Redistribution through technology

Equilibrium impacts of mandated efficiency in three electricity markets

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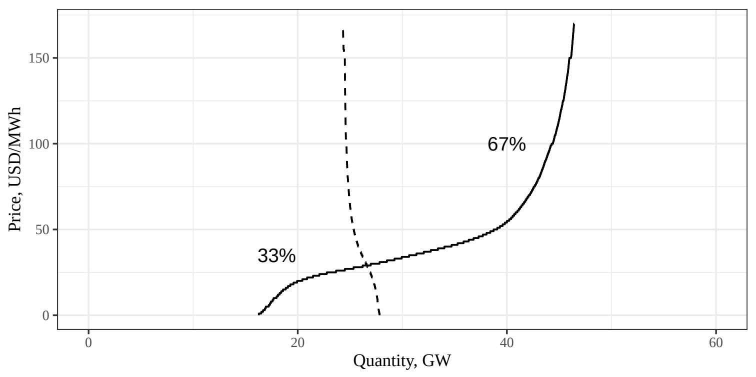
Intuition

Supply and demand of electricity in California
Mean bid curves at CAISO in 2015–2020



- Convex supply, inelastic demand: benefit to consumers
- But increasingly also concave supply (!?)

Mandated efficiency in electricity markets

Pressure to change the market design to

- Improve the security of supply
- Prevent prices from skyrocketing
- Employ technologies that are both economically and environmentally sustainable

One solution: technology mandates

- Smart consumer technologies, incl. smart meters
- Storage, incl. EVs

Question

Do consumers end up benefitting from the mandated allocative efficiency?

- Mandates have broad equilibrium impacts when the market adoption of technologies is not otherwise taking place
- Emerging literature on the equilibrium effects (e.g., Butters, Dorsey and Gowrisankaran 2021; Karaduman, 2021)

This paper

- **Price-theory results** to measure *equilibrium benefits* to consumers from technologies that improve efficiency
- **Efficiency-improving counterfactual experiment** in three major electricity markets using micro-data on over 160 million bids

Theory results

1. **Price dispersion incidence**: depends on pass-through rate
   - e.g., EV owner benefits from the option to charge at occasional bargain prices
   - pass-through measures who can respond to price variations, i.e., consumers or producers
2. **Price correlation incidence**: depends on the correlation structure
   - e.g., EV owner benefits if supplies are correlated with needs
3. **Price level incidence**: depends on convexity of excess demand
   - e.g., EV owner benefits if prices are on average lower

Building blocks for theory

Localized markets:

$i \in \mathcal{I}$ index for a local market

$$\underbrace{\big(D(p) + d_i\big)}_{\equiv D_i(p)} - \underbrace{\big(S(p) + s_i\big)}_{\equiv S_i(p)} \equiv X_i(p).$$

finite local price p_i such that $X_i(p_i) = 0$ for all $i \in \mathcal{I}$

Efficient trade:

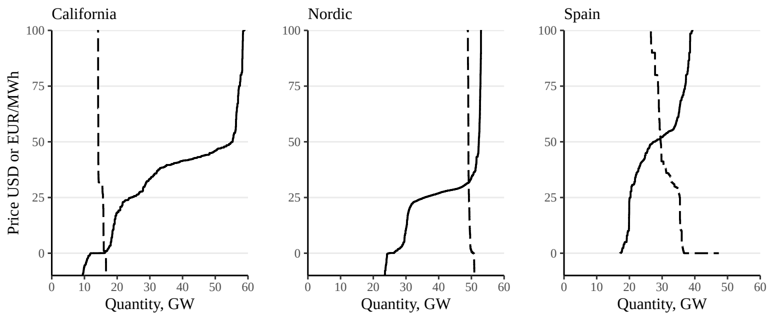
one price for all markets $\sum_{i \in \mathcal{I}} X_i(p) = 0$

$$\Rightarrow D(p) - S(p) = \overline{x}$$

where $\overline{x}$ is the mean of the local market conditions $x_i \equiv s_i - d_i$

Efficient trade $\rightarrow$ **localized markets**: mean-preserving spread of $\overline{x}$

Data set: Bid curves



- Actual hourly bids for market clearing in California, Nordics & Spain
- 160+ million bids from the years 2015–2020 → transformed into common bidding language (many assumptions)

Empirical results

Counterfactual market outcomes

- We experiment with 1 gigawatt (GW) of additional capacity for improving the efficiency of daily allocations

Large consumer benefits

- Exceed the social value of technologies by multiple times
- Flip side: producers lose

Convexity of excess demand dominates

- Explains 90% of the surplus variation for California, 80% Nordics, and 40% Spain

Empirical quantification

The approach: three steps

1. Run the market-clearing procedures of the power exchanges with actual bids
2. Re-run the market clearing with additional capacity for trading
3. Regression of outcomes on covariates capturing the three theory channels

Results #2 – Technology impact

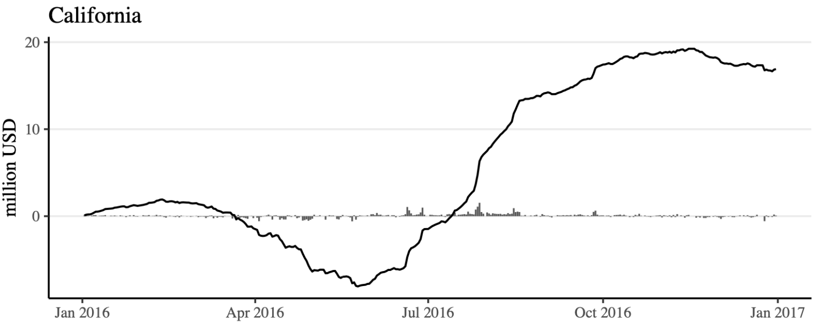
Table 1: Impact of 1 GW flexible technology

Area	Obs.	Share	Q	ΔQ	P	ΔP	Δ Consumer surplus	Δ New tech. surplus	Δ Total surplus
			GW		\$/MWh or €/MWh		Change in M\$ or M€ per year		
California	**All**	**1**	**26.53**	**-0.004**	**32.13**	**-0.23**	**114.15**	**55.64**	**62.17**
	Concave	0.33	25.10	-0.026	25.78	0.3	-16.27	16.05	18.04
	Convex	0.67	27.23	0.007	35.27	-0.5	130.68	39.61	44.14
Nordics	**All**	**1**	**41.24**	**0.004**	**28.06**	**-0.23**	**156.38**	**9.91**	**13.82**
	Concave	0.47	39.12	-0.003	28.61	0.26	-26.05	4.08	5.58
	Convex	0.53	43.13	0.01	27.58	-0.67	182.75	5.84	8.24
Spain	**All**	**1**	**26.74**	**-0.067**	**46.96**	**0.06**	**27.15**	**24.87**	**31.49**
	Concave	0.54	27.75	-0.065	49.84	0.33	-14.96	14.08	17.46
	Convex	0.46	25.57	-0.07	43.61	-0.27	41.86	10.8	14.03

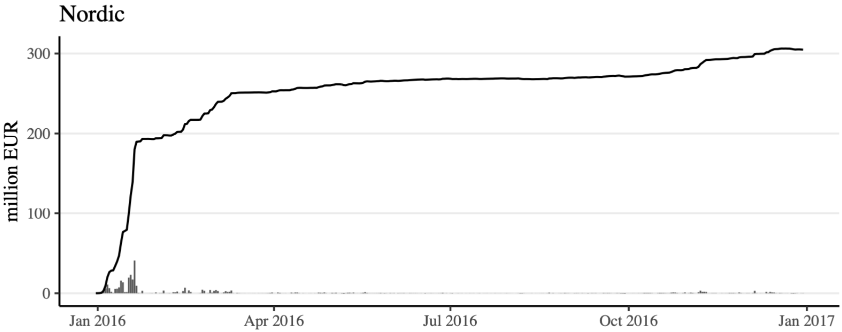
Notes: Table reports the mean values of the hourly data for volume (in GW) and price (in € or \$ per MWh), change in volume (in GW) and change in price (in € or \$ per MWh). Breakdown by observations is based on the convexity/concavity of the daily market (see Section 3.4 below for detail). The welfare measures are mean annual changes, and the Table presents change in consumer surplus, change in the total surplus in the market, and the private gain from trading (millions of U.S. dollars or euro). Data as reported in Table A.1.

Results #2 – Accumulated consumer surplus over a year

Figure 2: Change in consumer surplus



Results #2 – Accumulated consumer surplus over a year



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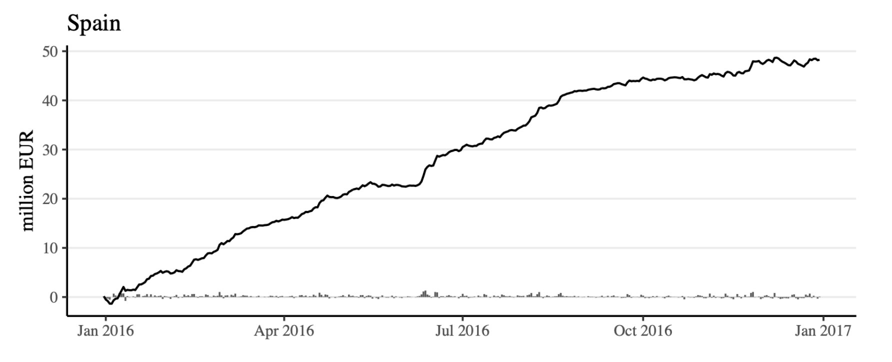


Results #3 – Connecting to theory

Outcome variables

- (Retail) consumer surplus changes, daily
- Measured from the bid curves

Covariates

- Price dispersion channel: elasticities of demand and supply from the bids
- Price correlation channel: variation of demand and supply as variation of the respective daily quantities at price fixed
- Price level channel: convexity of excess demand

Illustration of excess demand: two days in California

Figure 3: Illustration of bid and excess-demand curves

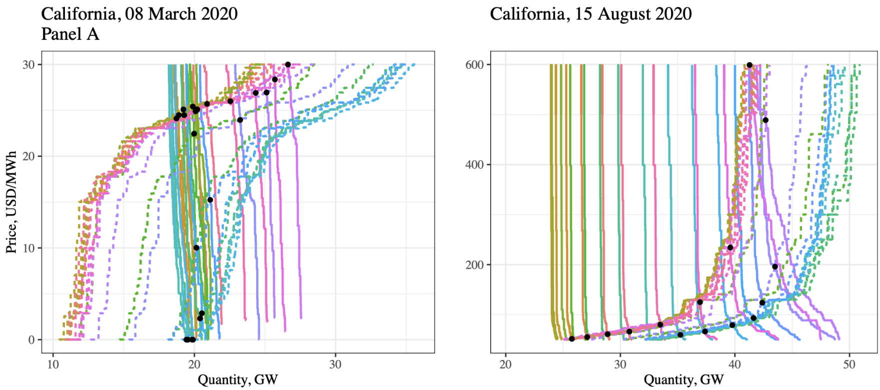
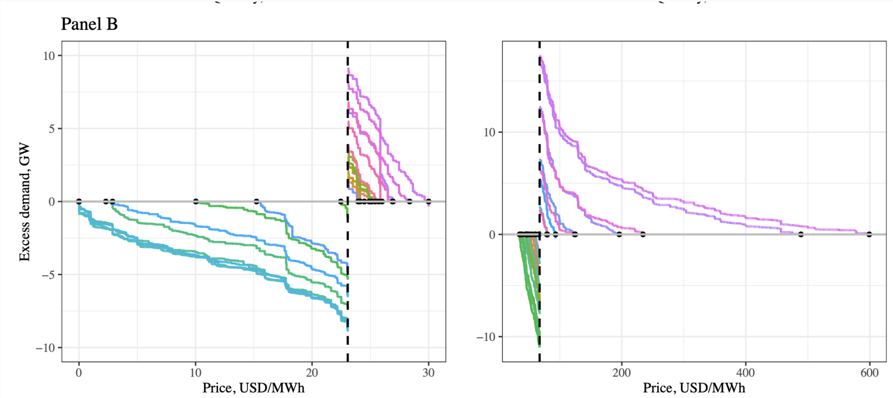


Illustration of excess demand: two days in California



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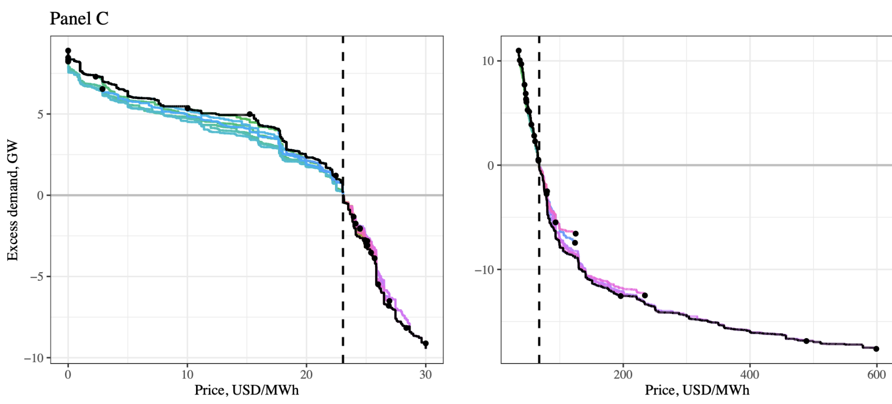

Results #3 – Example, California

Table 1: California, 1 GW experiment

Dependent Variable:	Change in consumer surplus				
	(1)	(2)	(3)	(4)	(5)
Convexity	0.226 (0.002)	0.226 (0.002)	0.226 (0.002)	0.226 (0.002)	0.229 (0.002)
Variation, Demand		-0.004 (0.008)	-0.007 (0.009)	0.0003 (0.010)	-0.005 (0.011)
Variation, Supply			-0.019 (0.013)	-0.018 (0.013)	-0.032 (0.015)
Correlation				-0.087 (0.056)	-0.017 (0.062)
Passthrough					0.274 (0.326)
R^2	0.90050	0.90051	0.90061	0.90073	0.90798
Observations	2,045	2,045	2,045	2,045	1,844

Conclusions

- Mandated efficiency of growing importance
  - Countries have different aspirations over their capacity portfolios, resort to mechanisms beyond the "energy-only" market
- Our convexity measure is new
- Analysis of three markets
  - The benefits of new technologies dependent on market primitives
  - Changes in consumer surplus many times larger than in total surplus
  - The benefit is not due to converging prices, but changes in price levels, and further in market primitives