Heterogeneity in demand responses to electricity spot prices

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Outline

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Introduction

Motivation

- Change towards more electricity production by renewable sources
- Only sustainable if demand can be directed to when production is ongoing

→ How does demand respond to price changes in electricity?

Background

Existing literature

Modest elasticities and limited data

- Lijesen (2007) finds a peak elasticity of -0.0043 for hour-by-hour total Dutch consumption, Wolak and Patrick (2001) find peak elasticities of -0.05 on half-hourly consumption for 5 British industries.
- In 36 non-time-of-day studies estimates range between -0.004 to -2.01 with median -0.81 in the short run (meta analysis)
- Experiments with time-of-use tariffs

Heterogeneity

- Across industries (UK)
- Under extreme weather (AUS)
- Under extreme prices (UKR)

Instrumenting for electricity spot price

- Lagged prices at cost of dynamic bias (using GMM estimation)
- Use wind speed as instrument (DEU)

Our contribution

Hour-by-hour data

- For both consumption and prices

Separate data for:

1. Wholesale consumption
2. Retail consumption
   (full population, not a survey)

A degree of regional disaggregation

- 52 different grid companies

New data (2016-2018)

- Ever increasing share of renewables calls for flexibility
- First look at time-of-use tariff introduced December 2017

Economics theory

Price formation in the electricity market

Electricity different from other goods: Essentially impossible to store

$\rightarrow$ Demand $\leq$ Supply at any given point in time

- Surplus is costly and inefficient

Organisation of market:

1. Long term contracts and forward market
2. Day-ahead market (80 per cent of volume traded)
3. Intra-day market
4. Balancing market

Production in merit order after marginal price

- E.g. wind power $>$ hydro $>$ coal $>$ gas
- Thus, wind power prognosis $\rightarrow$ decrease in spot price

Demand for electricity

Electricity demand is shaped by the demand for the use of other appliances that require electricity to function

→ Even less information on costs is available to the consumer which makes responding difficult

- Calculating the price of using an appliance requires knowledge of both electricity prices and how much each device uses
- Implies that many consumers rely on behavioral rules when deciding on electricity consumption

Important distinction

- Wholesale consumers (large and medium-sized firms)
- Retail consumers (households and small firms)

Data

Data and variables

Consumption for 2016-2018:

- Grid-level hourly consumption and number of electricity-meters, split by
  1. hourly-settled (wholesale)
  2. flex-settled from December 2017 (retail)
  3. residual consumption (retail)
- Scraped from Energinet via SQL statements

Prices and wind power

- Spot-price in the day-ahead-market
- Wind power prognosis
- Downloaded from Nord Pool

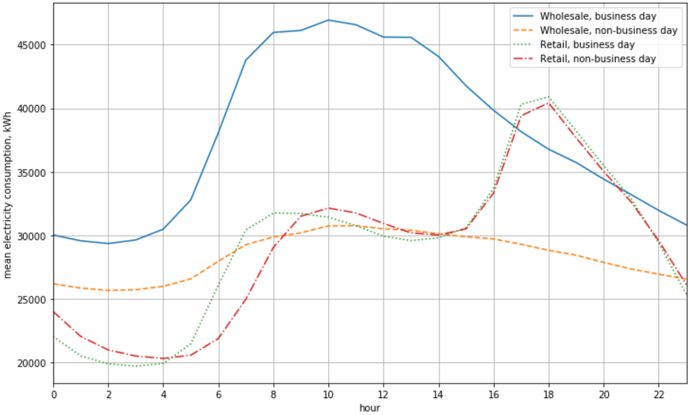
Weather variables

- Temperature (scraped from DMI)
- Daytime variable using sunset and sunrise (scraped from soltider.dk)
- Collected for the two biggest municipalities, Aarhus and Copenhagen
  → Extrapolated to all grids of price region DK1 and DK2 respectively

Time variables

- Time trend
- Calendar dummies and interactions with hour-of-day
- Sample split by business days and non-business days (holidays and weekends)

Figure 1: Mean electricity consumption by hour



Empirical strategy

Specifications

Baseline model for log electricity consumption, $\ln e_{it}$, in grid i at time t (date by hour)

$$\begin{aligned}\ln e_{it} = \; & \underbrace{\varepsilon \ln \hat{p}_{rt}}_{\text{Spot price in price region}} + \underbrace{\delta \ln n_{im}}_{\text{Number of meters by } 1^{\text{st}} \text{ of the month}} + \underbrace{w_{rt}^{'}\lambda}_{\text{Weather}} + \underbrace{\gamma \; days}_{\text{Time trend}} \\ & + \underbrace{\eta_{year} + \eta_{week}}_{\text{Year and week dummies}} + \underbrace{\eta_{month} \cdot \eta_{hour} + \eta_{day} \cdot \eta_{hour}}_{\text{Consumption pattern by month and weekday}} + \underbrace{c_i}_{\text{Grid effect}} + u_{it} \qquad (1)\end{aligned}$$

Effect of time-of-use-tariff in grid company Radius

- Since December 2017: Time-of-use tariff for the hours 17-19 during Winter
- Estimated using baseline specification (1) but only for Radius and hours 17-19
  - Without the grid-specific time-invariant constant term c_i
  - But including a term for the effect of the TOU tariff:

$$\alpha \frac{nf_{month}}{nr_{month}} \tau_{year,month} \qquad (2)$$

  - $\frac{nf_{month}}{nr_{month}}$ is the share of retail meters constituted by flex-settled meters
  - τ is a dummy for the months October-March after December 2017

Random Effects estimation (RE)

Different candidates for panel data estimation

- Least Squares Dummy Variables estimation (LSDV)
  - Unobserved heterogeneity, $c_i > 0$, leads to serial correlation
- Fixed Difference estimation (FD)
  - Strict exogeneity assumption, $cov(u_{it}, \boldsymbol{x}_{it}) = 0$, is violated by hourly-patterns
- Fixed Effects estimation (FE)
  - Time-demeaned, too extreme
- Dynamic Panel Estimation using Generalized Methods of Moments (GMM)
  - Only necessary if including lagged prices as instruments

We choose the **Random Effects estimator (RE)** for wholesale consumption

- Critical assumption for RE: No endogeneity, i.e. $cov(c_i, \boldsymbol{x}_{it}) = 0$.
- Hausman test: $\hat{\beta}^*_{RE} = \hat{\beta}^*_{FE} \rightarrow$ no endogeneity $\rightarrow$ both RE and FE are consistent, but RE is more efficient.

Estimate RE estimation using **feasible Generalized Least Squares (fGLS)**

1st stage: Estimate eq. (1) using LSDV estimation $\rightarrow$ store $\hat{\lambda} = 1 - \left(\frac{\sigma_u^2}{\sigma_u^2 + T\sigma_\alpha^2}\right)^{\frac{1}{2}}$

2nd stage: LSDV using $\hat{\lambda}$ to estimate the quasi-time demeaned system of the form:
$$y_{it} - \hat{\lambda}\bar{y}_i = \beta_0(1-\hat{\lambda}) + \beta_1(\boldsymbol{x}_{it} - \hat{\lambda}\bar{\boldsymbol{x}}_i) + c_i(1-\hat{\lambda}) + u_{it} - \hat{\lambda}u_{it}.$$

Instrumenting for prices

Endogeneity problem

- Price and demand affects each other simultaneously
- Wind power prognosis (*wpp*) is used as a proxy for predicted wind strength
  - We expect different level and slope depending on being in Western Denmark ($DK1 = 1$)
  - We expect an effect from *wpp* in the other region as well due to electricity flows
- However, *wpp* is not completely exogenous but also considers spot prices.

Wholesale consumption with grid-specific time-invariant constant term, eq. (1)

- $\ln \hat{p}_{rt} = DK1 \cdot wpp_{rt} + (1 - DK1) \cdot wpp_{rt} + DK1 \cdot wpp_{r-1,t} + (1 - DK1) \cdot wpp_{r-1,t} + DK1$
- Estimated using the 3-stage Random Effects Instrumental Variables (REIV)

Retail consumption for the single grid Radius, including eq. (2)

- $\ln \hat{p}_{rt} = wpp_{rt} + wpp_{r-1,t}$
- Estimated using 2SLS estimation

Results and discussion

Elasticity for large and medium-sized firms

Table 1: log wholesale electricity consumption (REIV)

	(1) Peak: 11-15 b/se	(2) Off-peak: 00-04 b/se	(3) Shoulder b/se	(4) Non-business days b/se
log spot price	-0.05395***	-0.02602***	-0.03519***	-0.01843**
	(0.01526)	(0.00803)	(0.01347)	(0.00869)
log wholesale meters	0.77368***	0.77700***	0.76910***	0.78972***
	(0.19452)	(0.21942)	(0.21198)	(0.22659)
Temperature	-0.00374***	-0.00188***	-0.00282***	-0.00475***
	(0.00072)	(0.00058)	(0.00041)	(0.00068)
Temperature squared	0.00016***	0.00019***	0.00015***	0.00021***
	(0.00003)	(0.00004)	(0.00002)	(0.00003)
Daytime			-0.03280***	-0.02832***
			(0.00855)	(0.00712)
Time variables	Yes	Yes	Yes	Yes
Observations	191,100	191,100	685,256	450,320

Cluster robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Log spot price is instrumented for by wind power prognosis for the same and the other region.

Time-of-use tariff for households and small firms in Radius

Table 2: log retail electricity consumption in Radius, hours 17-19 (2SLS)

	(1) All days b/se	(2) Business days b/se	(3) Non-business days b/se
log spot price	-0.01597**	-0.02624***	-0.00515
	(0.00734)	(0.00803)	(0.01823)
Share time-of-use tariff	-0.01907**	-0.01382*	-0.04444***
	(0.00796)	(0.00800)	(0.01553)
log retail meters	-0.92839	-1.31922	-0.29035
	(0.85359)	(0.92132)	(1.53637)
Temperature	-0.00332***	-0.00405***	-0.00395***
	(0.00058)	(0.00073)	(0.00133)
Temperature squared	0.00002	0.00004	-0.00000
	(0.00002)	(0.00003)	(0.00005)
Daytime	-0.04708***	-0.04502***	-0.02614
	(0.01018)	(0.01084)	(0.01884)
Time variables	Yes	Yes	Yes
Observations	3,288	2,205	1,083

Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Log spot price is instrumented for by wind power prognosis for the same and the other region.

Robustness checks for wholesale consumption

Sample split results for price-elasticity of wholesale consumption

- By month: Heterogeneous. Insignificant elasticity for May, August, December
- By year: A small increase in 2018, though difference is statistically insignificant
- By price region: Insignificant elasticity for Eastern Denmark
  - Wind power is less important for price formation in Eastern Denmark
  - $\rightarrow$ IV estimation might be worse at capturing variation in prices
- By grid company: Significant estimates for the five biggest grid companies
  - Smallest elasticities for Aarhus (NRGI) and Copenhagen (Radius)
  - Service industry plays a higher role than manufacturing?

Table 3: log wholesale electricity consumption, business days from 11-15 (2SLS)

	(1) EnergiMidt b/se	(2) NRGI b/se	(3) SE b/se	(4) SEAS-NVE b/se	(5) Radius b/se
log spot price	-0.07786***	-0.00909***	-0.05986***	0.01722***	-0.01125***
	(0.00821)	(0.00322)	(0.00513)	(0.00624)	(0.00276)
Control variables	Yes	Yes	Yes	Yes	Yes
Price region	DK1	DK1	DK1	DK2	DK2
Observations	3,675	3,675	3,675	3,675	3,675

Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Log spot price is instrumented for by wind power prognosis for the same and the other region.

Robustness checks for retail consumption

Effect of time-of-use tariff in Radius given by eq. (2) included for other grid-companies, though meaningless as such

- Pseudo regression run for the remaining 51 grid companies
- "Effect" is significant and even higher for many of the other grid companies
  - $\rightarrow$ The identifying assumption that hour-by-month and hour-by-day patterns are constant over the years is clearly violated

Instead we need micro data to construct a proper Regression Discontinuity Design

- Identify the individual discontinuity that each retail consumer faces
- i.e. being moved from residual to flex-settled metering

Discussion

Possible extensions to our analysis:

- Micro-data would allow us to further explore demand responses and heterogeneities therein

Limited prospects for using price tools to lower (peak) demand for electricity

$\rightarrow$ Smart devices might be better

Possible improvement of instrumental variable estimation

- Including wind power prognosis for Sweden
- For full exogeneity use pure wind speed instead, ideally the day-ahead forecast
- Weekly hydro reservoir for Norway (Sweden and Finland) could be used but would create a dynamic bias $\rightarrow$ GMM

Conclusion

To sum up

Wholesale electricity demand

- Price elasticity is modest but quite consistent over time
- While the estimated elasticities are highly statistically significant same cannot be said for the economic significance
- Micro data with industry codes could help explain regional differences

Retail electricity demand

- Demand for electricity is quite inelastic and inconsistent
- Micro data is needed to identify the effect of the time-of-use-tariff in Radius