. electricity sector over the last 3 decades.

Electricity sector restructuring

Regulatory restructuring has transformed the U.S. electricity sector over the last 3 decades.

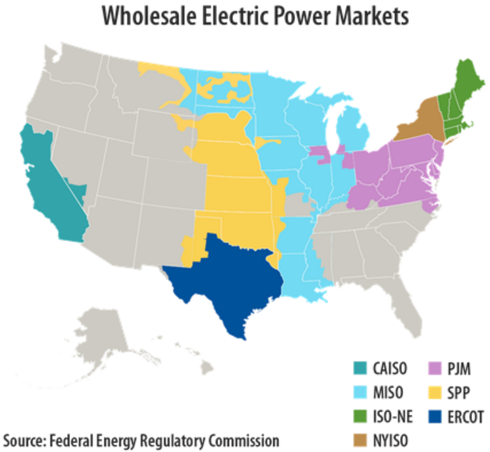
1. Creation and expansion of Regional Transmission Organizations (RTOs) to promote non-discriminatory access and facilitate market-based dispatch.
2. Energy market restructuring: Move away from compensation based on cost recovery towards payment based on the market value of electricity produced.

The hope: Discipline of the competitive market would provide powerful incentives for efficiency improvements.

U.S. Electricity sector restructuring

- The deregulation process separated electricity generation, which most economists believe is potentially competitive, from transmission and distribution.
- Wholesale electricity markets were established in several different regions, and these markets facilitated the growth of independent power producers.
- In many cases, incumbent utilities required to sell part of their existing electric generating portfolios.

A large scale market design experiment!



Markets are run by independent system operators using competitive market mechanisms to coordinate dispatch (and investment to a lesser extent).
Gray area: Vertically-integrated utilities are responsible for the entire flow of electricity to consumers.

A large scale market design experiment!

- In theory, competition provides incentives for firms to increase efficiency (on both operating and investment margins).
- Quasi-random(?) piecemeal restructuring provides an opportunity to test theory.
- A broad literature investigates this market transformation both from a theoretical and empirical perspective.
- If you were analyzing the impacts of electricity industry restructuring, what kinds of efficiency gains (or losses) might you focus on?

Causal inference meets electricity sector restructuring

A large empirical literature investigates the causal impacts of restructuring on..

Causal inference meets electricity sector restructuring

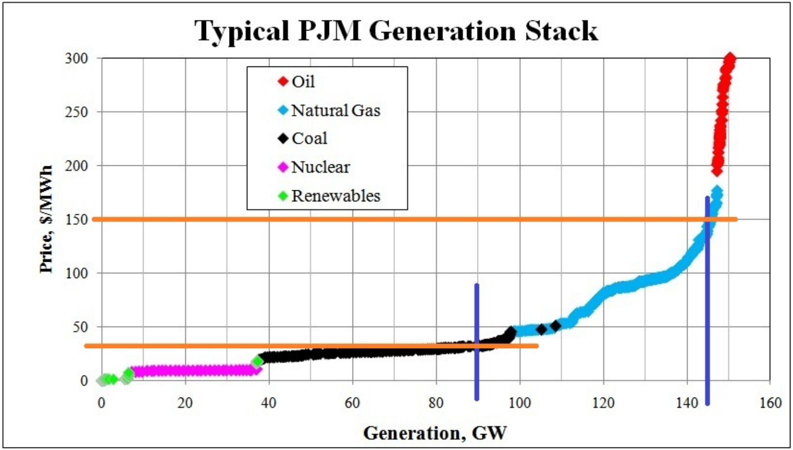
A large empirical literature investigates the causal impacts of restructuring on..

- Market competitiveness
- Plant-level outcomes: fuel efficiency, operating efficiency
- System-level efficiency (e.g. efficient dispatch?)
- Investment (much harder... why?)
- Retail prices
- Environmental performance

Market power in power markets - a rich literature..

- Markups and conduct, incentives and ability to exercise market power Wolfram (1999), Puller (2007), McRae and Wolak (2012)
- Market performance in deregulated wholesale markets Borenstein, Bushnell, Wolak (2002), Wolak (2007), BMS (2008), Mansur (2008)
- Using auction data/framework
- Wolak (2000), Hortascsu and Puller (2008), Reguant (2014)
- Sequential markets, financial traders Saravia (2003), BBKW (2007), Jha and Woalk (2016), Ito and Reguant (2016), Mercadal (2016)

Why has market power been a concern?



Some lessons learned?

- We have seen the exercise of market power in wholesale electricity markets during high-demand hours.
- Long-term contracts between wholesale buyers and sellers mitigate the exercise or market power. (Why?)
- Real-time pricing of electricity can also mitigate market power distortions. (Why?)
- Capacity investments are critical, both transmission (electricity and natural gas), and generation. How to design competitive capacity markets?

What is the causal effect of electricity industry restructuring on....

- Market competitiveness
- **Plant-level outcomes: fuel efficiency, operating efficiency**
- System-level efficiency (e.g. efficient dispatch?)
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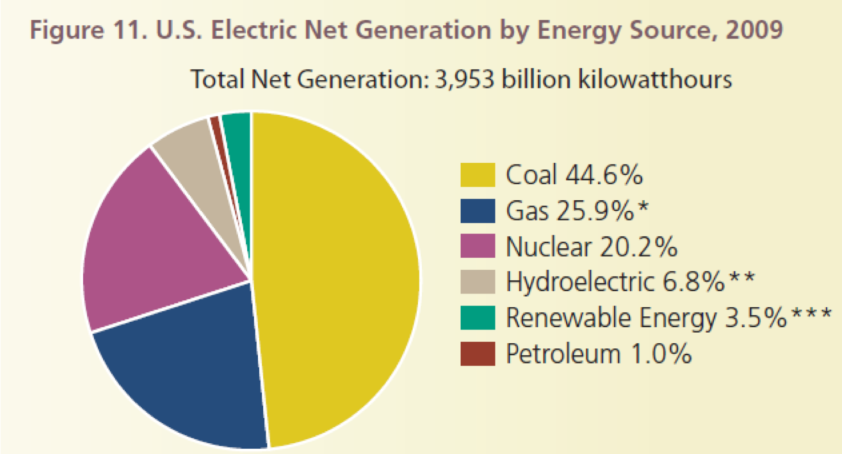
Impact on nuclear plant operations (Davis and Wolfram, 2012)



Identifying the effect of restructuring on nuclear plant operations

- Nuclear plants provide baseload power (no confounding demand shocks).
- There was essentially no entry or exit after deregulation.
- Prior to restructuring, approx. one nuclear plant per company
- After restructuring/divestitutre, three largest companies control one-third of U.S. nuclear capacity!

Empirical strategy exploits the fact that divestment occurred rapidly and is mostly (?) exogenous.

Balanced observables across treatment and control groups

TABLE 1
Comparing Divested With Non-Divested Nuclear Reactors

	(1) Reactors Divested 1999-2007 (n=48)	(2) All Other Reactors (n=55)	(3) *p*-value (1) vs (2)
Mean Reactor Characteristics			
Design Capacity (in MWe)	921.9	959.7	.38
Reactor Age as of December 1998	18.8	18.4	.74
Number of Reactors Operated by the Same Reactor Operator as of December 1998	2.7	2.8	.86
Original Construction Cost Per Kilowatt Capacity (in Year 2010 dollars)	$2,397	$2,298	.81
Reactor Type			
Pressurized Water Reactor	54%	78%	.01
Boiling Water Reactor	46%	22%	.01

Average treatment effects

Dependent variable is net generation as a percent of design capacity.

TABLE 2

The Effect of Divestiture on Nuclear Operating Efficiency

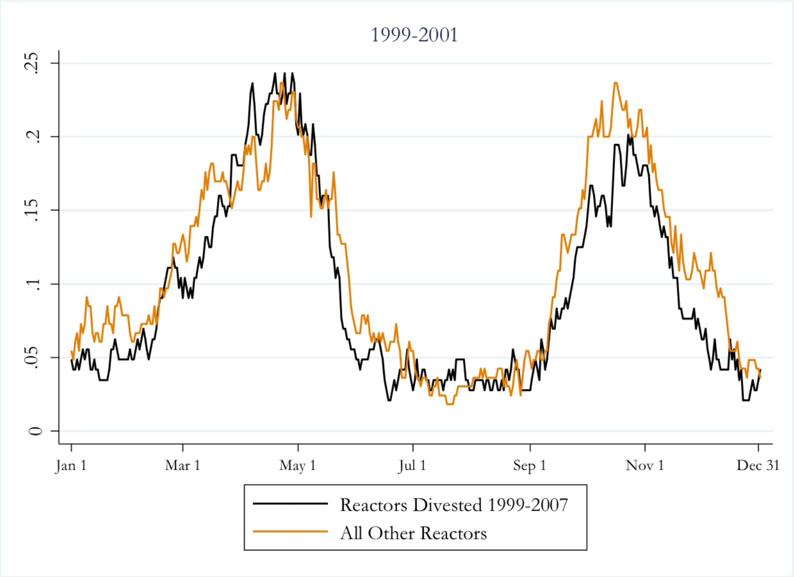
	(1)	(2)	(3)	(4)	(5)
$1[Divested]_{it}$	6.5**	10.4**	10.2**	10.2**	9.7**
	(1.2)	(2.1)	(2.0)	(2.0)	(2.0)
Month-of-Sample Fixed Effects (480 months)	Yes	Yes	Yes	Yes	Yes
Reactor Fixed Effects (103 reactors)	No	Yes	Yes	Yes	Yes
Reactor Age (cubic)	No	No	Yes	Yes	Yes
Observations Weighted By Reactor Capacity	No	No	No	Yes	No
Dataset Collapsed To Plant Level	No	No	No	No	Yes
Number of Cross Sectional Units	103	103	103	103	65
Number of Observations	36,667	36,667	36,667	36,667	23,796
R^2	.18	.22	.22	.22	.26

10 percent is a big deal!

- A 10.4 percentage point increase is 42 billion kilowatt hours annually.
- Approximately $2.5 billion US dollars worth of power annually
- Implies annual decrease of 38 million metric tons of carbon dioxide.
- More than all the electricity produced by U.S. wind and solar generation combined over this period.

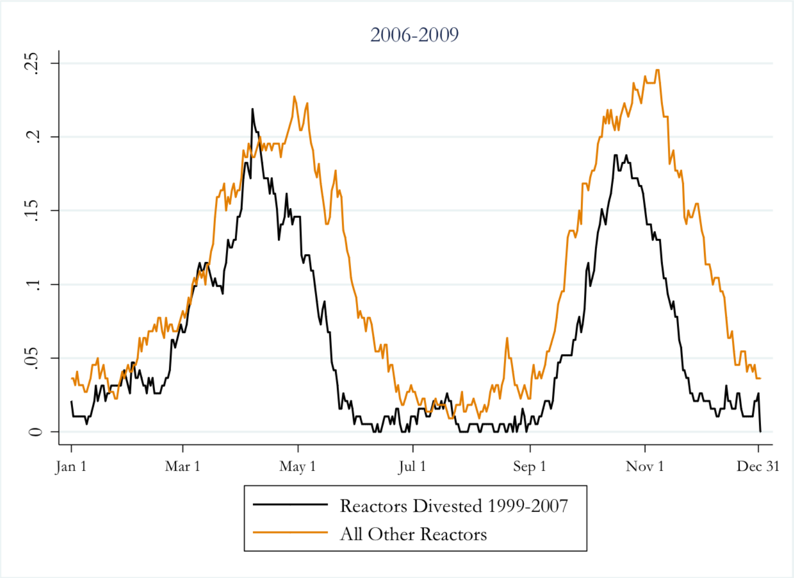
Pre-period outtages

Most important response margin: Plant outtages!



Post-period outtages

Most important response margin: Plant outtages!



Upshot

- Moving away from the traditional regulatory regime yielded efficiency gains in operating performance at nuclear plants.
- A broader lesson: Even modest improvements in operating efficiency can have substantial environmental implications when that technology represents a large share of total generation.
- A related and perhaps issue is the effect of restructuring on the risk of nuclear accidents. Paper presents weak evidence that one measure of reactor safety may have actually improved with divestiture,

What is the causal effect of electricity industry restructuring on...

- Market competitiveness
- Plant-level outcomes: fuel efficiency, operating efficiency
- **System-level efficiency gains?**
- Investment (much harder... why?)
- Retail prices
- Environmental performance

Cicala 2021

What does the paper do?

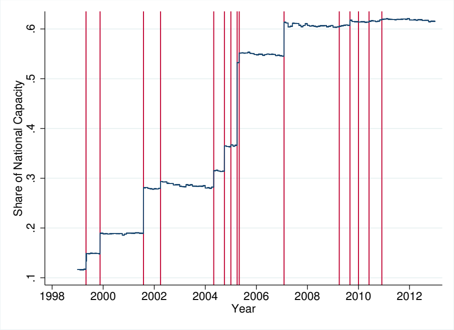
- Assess the welfare implications of transitions to market-based dispatch over the period 1999-2012.
    - Evaluates the efficiency implications of moving to a regime in which a wholesale electricity market plays a larger role in coordinating dispatch.
- Focuses exclusively on supply-side efficiency (Why ?)

Key findings?

- Estimated gains from trade increase by 55%.
- Costs from using uneconomical units fall 16%.

Effects of restructuring on system-wide efficiency?

Figure II: Share of Generating Capacity Dispatched by Markets



Note: Vertical red lines indicate dates of transition to market-based dispatch.

'The abrupt and staggered manner in which some PCAs adopted market mechanisms suggests that the impact of markets on costs can be evaluated with a difference-in-difference analysis.'

Heaps of great data

- Detailed hourly data on hourly plant operations, demand across the U.S. from 1999 - 2012.
- Unit-level data on fuel costs, capacities, heat efficiency, and operations which he uses to build supply curves for 98 power control areas.
- Observed dispatch of units to meet demand at every point in time.

Empirical framework

Treated areas: We observe 15 different events in which PCAs have transitioned to market-based dispatch between 1999-2012.

'Control' areas: Remaining areas (40% of generation capacity) stick with traditional dispatch methods for the duration.

Identification challenge : Estimate counterfactual unit-level operations/market dispatch using a rich characterization of 'control' areas to control for changes that might otherwise bias a simple DID comparison

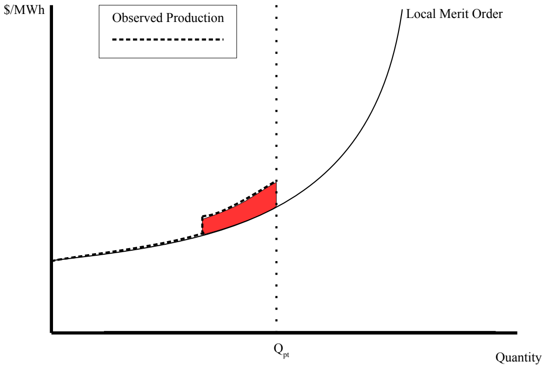
DID complications?

- SUTVA? Trading power between PCAs complicates comparisons across ‘treated’ and ‘control’ areas.
  - Changes in trade across treatment/control group will yield a biased estimate of the net impact of market-based dispatch on costs.
- Fuel price fluctuations over space and time can also confound comparisons across time and space.
  - Differences in fuel mix across areas mean that different areas would experience different fuel price cost shocks even absent treatment (parallel trends assumption not a safe assumption in this dynamic setting)

Production cost decomposition?

Compare observed generation costs against merit order benchmark

(A) Out of Merit Costs



Estimate 'out of merit' losses from dispatching higher marginal cost units. Concerns?

Out-of-merit costs as a welfare measure?

$$O_{pt} Q_{pt} = C_{pt}(Q_{pt}) - C^*_{pt}(Q_{pt})$$

- A static efficiency benchmark is constructed by estimating the variable operating costs of the electricity generating units supplying the market $C^*_{pt}(Q_{pt})$.
- This benchmark is used to approximate the cost minimizing allocation and to estimate "out of merit" dispatch.
- Past work (e.g. Mansur(2008), Reguant (2014)) show how comparing observed production against this static benchmark can generate misleading estimates.

Aside: Static efficiency benchmarks are becoming less relevant...

System cost decomposition

Decomposes observed costs into mutually exclusive components:

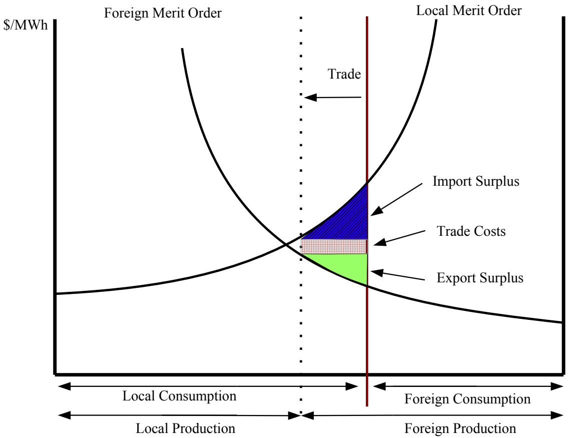
gate national quantity Q_t by adding up all active generation costs in hour t. By adding and subtracting the sum of merit order costs for each PCA's production ($C^*_{pt}(Q_{pt})$) and those under autarky ($C^*_{pt}(L_{pt})$), total costs over all PCAs become

$$\sum_p C_{pt}(Q_{pt}) = \underbrace{\sum_p \left[C_{pt}(Q_{pt}) - C^*_{pt}(Q_{pt})\right]}_{\text{Out of Merit Costs}} + \underbrace{\sum_p \left\{C^*_{pt}(L_{pt}) - \left[C^*_{pt}(L_{pt}) - C^*_{pt}(Q_{pt})\right]\right\}}_{\text{In Merit Costs Relative to Autarky}} \tag{2}$$

The first term holds each PCA's total production fixed, and aggregates out of merit costs as defined above. The second term measures the aggregated extent to which the merit order costs of the observed production quantities are below those of autarky. Let $c_t(i = Q_t)$ denote the marginal cost in the national merit

Gains from trade is the second key outcome

(B) Gains From Trade



Concerns with this gains from trade metric?

- Gains from trade are calculated as wedges measured on a PCA by PCA basis
- This approach ignores the full social implications of increased trade across regions.
- Emissions implications can be significant if older and under-utilized coal-fired generators increase their generation (and associated emissions) as a result of increased trade between areas.

DID specification

Using the out of merit cost and gains from trade metrics from Section II as outcomes, I estimate equations of the form

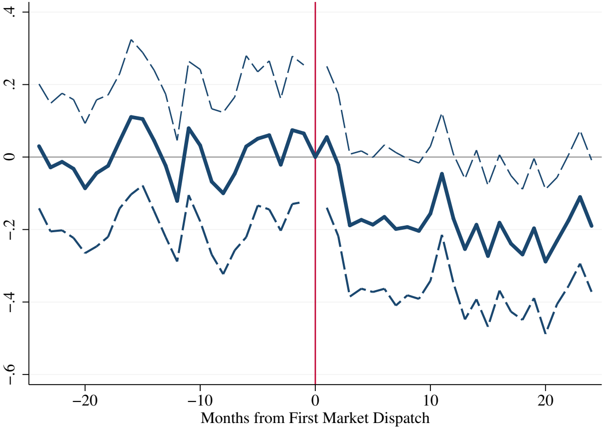
$$y_{pt} = \tau D_{pt} + \gamma_{pm} + \delta_{tr} + \lambda_{pm} Log\left(L_{pt}\right) + \kappa_{pm} Log\left[C^*_{pt}\left(L_{pt}\right)\right] + \eta\chi_{pt} + \varepsilon_{pt} \tag{6}$$

where y_{pt} is the logged value of the outcome variable for PCA p in date-hour t, and D_{pt} is an indicator of market dispatch. Separate fixed effects and slopes for load and merit order costs are estimated by PCA-month of year (i.e. New York in May). These account for the fact that PCAs vary in how they respond to load in a time-invariant manner, and that there are also persistent seasonal differences across areas, particularly with respect to how maintenance and refueling downtime

- Both gains from trade and out of merit costs depend critically on load (L) and the cost of meeting load according to the merit order, C*(L).
- τ measures the short-run average effect (ATT) of market dispatch on out of merit costs and gains from trade (conditional on identifying assumptions).

Out of merit costs

(B) *Log*(Out of Merit Costs)

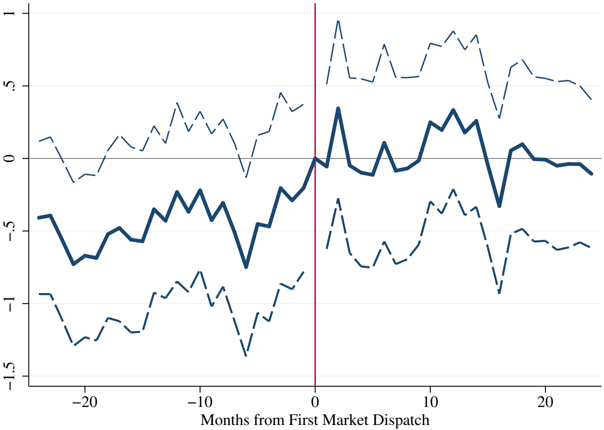


Note: These figures are based on regressing logged outcomes on a set of indicator variables for each month until (after) the transition to market dispatch. The specification corresponds with column (4) of Table 2, where observations are weighted by mean PCA load in 1999. The month prior to treatment is normalized to zero. 95% Confidence intervals in dashed lines are based on clustering at the PCA-month level.

Gains from trade

Figure 8. Treatment Effects by Months to Market: Gains from Trade and Out of Merit Costs

(A) *Log*(Gains from Trade)



Key findings

- Evaluates impacts of market-based dispatch on out of merit dispatch costs and gains from trade (relative to merit order).
- Estimates a 16% reduction in out of merit dispatch.
- Gains from trade increase 55%.
- Estimates savings of $\$3 - 5B$ per year (or 5% of variable operating costs).
- Can we extrapolate??

Electricity sector restructuring report card

Good news:

- Market prices close to short-run marginal cost much of the time.
- Power plants operating more efficiently
- System operators dispatching power plants more efficiently within and across control areas.

But what about reliability/resource adequacy?

- Can energy and ancillary service markets attract *sufficient and efficient* investment in generation/storage resources?
- How to design capacity markets?
- What are the implications of increased renewable energy/storage integration for wholesale electricity market design?

Section 2

Electricity Demand

Why might it be important to focus empirical attention on the demand side?

Implications for...

- Electrification!
- Demand response (resource adequacy, renewables integration)
- Impacts of carbon pricing (incidence)
- Price regulation
- Policy design for low-income programs

Where to find exogenous variation in electricity prices?

- Cross-sectional price variation between states, counties, and electric utilities.
- Price variation over time within a single electric utility
- Price variation in a non-linear price schedule

Concerns?

Where to find exogenous variation in electricity prices?

- Cross-sectional price variation between states, counties, and electric utilities.
- Price variation over time within a single electric utility
- Price variation in a non-linear price schedule

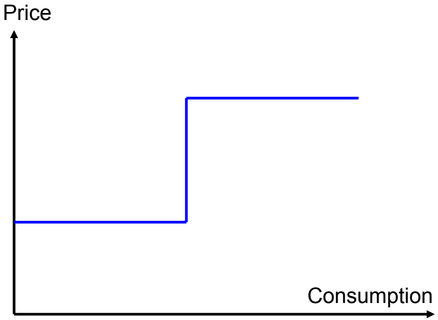
Concerns?

- Price variation by policy changes in a nonlinear price schedule
- Price variation across a spatial discontinuity (utility service areas)
- Experimental price variation in a RCT/RED

Block-rate electricity pricing

$$\ln x_{it} = \alpha + \beta \ln p_{ut}(x_{it}) + \varepsilon_{it}$$

- x_{it}: consumption of household i at time t
- p_{ut}: price schedule in electric utility u at time t

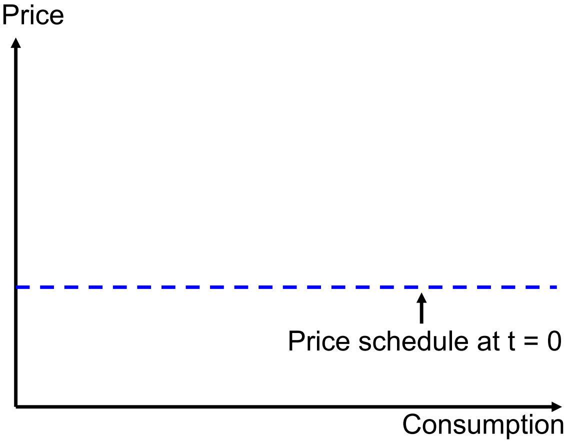


Marginal price is endogenous – determined by consumption choices.

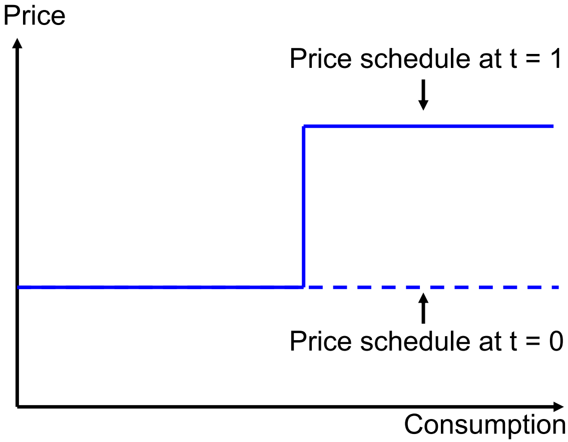
Simulated instruments?

- Nonlinear pricing presents an identification challenge – the price variables are partly determined by consumption and thus correlated with unobserved demand shocks.
- To address this endogeneity, past studies use policy-induced price changes.
- The 'simulated' instrument is the price change induced by a policy change in the non-linear price schedule for the consumption level x.

Simulated instrument?



Changes in price schedules can be used to estimate demand

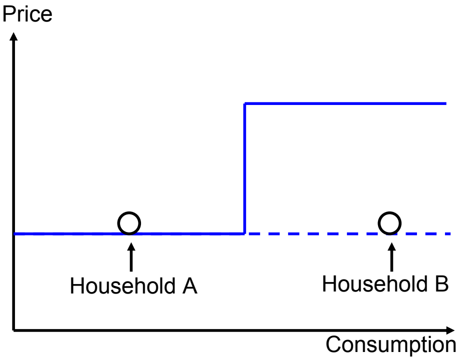


$$\triangle \ln x_{it} = \alpha + \beta \triangle \ln p_{ut}(x_{it}) + \varepsilon_{it}$$

- Previous studies use simulated instruments (policy-induced price changes):

$$\triangle \ln p^{PI}_{ut}(x_{it}) = \ln p_{ut}(x_{it_0}) - ln p_{ut_0}(x_{it_0})$$

- Typically, the first stage is very strong
- An identification assumption: a parallel trend between A and B



Why might parallel trends assumption be violated?

- There is natural mean reversion in household electricity consumption over time.
- Why? If households experience transitory consumption shocks — such as positive shocks from having visitors or negative shocks from being away from home — then any household observed at a more extreme part of the distribution will be likely to migrate back towards the center over time.
- Over longer term, families that have children go through natural stages of consumption levels as they expand from no children to small children to teenagers, and (in most cases) back to no children at home.
- Mean reversion in household consumption creates a negative correlation between today's demand shock and lagged demand shocks.

A classic paper on electricity demand estimation: Ito(2014)

- Earlier, more structural work (e.g. Reiss and White (2005) and Olmstead et al. (2007)) make heroic assumptions about consumer behavior.
- Starting with Borenstein (2009), researchers have raised concerns about these estimators and the underlying assumptions.
- Ito (2014) provides an elegant and influential empirical study of consumer behavior under non-linear pricing.

Empirical question?

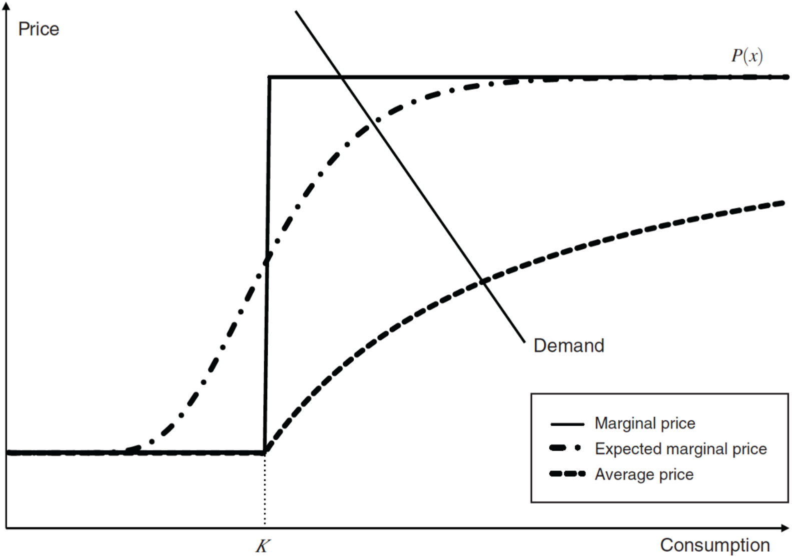
- Distinguish whether consumers respond to:
  - Marginal price
  - Perceived marginal price
  - Average price
- **Setting**: Non-linear electricity pricing in California
- **Empirical strategy:** Exploit price variation utility boundary

Theoretical framework

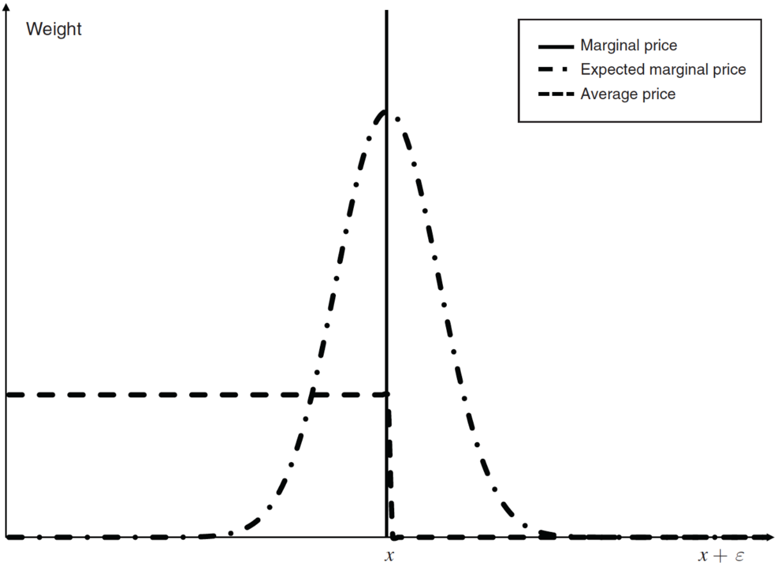
- Consumption is given by: x.
- Consumers may be uncertain about how much they consume: ϵ.
- Consumers weight ϵ with the function $w(\epsilon)$.
- The perceived price is thus given by:

$$p(\overline{x}) = \int p(x+\epsilon)w(\epsilon)d\epsilon$$

Perceived electricity price



Weighting function



Empirical design

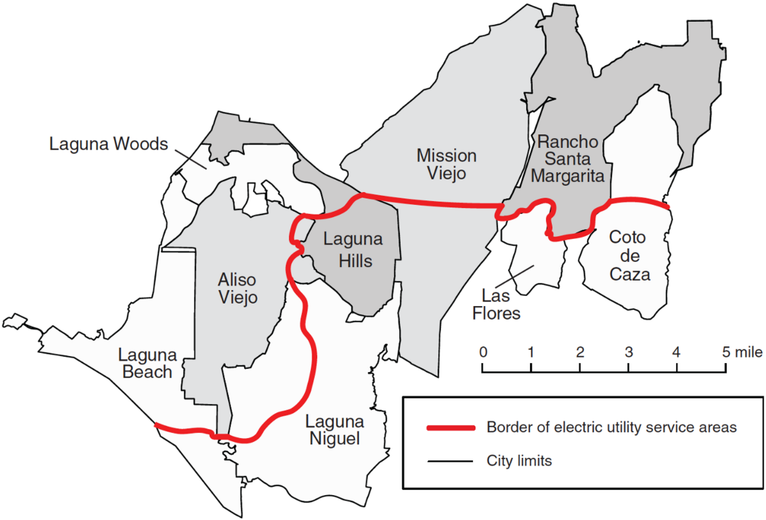


FIGURE 2. BORDER OF ELECTRICITY SERVICE AREAS IN ORANGE COUNTY, CALIFORNIA

Sorting along the border?

Unlikely!

- Panel data with household fixed effects
- Consumers are balanced with respect to observables.
- Consumers cannot choose electricity providers
- Frequent variation in prices makes it hard to believe that consumers will move to adjust to prices.
- Same climate zone

Price variation used for identification?

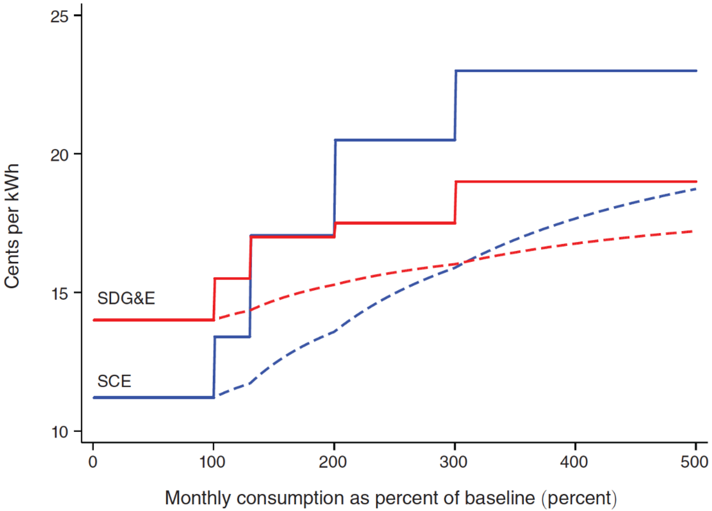


FIGURE 3. AN EXAMPLE OF CROSS-SECTIONAL PRICE VARIATION IN NONLINEAR ELECTRICITY PRICING

Start with a bunching analysis...

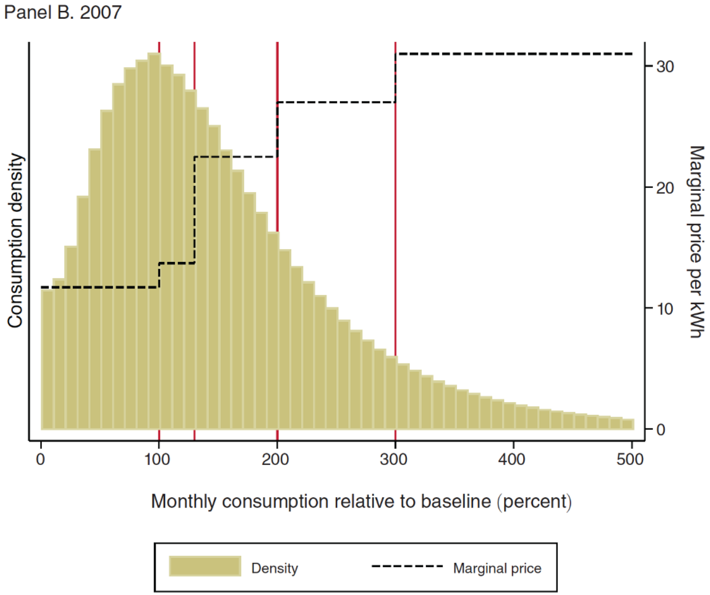


FIGURE 5. CONSUMPTION DISTRIBUTIONS AND NONLINEAR PRICE SCHEDULES

Estimating equation

$$\Delta lnx_{it} = \beta_1 \Delta lnMP_{it} + \beta_2 \Delta lnAP_{it} + \gamma_c t + \eta_i t$$

This first-difference eliminates household-by-month fixed effects.

But remember – price is endogenous! We need an instrument that is uncorrelated with η_{it}:

$$\Delta lnMP_{it}^{IV} = lnMP_{it}(\tilde{x}_{it}) - lnMP_{i0}(\tilde{x}_{it})$$

where:

$$\tilde{x}_{it} = x_{i\frac{t}{2}}$$

Consumption in a period midway between $t = 1$ and $t = 0$ helps address the mean reversion problem.

Parallel trends assumption?

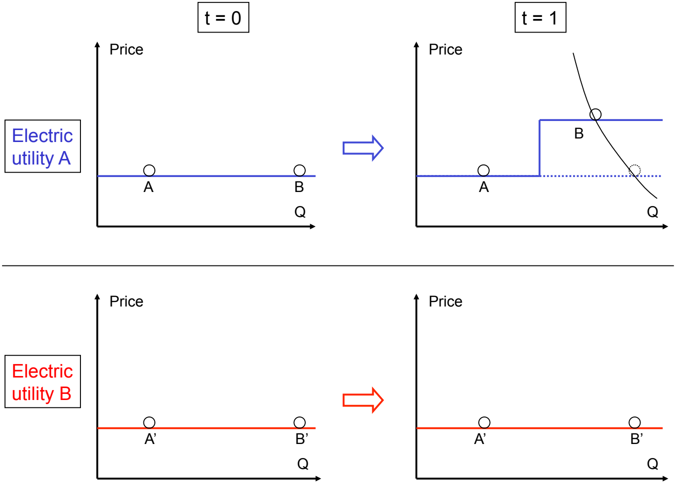
- Even with mean reversion addressed, an instrument based on consumption levels can still be correlated with the error term if high and low electricity users have different consumption trajectories.
- Extreme example – high and low income users did not follow parallel trends through the pandemic!
- Koichiro exploits the spatial discontinuity in electricity service areas – assumes that confounding factors driving differences in consumption trajectories do not vary across the border.

IV regression

$$(3) \qquad \Delta \ln x_{it} = \beta_1 \Delta \ln MP_{it} + \beta_2 \Delta \ln AP_{it} + f_t(x_{it_m}) + \gamma_{ct} + \delta_{bt} + u_{it},$$

- f(x) controls non-parametrically for consumption percentiles.
- For each percentile of consumption in t_m, he defines percentile-by-time FE to control for underlying changes in consumption for each part of the consumption distribution.
- If all consumers were on the same price schedule, these flexible controls would absorb all price variation.

Koichiro's strategy in a picture



Results

Table 2—Encompassing Tests: Marginal Price versus Average Price

	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln(\textit{marginal price}_t)$	−0.034		0.002			
	(0.004)		(0.011)			
$\Delta \ln(\textit{average price}_t)$		−0.051	−0.054			
		(0.005)	(0.015)			
$\Delta \ln(\textit{marginal price}_{t-1})$				−0.050		0.006
				(0.004)		(0.011)
$\Delta \ln(\textit{average price}_{t-1})$					−0.074	−0.082
					(0.005)	(0.015)

Notes: This table shows the results of the IV regression in equation (3) with fixed effects and control variables specified in the equation. The unit of observation is household-level monthly electricity usage. The dependent variable is the log change in electricity consumption in billing period t from billing period $t - 12$. The sample period is from January 1999 to December 2007 and the sample size is 3,752,378. Standard errors in parentheses are clustered at the household level to adjust for serial correlation.

Additional empirical insights

Rather than specify specific prices (e.g. average versus marginal), Koichiro specifies a more flexible weighting function:

- Suppose a household consumes x_t and faces a nonlinear price schedule $p(x_t)$.
- Define a series of surrounding consumption levels around x_t by x_{kt}
- Let $p_k t = p(x_{kt})$ denote the marginal price for x_{kt}.
- Let α describe the relative weight on p_k. $\alpha = 1$ implies consumers focus exclusively on marginal price.
- Parameters θ_l and θ_r describe the right and left slopes of the density function.

x_{it}. The second example shows a similar case, but consumers care about the price further away from x_{it}. Using the weighing function, I estimate:

$$\text{(5)} \qquad \Delta \ln x_{it} = \beta \sum_{k=-100}^{100} w_k(\alpha, \boldsymbol{\theta}) \cdot \Delta \ln p_{k,it} + f_t(x_{it_m}) + \gamma_{ct} + \delta_{bt} + u_{it}.$$

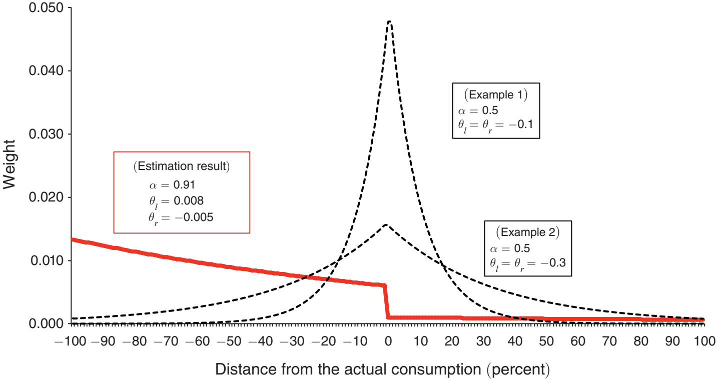


FIGURE 7. SHAPE OF WEIGHTING FUNCTIONS: EXAMPLES AND ESTIMATION RESULTS

Notes: The dashed lines illustrate two examples of the weighting functions of equation (5). The first example shows the case with $\alpha = 0.5$ and $\theta_l = \theta_r = -0.1$, in which consumers care about the price to the left and right of x_{it} equally but put larger weights on the price close to x_{it}. The second example shows a similar case but consumers care about the price further away from x_{it} The solid line shows the estimation result of $w(\alpha, \theta)$, which is shown in Table 5.

Implications?

- Policymakers often claim that increasing block pricing creates incentive for energy conservation because marginal price increases with consumption level. .
- Note that a switch from uniform pricing to block pricing lowers price for some tiers, raises price for others.
- The effect of block pricing on aggregate consumption is ambiguous (some see an increase in price/others a decrease).
- Ito examines how nonlinear pricing impacts consumption (compared to a flat rate) for two scenarios: consumers respond to average versus marginal price.

Welfare implications of nonlinear pricing

- Consumption increases under nonlinear pricing if consumers respond to average price!
- Lower usage consumers see their average price fall.
- Higher usage customers decrease - but only slightly as their average price does not increase much.
- Aggregate consumption decreases if consumers respond to marginal price.

Table 6—Effect of Nonlinear Pricing on Energy Conservation

	Assumption on consumers' perceived price	
	Average price	Marginal price
(A) Consumption under five-tier nonlinear pricing	20,526	19,993
(B) Consumption under counterfactual flat rate	20,471	20,471
Percent change from (B) to (A)	0.27	–2.33
	(0.02)	(0.05)

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Deryugina, Tatyana, Alexander MacKay, and Julian Reif. 2020. "The Long-Run Dynamics of Electricity Demand: Evidence from Municipal Aggregation." American Economic Journal: Applied Economics, 12 (1): 86-114.

Shaffer Blake (2020). "Misunderstanding nonlinear prices: Evidence from a natural experiment in electricity demand". American Economic Journal: Economic Policy. 12(3).