



Heterogeneity in demand responses to electricity spot prices

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Outline

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Introduction

Background

Economics theory

Data

Empirical strategy

Results and discussion

Conclusion

Introduction

- 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

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

Electricity different from other goods: Essentially impossible to store

→ 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 → decrease in spot price

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

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

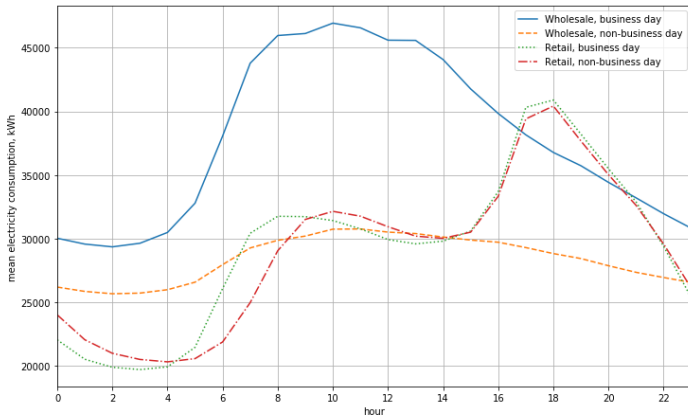
Weather variables

- 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

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

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

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

$$\propto \frac{nf_{\text{month}}}{nr_{\text{month}}} \tau_{\text{year, month}} \quad (2)$$

- $\frac{nf_{\text{month}}}{nr_{\text{month}}}$ 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, $cov(u_{it}, \mathbf{x}_{it}) = 0$, 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. $cov(c_i, \mathbf{x}_{it}) = 0$.
- 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:
$$y_{it} - \hat{\lambda}\bar{y}_i = \beta_0(1 - \hat{\lambda}) + \beta_1(\mathbf{x}_{it} - \hat{\lambda}\bar{\mathbf{x}}_i) + c_i(1 - \hat{\lambda}) + u_{it} - \hat{\lambda}u_{it}.$$

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

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*** (0.01526)	-0.02602*** (0.00803)	-0.03519*** (0.01347)	-0.01843** (0.00869)
log wholesale meters	0.77368*** (0.19452)	0.77700*** (0.21942)	0.76910*** (0.21198)	0.78972*** (0.22659)
Temperature	-0.00374*** (0.00072)	-0.00188*** (0.00058)	-0.00282*** (0.00041)	-0.00475*** (0.00068)
Temperature squared	0.00016*** (0.00003)	0.00019*** (0.00004)	0.00015*** (0.00002)	0.00021*** (0.00003)
Daytime			-0.03280*** (0.00855)	-0.02832*** (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** (0.00734)	-0.02624*** (0.00803)	-0.00515 (0.01823)
Share time-of-use tariff	-0.01907** (0.00796)	-0.01382* (0.00800)	-0.04444*** (0.01553)
log retail meters	-0.92839 (0.85359)	-1.31922 (0.92132)	-0.29035 (1.53637)
Temperature	-0.00332*** (0.00058)	-0.00405*** (0.00073)	-0.00395*** (0.00133)
Temperature squared	0.00002 (0.00002)	0.00004 (0.00003)	-0.00000 (0.00005)
Daytime	-0.04708*** (0.01018)	-0.04502*** (0.01084)	-0.02614 (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*** (0.00821)	-0.00909*** (0.00322)	-0.05986*** (0.00513)	0.01722*** (0.00624)	-0.01125*** (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.

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
 - 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

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

→ 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

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