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

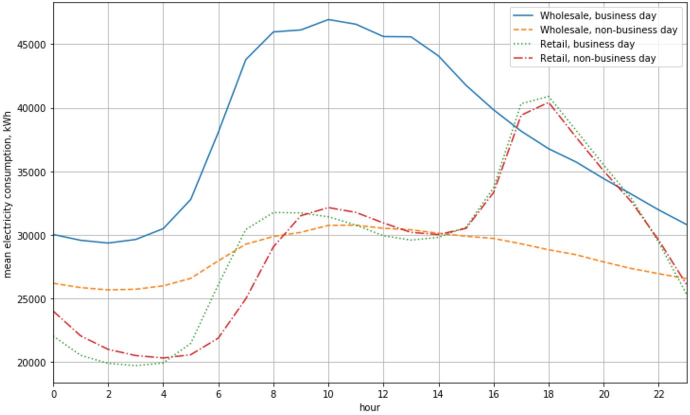
Weather variables

- Temperature (scraped from DMI)
- Daytime variable using sunset and sunrise (scraped from soltider.dk)
- Collected for the two biggest municipalities, Aarhus and Copenhagen
  $\rightarrow$ 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)

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

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 ψ_i
  - But including a term for the effect of the TOU tariff:

$$\beta \frac{nf_{month}}{nr_{month}} \tau_{year,month} \tag{2}$$

  - $\frac{nf_{month}}{nr_{month}}$ 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, $\psi_i > 0$, 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. $cov(\psi_i, \boldsymbol{x}_{it}) = 0$.
- Hausman test: $\hat{\beta}^*_{RE} = \hat{\beta}^*_{FE} \rightarrow$ no endogeneity 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:
$y_{it} - \hat{\lambda}\bar{y}_i = \beta_0(1-\hat{\lambda}) + \beta_1(\boldsymbol{x}_{it} - \hat{\lambda}\bar{\boldsymbol{x}}_i) + \psi_i(1-\hat{\lambda}) + u_{it} - \hat{\lambda}u_{it}.$

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
  - → 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 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