The Changing Economics of Electricity Markets

Meredith Fowlie
Department of Agricultural and Resource Economics
Class of 1935 Chair in Energy
UC Berkeley

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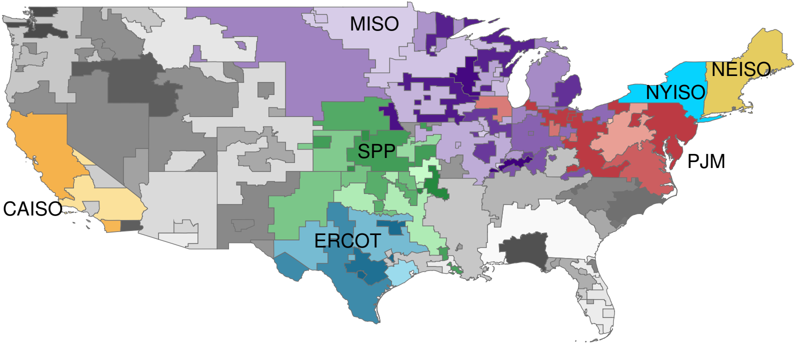
The U.S. Electricity Market is Big (by any measure)

- 150 million utility customers (residential/commercial/ industrial).
- 4.08 trillion kilowatthours (kWh) of electricity generated at utility-scale sources in 2016 (additional 0.02 trillion kWh generated by distributed, small-scale solar PV).
- 2016 revenues from the sale of electricity: $386 billion.
- Annual CO_2 emissions (35% of the total U.S. energy-related CO2 emissions) were 1,821 million metric tons in 2016. (Canadian emissions were 722 mmt).

U.S. electricity sector has seen some big changes

(b) PCAs by Market Dispatch in 2012

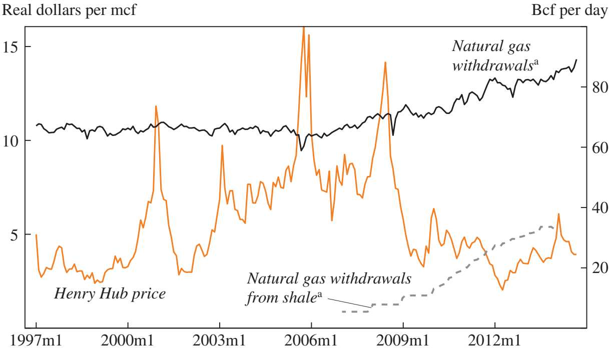


Source: Cicala, 2017

Electricity sector restructuring brought big changes in the 1990s and 2000s.

U.S. electricity sector has seen some big changes

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



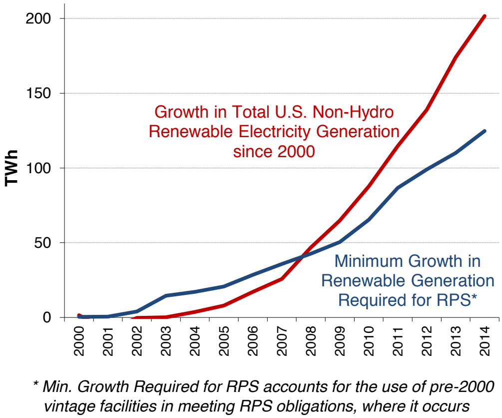
Source: EIA.

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.

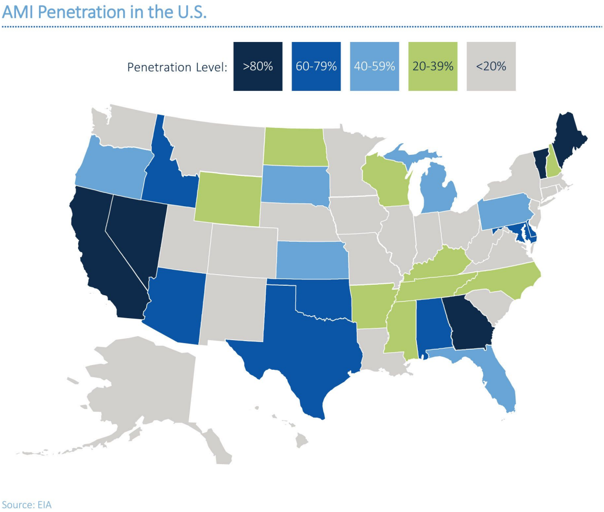
U.S. electricity sector has seen some big changes



Source: Barbose et al. 2015.

VRE deployment has been significantly driven by state and federal policies.

U.S. electricity sector has seen some important changes

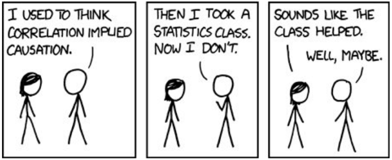


Source: Tweed, 2015

Increasing penetration of smart meters (as of 2015) /AMI.

What are the causal impacts of these developments?

- It can be difficult to isolate the effect of one factor (e.g. shale gas) from other confounding factors (renewable energy policies, recessions, etc).



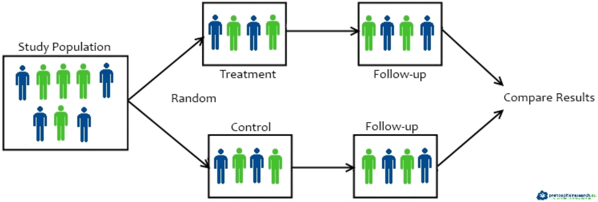
Source: https://xkcd.com/552/

- To evaluate causal impacts, we need a credible estimate of the 'counterfactual'.
- One approach: Build an electricity market simulation model to capture key structural aspects and relationships.
- Alternative approach: Use quasi-experimental (or experimental) variation to empirically identify causal effects.

Causal inference meets electricity markets

We wish we could simultaneously observe the same "subjects" (i.e. markets, firms, consumers) in different states of the world.

Field experiments: Randomly assign intervention across subjects to eliminate bias introduced by confounding factors.



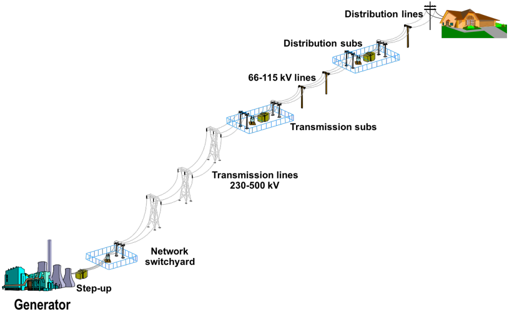
Quasi-experiments: Identify a comparison group that is as similar as possible to the treatment group. Use comparison group(s) to estimate counterfactual.

Goal for today: Highlight empirical research that seeks to tease apart cause and effect in U.S. electricity market interactions.

- Experimentation with electricity sector restructuring.
- Emerging impacts of :
  - Shale gas boom/low gas prices
  - Increased penetration of variable renewable energy generation
  - Smart grid facilitated demand response

Upshot: Careful empirical studies help us understand how electricity markets work in the real world... and shed some light on what the future holds.

The Old Model



- Under rate-of-return regulation, vertically integrated regulated monopolies recovered operating costs and earned a rate of return on prudently incurred capital investment.
- This regulatory environment provided a stable level of resource adequacy.. but weak incentive to invest and operate efficiently!

Electricity sector restructuring

No single definition of restructuring in the U.S. context.

We'll focus on two key elements:

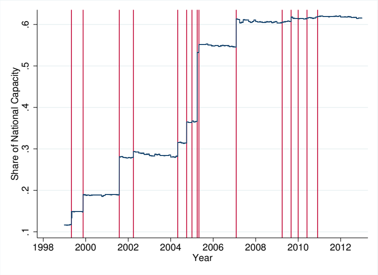
1. Creation and expansion of Regional Transmission Organizations (RTOs) to promote non-discriminatory access and facilitate market-based dispatch.
2. Move away from compensation based on cost recovery towards payment based on the market value of electricity produced.

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

Effects of restructuring on system-wide efficiency?

Cicala(2017) uses the staggered expansions of wholesale electricity markets to estimate the causal impact of market-based dispatch.

Figure II: Share of Generating Capacity Dispatched by Markets



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

He compares outcomes before and after a market transition with changes over the same time period in areas that had not (yet) undergone any regulatory changes.

Effects of restructuring on system-wide efficiency?

Cicala (2017): 'Imperfect Markets versus Imperfect Regulation in U.S. Electricity Generation'

- Detailed hourly data on plant operations, demand across the U.S. from 1999 - 2012.
- Estimates an econometric model to evaluate:
  - 'Out of merit' losses from dispatching higher marginal cost units relative to installed capacity.
  - Gains from trading electricity across areas.
- Estimates that market-based allocation of production reduce production costs by $3B per year:
  - Estimated gains from trade across service areas increase by 20%.
  - Costs from using uneconomical units fall 20%.

Effects of restructuring on plant-level operating efficiency?

- Prior to restructuring, all U.S. nuclear power reactors owned by regulated utilities.
- During restructuring, 48 nuclear power reactors (out of 103 total) were sold to independent power producers selling power in competitive wholesale markets.
- Using a 40-year monthly panel of all nuclear reactors in the United States, Davis and Wolfram(2012) look at differences-in-differences in operating efficiency, carefully control for reactor characteristics.

Deregulation, Consolidation, and Efficiency: Evidence from US Nuclear Power (Davis and Wolfram, 2012)

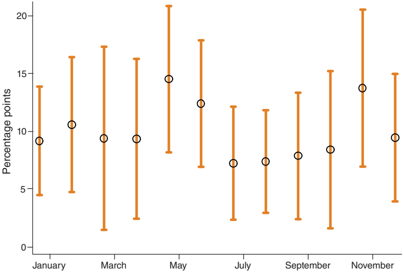


FIGURE 2. THE EFFECT OF DIVESTITURE ON OPERATING PERFORMANCE BY MONTH OF YEAR

Deregulation and consolidation associated with a 10 percent increase in operating performance (primarily via reduced reactor outages)

- Increase in electricity production due to deregulation and consolidation exceeds 40 billion kilowatt hours annually.
- Annual decrease of 35 mmt of CO_2 (more abatement than all US wind and solar generation during the same period!)

Effects of restucturing on capital investment?

> *The most important opportunities for cost savings (under restructuring) are associated with long-run investments in generating capacity.*
>
> Paul Joskow, 1997

In theory, rate-of-return regulation favors gold plated capital investment and excessive capacity margins.

In practice, it's really hard to isolate causal effect of restructuring on investment efficiency (given long investment time horizons and infrequency of capital investments).

Effects of restucturing on capital investment?

- Fowlie (2010) compares compliance decisions in a cap-and-trade program at generating units in restructured states with very similar units in regulated markets.
- Generators in restructured markets less likely to invest in capital-intensive forms of abatement and more likely to pursue lower cost compliance options (e.g. purchase pollution permits).

A coal plant being retrofit with capital intensive ($200M) pollution abatement equipment.

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

But what about reliability/resiliency/resource adequacy?

- Can energy and ancillary service markets attract *sufficient* investment in resources?
- How much of the planning and financing of power plants should be coordinated outside the energy market via resource adequacy incentives?

Resource adequacy in restructured U.S. electricity markets

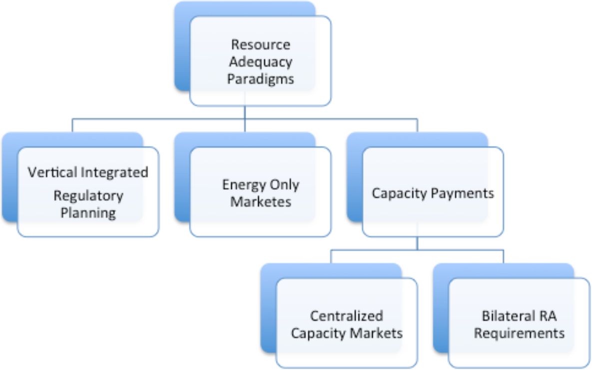


Figure 5: Resource Adequacy Paradigms

Source: "Electricity Capacity Markets at a Crossroads". James Bushnell, Michaela Flagg, and Erin Mansur.

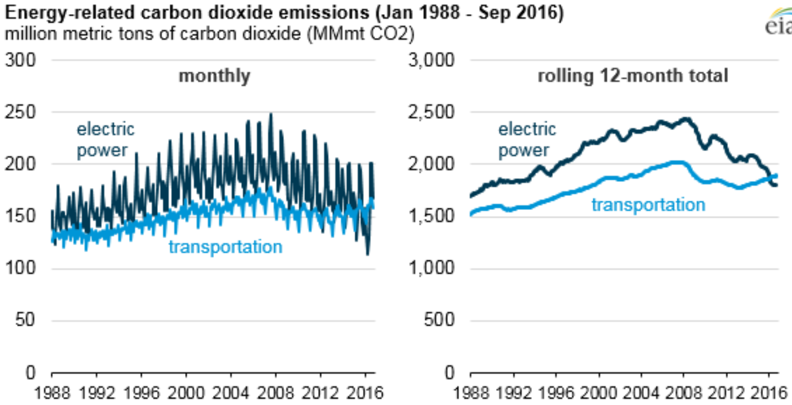
There is an emerging and controversial mismatch between 2000's era resource adequacy regimes and changing market conditions...

Goal for today (Revisited): Highlight empirical research that seeks to tease apart cause and effect in U.S. electricity market interactions.

- Experimentation with electricity sector restructuring.
- Emerging impacts of :
  - Shale gas boom/low gas prices
  - Increased penetration of variable renewable energy generation
  - Smart grid facilitated demand response

A growing empirical literature investigates the causal impacts of low natural gas prices and increasing renewable energy penetration on key economic outcomes (e.g. emissions, electricity prices).

Electricity sector GHG emissions: The big picture

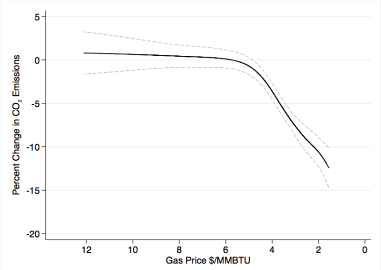


A data-driven approach to analyzing emissions impacts of low gas prices

- Cullen and Mansur (2016) use variation in natural gas prices to estimate the relationship between domestic power sector CO_2 emissions and the coal-to-gas cost ratio.
- A decrease in the natural gas spot price from $12/mmbtu to $2/mmbtu (2008-present) is associated with a 10 percent drop in emissions.

Figure 6: Estimated CO_2 Response to Fuel Prices

(a) Eastern Interconnection



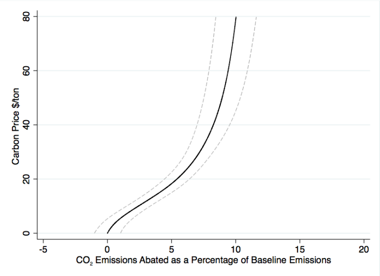
Source: Cullen and Mansur(2016)

A data-driven approach to analyzing emissions impacts of a carbon tax?

- A carbon price provides similar incentives for fuel switching as does a change in the coal:gas price ratio.
- This mapping is important; We have no national carbon price that we could use to identify the marginal cost of abating carbon (limited variation in regional carbon pricing programs).
- Use estimates to impute implications for fuel switching under a carbon price:

Figure 7: Imputed CO_2 Response to Carbon Prices

(a) Eastern Interconnection

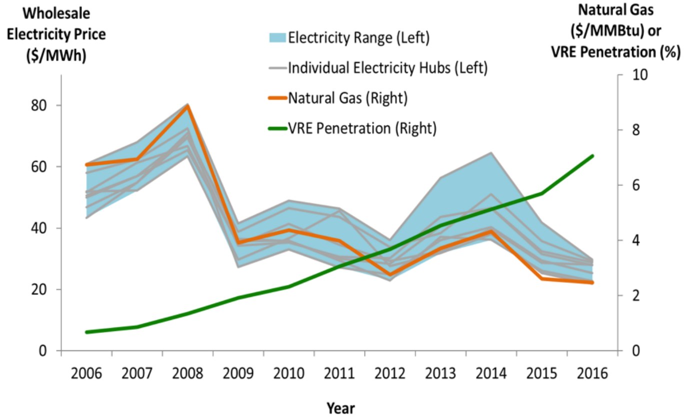


Source: Cullen and Mansur, 2016

A data-driven approach to analyzing marginal benefits of increased renewable energy generation

- A growing literature investigates the emissions impacts of marginal increases in renewable energy generation and investment (e.g. Callaway et al., 2017; Novan, 2015).
- Empirical estimates can depart significantly from simulation model predictions.
- Empirical estimates vary significantly across regions and across time
- Fell and Kaffine (2017) underscore the importance of the interaction between rising wind penetration and low natural gas prices.
  - The marginal response of emissions to fuel prices is larger in magnitude under high levels of wind generation.
  - The marginal effect of wind generation to be multiple times larger in magnitude in several regions under low natural gas prices than it otherwise would have been.

What's driving wholesale price changes?



Wholesale prices have declined substantially since 2008.
Source: Wiser et al. 2017

Wholesale price impacts (in theory)?

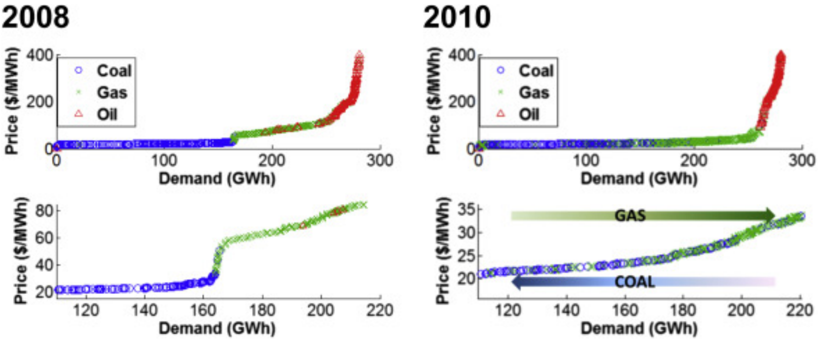
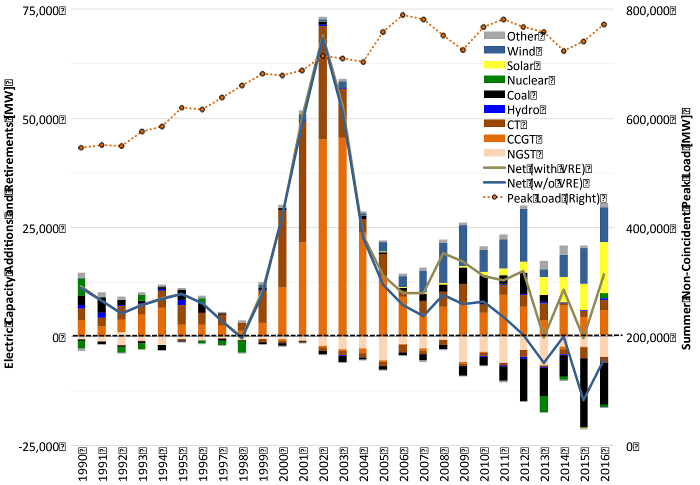


Figure illustrates a competitive market dispatch curve. The curves on the left are calibrated to match fuel prices in 2008. The curves on the right are calibrated using 2010 fuel prices. Source: Sahraei-Ardakani (2015)

- Simulation models suggest renewable energy has played a relatively small role in driving down wholesale prices.
- Empirical research-in-progress is trying to disentangle the causal effects of increased renewables and low gas prices on wholesale electricity prices in different regional power markets.

Retirements of thermal generation assets



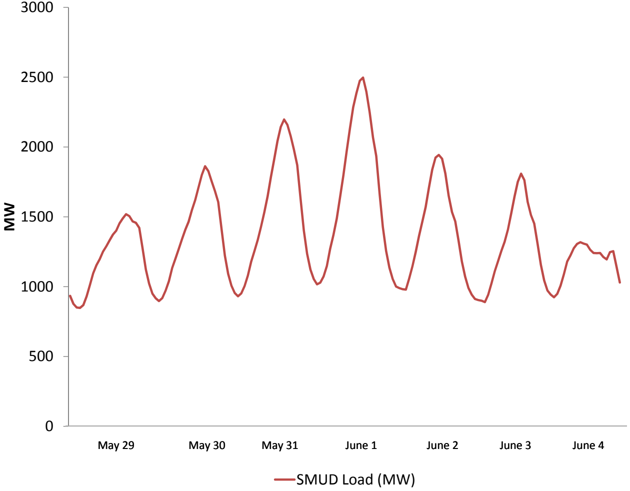
Source: Wiser et al. 2017

What to do about 'Missing Money'?

- Tenuous financial position of some baseload plants need not imply that restructured markets (and associated resource adequacy policies) are broken.
- Key question: Do RA policies adequately value characteristics of incumbent baseload relative to the new resources that are crowding them out?
- Simplifications used to operationalize capacity procurement do become more important when very different resources compete for capacity payments.
- In the U.S., to shield baseload plants from the competition that threatens their future viability, the U.S. Department of energy has proposed to reverse twenty years of regulatory restructuring.....

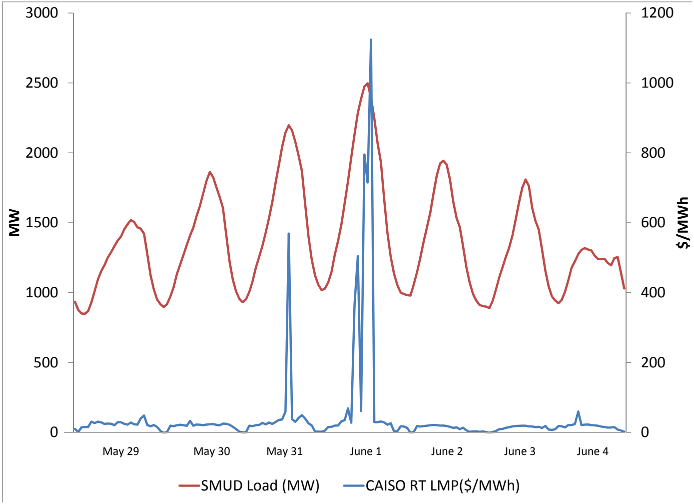
We've spent a lot of time on the supply-side.. let's not forget the demand-side!

Figure: Hourly electricity demand (SMUD) May 29-June 4, 2013



Variable demand begets variable wholesale prices

Figure: Hourly electricity demand (SMUD) and RT LMP (CAISO)



Majority of electricity customers pay time-invariant rates!

- Over-consumption in periods of high marginal costs requires over-investment in capacity to meet peak demand.
- Can also lead to under-consumption in periods of relatively low marginal costs.
- Aggressive renewable energy targets are much more costly to meet absent demand response.
- If the grid operator has no way to elicit a demand response, she must rely on supply response to maintain reliability etc..

Lots of reasons to grease the wheels of a more responsive demand-side!

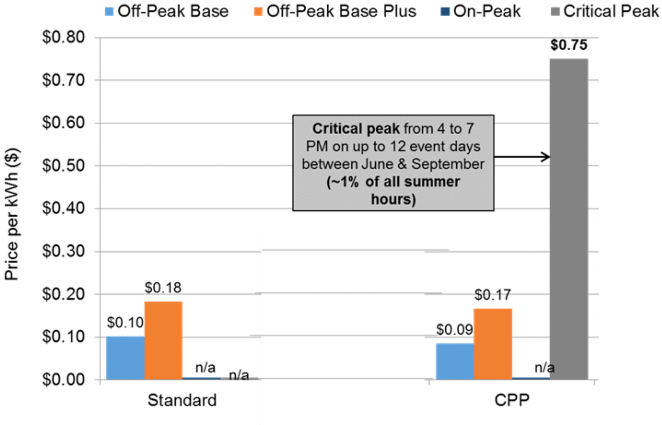
The electricity grid is getting smarter!

- More than 60 million smart meters deployed to almost half of US households (EIA, 2016).
- Demand response resources are starting to play a role in capacity markets in some regions.
- Smart grid infrastructure investment *could* facilitate widespread adoption of time varying pricing programs (and leverage valuable demand response resources).

Some important policy questions:

- Will consumers accept/participate in time-varying pricing programs?
- Do consumers respond to time-varying prices?
- How does automation affect this demand response?
- Can demand response to dynamic prices be dispatched like supply?

What is time-varying pricing (for now)?



Critical Peak Pricing (CPP) programs charge lower rates during a majority of hours, but high prices during a few peak event days when wholesale prices are high/grid stability compromised.

Give consumers a nudge?

- When confronted by a choice with a default option, people seem predisposed to accept the default.
- A 'default bias' has been documented for a range of important choices: health care plans, retirement plans, organ donation ...
- We tested whether making time varying electricity pricing becomes the default option would increase household participation? [Answer: Yes!!]
- How does this default effect affect electricity demand response?

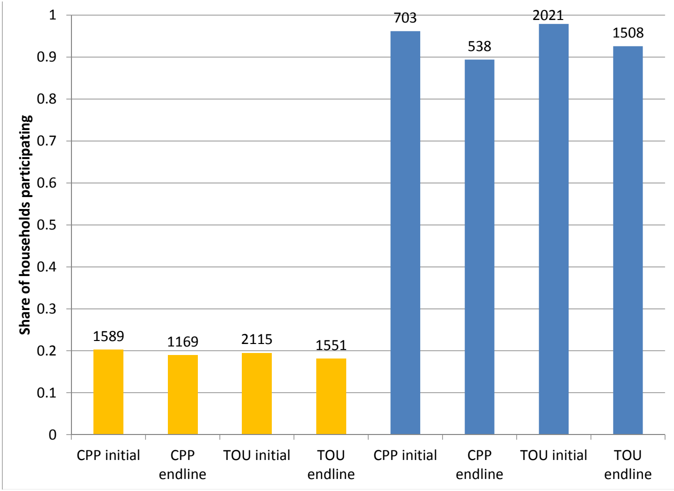
Opt in!


Off-Peak
Discount
Plan
Sign up today and you could save on your electric bills next summer!
SMUD

Opt out!

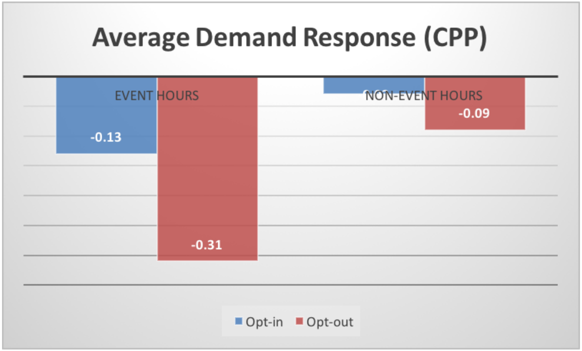

Welcome to
SmartPricing
Options!
Your new pricing plan begins June 1.
SMUD

A powerful nudge!



Opt-in (gold); opt-out (blue). Household counts appear above each bar. Customers who move away are removed from participation count. Endline date is 10/2013

Average kW impacts - critical peak and non-critical peak events



Average reduction in peak demand (averaged across all households receiving the opt-in or opt-out offers) are approximately 5% (opt-in) and 13% (opt out).

The demand reduction among *participants* in the opt-in group is consistent with a price elasticity of approximately -0.25.

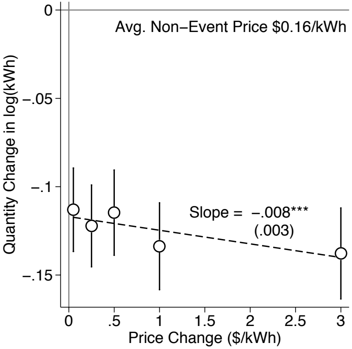
Do consumers respond to varying price levels?

- Gillan (2017) partnered with a demand response provider that recruits residential customers who are willing to receive text messages that incentivize them to reduce their consumption during 1-hour event windows.
- A subset of customers assigned to the control group.
- Remaining customers were exposed to between 1 and 3 events per week, called between 11AM and 10PM.
- The price incentive during these events from \$0.05 per kWh to \$3.00 per kWh (average utility price is \$0.16 per kWh).

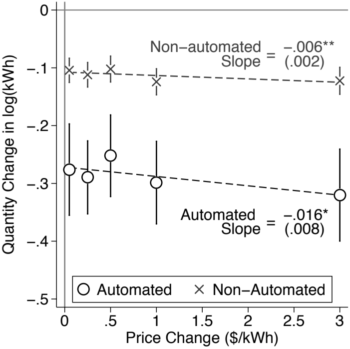
Do consumers respond to varying price levels?

Customers in the treated group consumed on average 12 percent less than the customers in the control group.. but remarkably price insensitive!

Figure 5: Effect of Marginal Price



(a) Effect of Price Change in log(kWh)



(b) Automated vs. Non-Automated in log(kWh)

The figure plots the point estimates for the change in the conditional mean of consumption as a result of changes in the effective price of electricity in dollars per kWh. Note the difference in the scales of the axes between the left and right

The Changing Economics of Electricity Markets

- Quasi-experimental variation in restructuring activity has helped us identify important effects on operating efficiency, dispatch efficiency, investment.
- Quasi-experimental variation in natural gas prices and renewable energy production harder to isolate, but researchers are examining impacts on emissions, wholesale prices, fuel mix.
- Field experimentation shows us the ways in which consumer response to dynamic electricity prices aligns with - and departs from- standard demand theory.
- More empirical work to do!! The changing landscape creates challenges and opportunities for market design, policy implementation, and economics research.