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Research Brief

Redistribution Through Technology: Equilibrium Impacts of Mandated Efficiency in Three Electricity Markets

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Policy makers have mandated the adoption of smart consumer technologies and new producer technologies such as large-scale storage. The mandates have broad equilibrium impacts when market adoption of technologies is not otherwise taking place. On account of equilibrium impacts, do consumers end up benefitting from the mandated allocative efficiency? We conduct the same efficiency-improving counterfactual experiment in three major electricity markets. The convexity of excess demand, obtained from bids to buy and sell, is a novel measure that strongly predicts consumer benefits in all markets. It highlights that small allocative improvements from technology mandates lead to large surplus redistributions benefitting consumers.

New technologies offer captivating opportunities to trade and improve efficiency in markets, illustrations ranging from ICT to smart technologies for electricity consumption. Aware of this, policy makers have sought to harness these opportunities in electricity markets by mandating the adoption of smart consumer technologies and new producer technologies such as large-scale storage. The mandates have broad equilibrium impacts when market adoption of technologies is not otherwise taking place. On account of equilibrium impacts, do consumers end up benefitting from the mandated allocative efficiency?

First, the mandates impact equilibrium price dispersion and thereby one source of surplus to consumers. Intuitively, a consumer benefits from the option to optimize, e.g., to charge an electric vehicle at occasional bargain prices rather than at a flat mean-equivalent price. The importance of this option can be captured by a pass-through rate measuring the incidence of allocative inefficiency between consumers and producers. Second, if supplies are positively correlated with demands, consumers can get frequent bargain prices even when they do not respond to prices at all. The mandated efficiency makes such bargains smaller. Third, the mandates change the overall price level that consumers face. We develop a novel measure predicting the price-level change: it measures the convexity of market excess demand, linking the consumer surplus gains to the market rudiments, the shapes of demand and supply.

We then develop empirical counterparts of the pass-through rate, correlation, and convexity of excess demand by using micro-data on over 160 million bids from three distinct markets trading identical goods: the electricity wholesale markets in California, Nordic countries, and Spain. This enables us to conduct the same efficiency-improving "mandate" in each market to quantify the three determinants of surplus variations. In the experiment, we use the actual bids for market clearing after adding 1 gigawatt (GW) of capacity for improving the efficiency of allocations, hour by hour. Whether it is a retailer controlling customers' consumptions taking advantage of smart meters and remote controls, a producer exploiting grid-based storage solutions, or an individual optimizing the charging of EV, the idea is to buy market electricity when prices are low and sell (or, not use) it when prices are high.

A consistent result arises from all three markets: the private trading surplus may be lost with a reduced price dispersion but the consumer benefit from a lower price level is overwhelming. This price-level effect is captured by the empirical convexity measure of excess demand. It explains close to 90% of the surplus variation in California, 80% in the Nordics, and 40% in Spain. Price level changes have a flip-side implication: incumbent firms end up losing surplus in all markets; the surplus redistribution is substantially larger than the social value of the technologies which is low in all markets.

Excess demand, the difference between demand and supply, inherits its convexity properties mainly from supply if demand is relatively inelastic. Consumers tend to benefit (lose) from an efficiency mandate when the supply is convex (concave) in quantities. Intuitively, a steeply rising supply reservation price of a convex supply reflects a shortage, an "under- supply" situation in which a technology such as a large-scale storage helps in lowering the average price. In contrast, the same technology increases the average price when the supply is concave, an "over-supply" situation in which there is a large supply (e.g., gas-fired power) coming available when the price exceeds a certain reservation level.

We estimate that when the mandate changes the daily price expectation by one euro/dollar, the daily consumer surplus changes by .226 million in California, 1.06 million in the Nordics, and .147 million in Spain. The mandate can change the price expectation in either direction, depending on the variation of under- and over-supply situations, and therefore the final impact of the mandate on consumer surpluses accumulates as a function of this variation in days over a year. For 2015-2020, we evaluate that the mandate of controlled size 1GW would have benefitted consumers in all markets. In the Nordics, the surplus gain to consumers from a mandate of size 1GW is ten times larger than the total (gross) social surplus!

In California, hourly price differences within a day start to increase in the spring, with depressed day prices and peaking evening prices. Solar PV systems crowd out a mix of gas-fired generation when the sun rises but the gas-fired units must quickly ramp up when the sun sets. In these situations, the supply is typically convex in prices (i.e., concave in quantities), and the demand is relatively inelastic (see Video, Panel A). Then, the excess demand is concave, and efficiency improvement works against the consumer surplus, as it increases the daily price level. Consumers lose day-by-day, until the trend is reversed later in the summer. A higher demand for cooling pushes the power system closer to full capacity, and the concave part of the supply curve applies (i.e., convex in quantities, see Video, Panel B). The efficiency improvement reduces the peak power generation and this lowers the peak prices more than what the prices rise during the off-peak periods. In the end, over the year, the consumer surplus remains positive.

In the Nordics, the daily price dispersion is small for a large part of the year, as the hydro resource provides flexibility for counterbalancing the wind power intermittency and demand variation. Nearly all of the consumer surplus gain for 2016 comes from a few winter days when a cold spell leads to peaks in electric heating demand and prices. Demand is inelastic, and supply is concave in prices (i.e., convex in quantities, see Video, Panel C). 1GW additional capacity for reallocating loads reduces the impact of the market-level supply shortage in production and this brings consumer surplus gains that are significantly larger than for the other markets.

In Spain, the data suggest that the demand is more elastic than in the other markets, bringing stability to the surplus gain development over the course of the year: the demand elasticity reduces price peaks and also prevents prices from falling quickly in a positive supply shock. Intuitively, demand

and supply come close to being linear (see Video, Panel D), suggesting that the mandate has a moderate impact on price levels – an alluring consistency with the theory prediction.

Our approach in novel in using multi-market granular micro-data on bids to simulate how the equilibria implied by the bids are affected by the mandates. The approach lets the data tell if the excess demand is concave or convex, which allows us to firmly link the empirical and theory results to explain the variation of surpluses in the data. The results add to the emerging literature that emphasizes nonlinearities in understanding data – nonlinearities of electricity supply seem to be of growing importance because high shares of renewables increase the variation of capacity utilization rates. We also contribute to the literature on how to activate consumers to use ever-better smart appliances by analyzing how a large-scale deployment of consumer-side technologies impacts the market equilibrium. The multi-market approach may prove useful when studying, for example, the impact of data centers and cryptocurrency mining on the "world electricity market".

References

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