Prices as Climate Policy: Assessing the Causal Effect of Electricity Prices on German Manufacturing Plants

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Camp Resources XXIV

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Motivation

- Climate policies play an important role in current policy making around the globe
  - $\Rightarrow$ Often resulting in higher energy and electricity prices
- Industry representatives and politicians are concerned about negative impacts on competitiveness or employment
  - $\Rightarrow$ Because of incomplete regulation worldwide
- Evidence from microdata on the effects of increasing energy costs on firm performance is still relatively scarce

- Germany is interesting because...
  - the Energy Transition has resulted in rising energy costs
  - manufacturing remains an important sector
    - Roughly 20% of employment
    - 40% of electricity use & 20% of CO_2 emissions

Summary

- Aim of our study:
  Assessing the causal impacts of electricity prices on electricity use and economic performance of plants in the German manufacturing sector.
- Data sources:
  Official plant-level census data by the German Statistical Offices in combination with data on electricity prices and network charges.
- Identification strategy:
  Identifying the causal impact with an instrumental variable approach utilizing exogenous variation in electricity network charges at spatial discontinuities and over time.
- Preliminary results:
  Our results suggest that a 1% increase in electricity prices results in a reduction of electricity use by around 1.5%. We find no statistically significant effects on employment, revenues, or investments.

Related literature

- Analyses of different tax and surcharges schemes in UK and Germany
  - Price instruments impact electricity use, but no statistically significant effects on economic performance measures. (Martin et al. 2014, *JPubE*; Flues and Lutz 2015, *DP*; Gerster 2015, *DP*)
- Simulation of a US wide carbon price
  - Small increase in net imports and a decrease in production.(Aldy and Pizer 2015, *JAERE*)
- Analysis on more aggregated levels
  - Energy-intensive US manufacturing industries concentrate in low electricity price counties. (Kahn and Mansur 2013, *JPubE*)
  - Higher electricity prices lead to output reductions and lower labor demand in the German manufacturing sector. (Cox et al. 2014, *EnergyPol*)
- Also related to literature on own price elasticities of industrial electricity demand ▸ Table

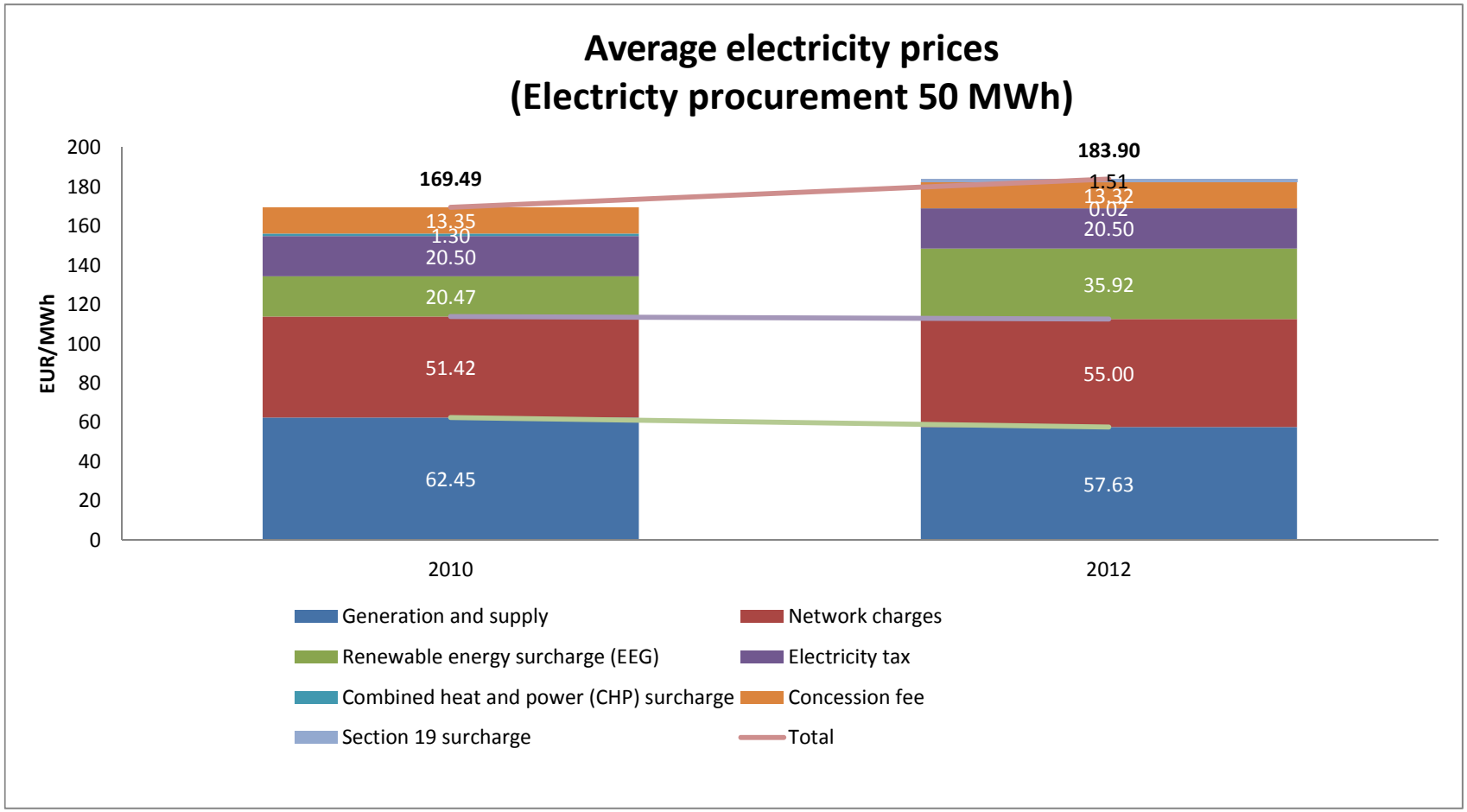
Identification strategy

- We construct the electricity price p as a function of electricity procurement x for each municipality j: $p_j(x)$ (two-part tariff)
- Our approximative electricity price is potentially endogenous and subject to measurement error
  - Every plant selects its electricity provider (unobservable)
- We can explain a large share of the electricity price by exogenous factors
  - Thirty to forty percent are taxes, levies, surcharges etc.
  - Thirty percent are regulated network charges
- Plants cannot select their network operator
  - The only way to choose different network charges is to change plant location

$\Rightarrow$ Network charges as an instrumental variable

▸ IV Approach

Composition of electricity prices

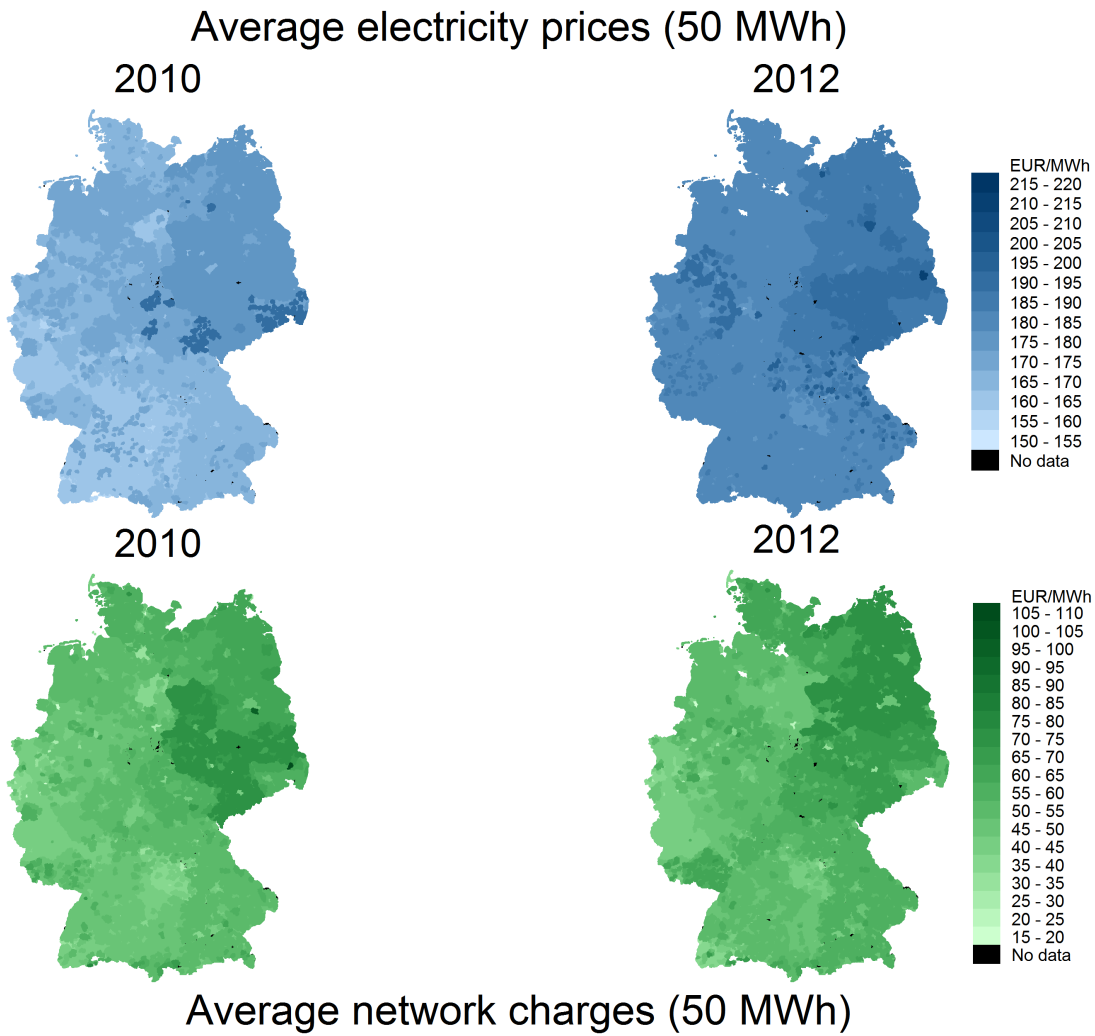


Why are network charges exogenous to each plant?

- Network operation is regulated by the federal network agency (*Bundesnetzagentur*)
  - Benchmarking of cost structure with efficiency criteria → Specific revenue cap
- Mandatory annual publication of network charges according to revenue cap
  - Cost components (⇒ No congestion pricing) ▸ Regression
    - Network operation (e.g. maintenance, infrastructure investments, connection of new plants and installations)
    - System support services (e.g. redispatch, balancing power)
    - Transmission losses
  - Every customer in the network area pays a network charge (depending on voltage level, metering, use etc.)

⇒ Based on the regulatory framework, the network charges are arguably exogenous to the individual plant

Spatial variation of electricity prices and network charges



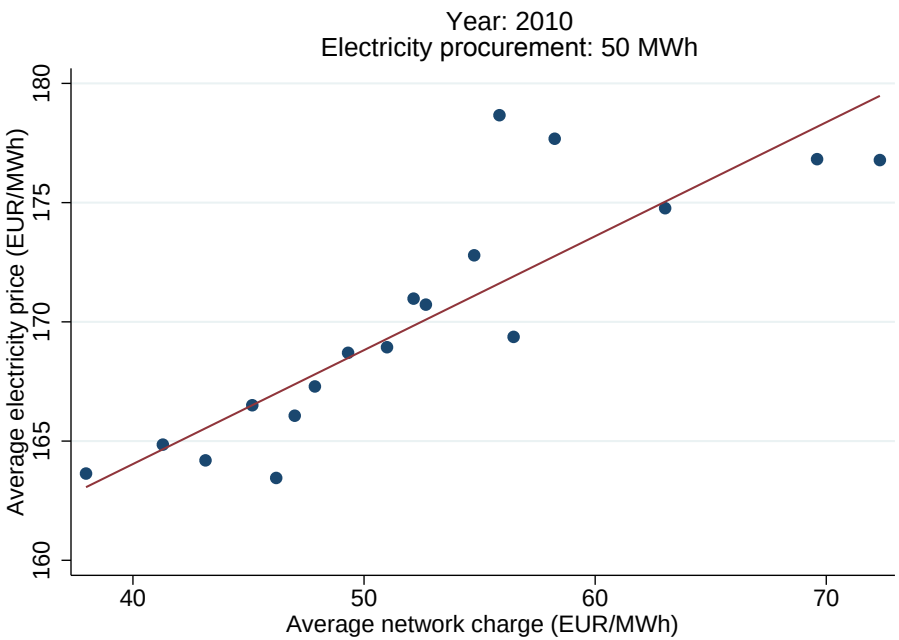
▸ Zoom

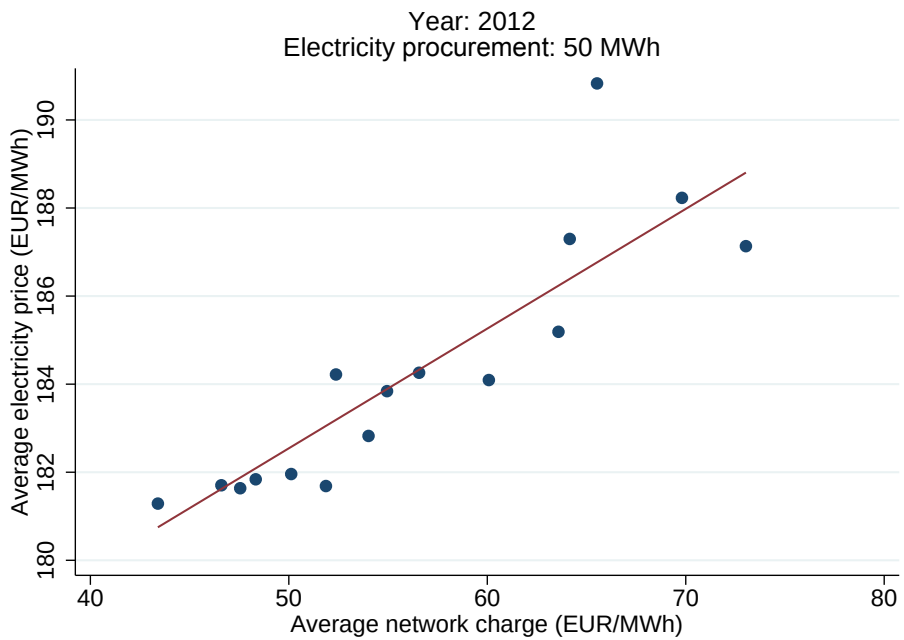
Data: Official firm data for Germany (AFiD)

- AFiD Panel Industrial Units and AFiD-Module Use of Energy
- All manufacturing firms with $\geq$ 20 employees
- Information on approx. 60,000 plants / 40,000 firms
- Annual data, current focus: 2010 - 2012
- Due to the availability of electricity price tariffs we limit attention to plants procuring $\leq$ 100 MWh/year ▸ Data

Descriptive statistics	**Mean**	**St. dev.**	**P10**	**P50**	**P90**	**N**
2010						
Total revenues (1,000 EUR)	5,194.27	29,086.75	753.57	2,439.39	7,786.69	7,456
Number of employees	34.72	50.98	8	28	54.17	7,625
Total investment (1,000 EUR)	81.59	390.52	0	17.01	166.52	7,206
Electricity use (MWh)	385.21	6,999.10	13.05	54.22	92.44	7,859
Electricity procurement (MWh)	51.28	28.06	10.80	52.12	89.9	7,859
Average electricity price (EUR/MWh)	170.58	13.32	161.56	169.79	177.13	7,505
Average network charge (EUR/MWh)	49.58	10.16	39.43	48.27	63.67	7,530
Average electricity cost/total cost	0.006	0.004	0.001	0.005	0.011	1,546
Average electricity cost/total revenues	0.006	0.028	0.001	0.003	0.011	7,104

Empirical relationship in the first stage





Results - Electricity demand 2010-2012

Dependent variable:	**Panel FE IV excl. self-generation** ln(electricity procurement)		**Panel FE IV incl. self-generation** ln(electricity procurement)		**Panel FE IV incl. self-generation** ln(electricity use)	
	Str. eq.	First stage	Str. eq.	First stage	Str. eq.	First stage
ln(average elec. price)	-1.474***		-1.529***		-1.446***	
	(0.111)		(0.111)		(0.111)	
ln(average netw. charge)		0.268***		0.266***		0.266***
		(0.006)		(0.005)		(0.005)
Constant	11.359***	4.141***	11.651***	4.148***	11.239***	4.148***
	(0.577)	(0.022)	(0.576)	(0.021)	(0.574)	(0.021)
Plant fixed effects	yes	yes	yes	yes	yes	yes
R^2	0.03	0.16	0.03	0.16	0.03	0.16
F test of excl. instruments		407.54		438.21		
Observations		21,233		22,399		22,399

* p<0.10, ** p<0.05, *** p<0.01. Standard errors in parentheses and clustered at the plant level.
The dependent variable varies across the columns with columns 1-4 concerning electricity procurement and columns 5-6 electricity use.
The sample varies across the columns with columns 1-2 concerning only plants without self-generation and columns 3-6 including those plants.
Results are also robust, if standard errors are clustered at the network or county level.

Development of self-generation capacities

- Plants with self-generation: 336 (2010) $\rightarrow$ 552 (2012)
- Share of total plants: 4.35% (2010) $\rightarrow$ 7.03% (2012)
- Own price elasticity with regard to self-generated electricity: 3.2

Results - Economic performance 2010-2012

	Panel FE IV					
Dependent variable:	ln(revenues)		ln(employment)		ln(investments+1)	
	Str. eq.	First stage	Str. eq.	First stage	Str. eq.	First stage
ln(average elec. price)	0.087		0.037		0.767	
	(0.115)		(0.066)		(1.631)	
ln(average netw. charge)		0.268***		0.271***		0.247***
		(0.006)		(0.005)		(0.006)
Constant	14.286***	4.140***	3.022***	4.127***	-7.753	3.767***
	(0.596)	(0.021)	(0.341)	(0.214)	(7.903)	(0.034)
Plant fixed effects	yes	yes	yes	yes	yes	yes
Controls	no	no	no	no	yes	yes
R^2	0.004	0.16	0.001	0.17	0.01	0.17
Observations	21,319		21,776		19,578	

* p<0.10, ** p<0.05, *** p<0.01. Standard errors in parentheses and clustered at the plant level.
The sample includes plants with own electricity generation.
Controls are employment, revenues, export status

Subsamples - Electricity demand 2010-2012

Sector (ISIC Rev. 4)	Dependent variable:	**Panel FE IV excl. self-generation** ln(electricity procurement)		**Panel FE IV incl. self-generation** ln(electricity procurement)		**Panel FE IV incl. self-generation** ln(electricity use)	
All sectors (10-33)	ln(average elec. price)	-1.474***	(0.111)	-1.529***	(0.111)	-1.446***	(0.111)
Food products (10)		0.267	(0.654)	-0.325	(0.611)	0.006	(0.567)
Bakery products (107)		0.540	(1.104)	0.232	(1.004)	0.205	(1.001)
Fabricated metal products (25)		-0.039	(0.301)	-0.033	(0.287)	0.002	(0.301)
Structural metal products (251)		0.064	(0.364)	0.052	(0.344)	0.165	(0.358)
Computer & electronics (26)		-1.099**	(0.432)	-1.043**	(0.430)	-0.992**	(0.430)
Electrical equipment (27)		-1.665***	(0.443)	-1.723***	(0.450)	-1.611***	(0.447)
Electric motors, generators, transformer etc. (271)		0.165	(0.402)	-0.116	(0.426)	0.020	(0.440)
Machinery (28)		-1.337***	(0.278)	-1.425***	(0.277)	-1.402***	(0.277)
Medical and dental instruments and supplies (325)		-2.063***	(0.390)	-2.174***	(0.400)	-2.178***	(0.390)
Repair of fabr. metal products, machinery, equipment (331)		-1.635***	(0.390)	-1.494***	(0.391)	-1.514***	(0.390)
Installation of industrial machinery and equipment (332)		-0.400	(0.508)	-0.576	(0.504)	-0.100	(0.501)

* p<0.10, ** p<0.05, *** p<0.01. Standard errors in parentheses and clustered at the plant level.
Coefficients of independent variable: ln(average elec. price).
Results are also robust, if standard errors are clustered at the network or county level.

Subsamples - Economic performance 2010-2012

		Panel FE IV			
Sector (ISIC Rev. 4)	Dependent variable:	ln(revenues)		ln(employment)	
All sectors (10-33)	ln(average elec. price)	0.087	(0.115)	0.037	(0.066)
Food products (10)		0.989	(0.714)	1.109	(0.698)
Bakery products (107)		1.924**	(0.937)	-0.043	(1.100)
Fabricated metal products (25)		0.502	(0.338)	-0.238	(0.175)
Structural metal products (251)		0.061	(0.404)	-0.250	(0.217)
Computer & electronics (26)		0.198	(0.333)	0.136	(0.178)
Electrical equipment (27)		-1.141	(0.330)	-0.125	(0.196)
Electric motors, generators, transformer etc. (271)		0.122	(0.440)	0.141	(0.223)
Machinery (28)		0.660*	(0.386)	0.357**	(0.161)
Medical and dental instruments and supplies (325)		0.031	(0.265)	-0.114	(0.172)
Repair of fabricated metal products, machinery and equipment (331)		0.216	(0.371)	-0.134	(0.207)
Installation of industrial machinery and equipment (332)		0.271	(0.517)	0.602**	(0.301)

* p<0.10, ** p<0.05, *** p<0.01. Standard errors in parentheses and clustered at the plant level.
The sample includes plants with own electricity generation.

Conclusion

- Analysis of causal effect of electricity prices on small manufacturing plants in Germany
- Increase in electricity prices leads to reductions in electricity procurement and electricity use
  - Electricity own price elasticity of around -1.5
  - Some plants respond by shifting to self-generation
    - Presumably avoidance behavior, effects are unclear (regulatory & environmental)
  - Heterogeneity across sectors
- No statistically significant effects on revenue, employment, or investment
  - Only short-run elasticities
  - Despite no effects on revenues, lower product sales possible $\rightarrow$ Cost pass-through

Road ahead

- Evaluation of self-generation as response to price changes
  - Regulatory framework (exemptions, taxes etc.)
  - Characteristics of self-generation (power plants, capacity etc.)
  - Composition of self-generation (fossil vs. renewable)
- Extend the analysis to the full sample ($>$ 100 MWh electrictiy procurement) and to 2014
  - More recent data will be accessible soon
  - Only possible with network charges $\rightarrow$ No electricity prices available
  - New matching strategy and assumptions necessary $\rightarrow$ Different tariff structure (load based metering)

Thank you!

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Instrumental Variable Approach

- Our model framework:

$$y_{ijt} = \alpha_i + \beta p_{ijt} + \varepsilon_{ijt} \quad (1)$$

$$p_{ijt} = \gamma_i + \xi nc_{ijt} + u_{ijt} \quad (2)$$

  - (1) model of interest
    - i – plant, t – year, j – electricity network provider
    - y – log of electricity procurement (electricity use incl. self-generation)
    - α_i – plant level fixed effects $\Rightarrow$ capture all time invariant plant-specific characteristics
    - β – elasticity, i.e. percentage change in electricity procurement for a 1% change in the electricity price
    - p – log electricity price
  - (2) first stage equation for the instrumental variable procedure
    - nc – log network charge

Back

The German electricity market

- The Energy Act of 1998 (start of liberalization process)
- The new Energy Act of 2005
  - Installment of a national regulatory agency (Bundesnetzagentur)
    $\rightarrow$ Regulated third party network access
  - Legal and operational unbundling of electricity generation and network operation

Generation		**Network**		**Retail**
– Competition on wholesale market	$\Rightarrow$	– Regulated monopoly	$\Rightarrow$	– Competition on retail market – All customers (firms and households) can choose their individual provider

Regulatory framework of German network charges

- Introduction of network tariff regulation in the electricity sector in 2005 (TSOs) and 2007 (DSOs)
  - Focus: Reduction of existing monopoly profits and inefficiencies in network operations
- Introduction of incentive regulation in 2009
  - Benchmarking with efficiency criteria
    - Since 2012 including a quality component
  - Specific revenue cap for every network operator
  - Adjustment of network charges according to the revenue cap
  - Every customer in the network area has to pay for the costs of the network operation

Network characteristics 2012

	TSOs	DSOs	Total
Network operators (number)	4	806	810
Total circuit length (km)	34,841	1,753,290	1,788,131
Extra high voltage	34,780	490	35,270
High voltage	61	95,364	95,425
Medium voltage	0	507,953	507,953
Low voltage	0	1,149,973	1,149,973
Total transmission route length (km)	17,961		
Extra high voltage	17,454		
High voltage	507		
Total final customers (metering points)	649	48,769,032	48,769,681
Industrial and business customers	509	3,046,244	3,046,753
Household customers	140	45,722,788	45,722,928

Source: BNetzA and BKartA (2013)

Determinants of low voltage network charges

Panel FE Avg. Network Charge				
Dependent variable: ln(avg. nwc 50 MWh)				
ln(number of demand connection points in low voltage)	-0.020	-0.021	-0.021	-0.022
	(0.018)	(0.018)	(0.018)	(0.018)
ln(capacity of non RES power plants)	0.018	0.020		
	(0.024)	(0.023)		
ln(capacity of RES in low voltage)	0.035**	0.037**		
	(0.017)	(0.017)		
ln(capacity of RES in high voltage)		0.001		
		(0.003)		
ln(capacity of RES in medium voltage)		-0.002		
		(0.002)		
ln(number of non RES power plants)			0.063	0.078
			(0.074)	(0.070)
ln(number of RES in low voltage)			0.048**	0.051**
			(0.022)	(0.023)
ln(number of RES in high voltage)				0.014
				(0.012)
ln(number of RES in medium voltage)				-0.007
				(0.010)
Constant	1.663***	1.670***	1.692***	1.694***
	(0.201)	(0.203)	(0.196)	(0.195)
Year FE	yes	yes	yes	yes
Number of observations	1,658	1,658	1,658	1,658
R-squared	0.032	0.033	0.031	0.033

* p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses and clustered at the network level.

Back

Electricity prices and network charges

Electricity prices

- Database of all offered electricity tariffs by retailers
  - Industry/business tariffs for electricity procurement $\leq$ 100 MWh
  - Municipality level (around 12,000)
  - Updated daily, one snapshot per year on December 31st
- Construction of electricity prices in sample
  - Relevant prices consist of a two-part tariff:
    - Price for electricity procurement (EUR/MWh)
    - Price per year (EUR/a)
  - Calculation of average costs per year and electricity procurement in every municipality
    - $\Rightarrow$ Assumption: Firms choose the tariff with the lowest yearly costs (5th percentile to correct for data errors)

Network charges

- Database of all published network tariffs
  - Mandatory annual publication of price sheets for network areas by network operators
  - Around 800 network operators

Construction of network charges in sample

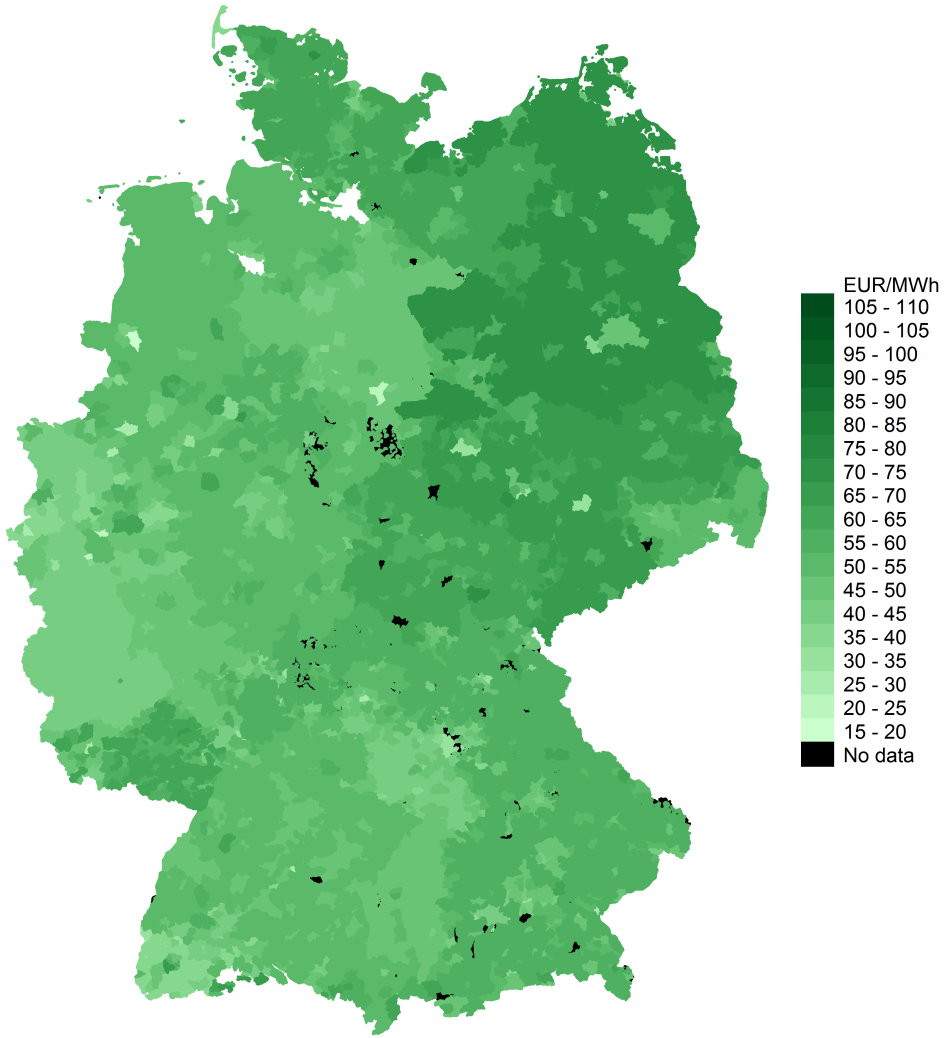
- Depending on relationship of municipality area and network area
  - One network in one municipality $\rightarrow$ Clear allocation of network charges
  - Multiple networks in one municipality $\rightarrow$ No clear allocation of network charges possible. In this case we use the average network charge.
- Different charges for
  - voltage levels (low, medium, high, (extra high voltage) voltage)
  - load profiles (Standard load profile (SLP) vs. Interval-metered (RLM))
  - usage hours ($<$ 2500h vs. $>$ 2500h)

Construction of electricity prices in sample

Year	2008	2012
Total number of products	305,140	1,292,663
Products for businesses/industry	83,754	125,337
Used products in sample [1]	28,098	119,335
Total number of tariffs resp. pricing schemes	1,215,822	4,360,548
Number of tariffs per municipality	100	388
Number of municipalities	12,238	11,253
Number of electricity networks	718	767

[1] Used products: No default contracts of default suppliers; Only standard products (no bonus, premium, rebates or discounts)

Spatial variation of network charges 2012 (50 MWh)



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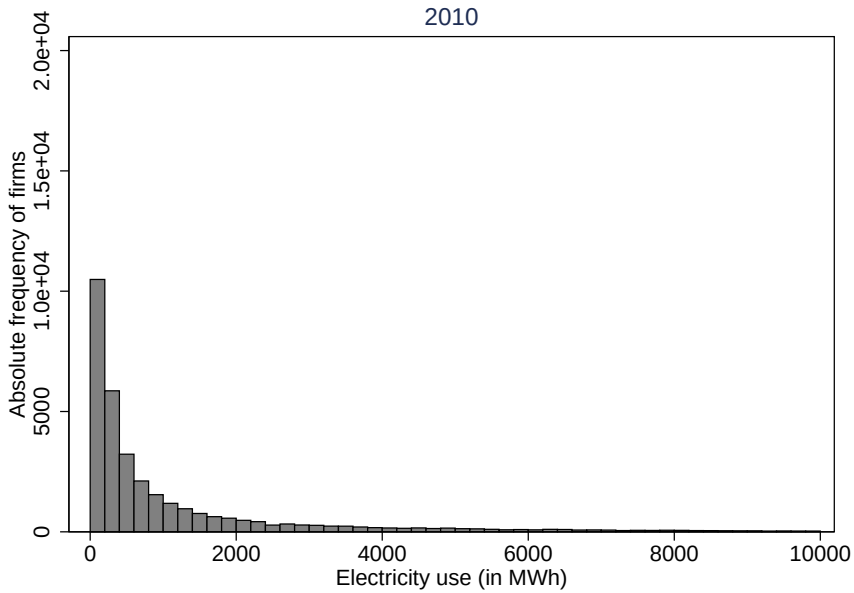
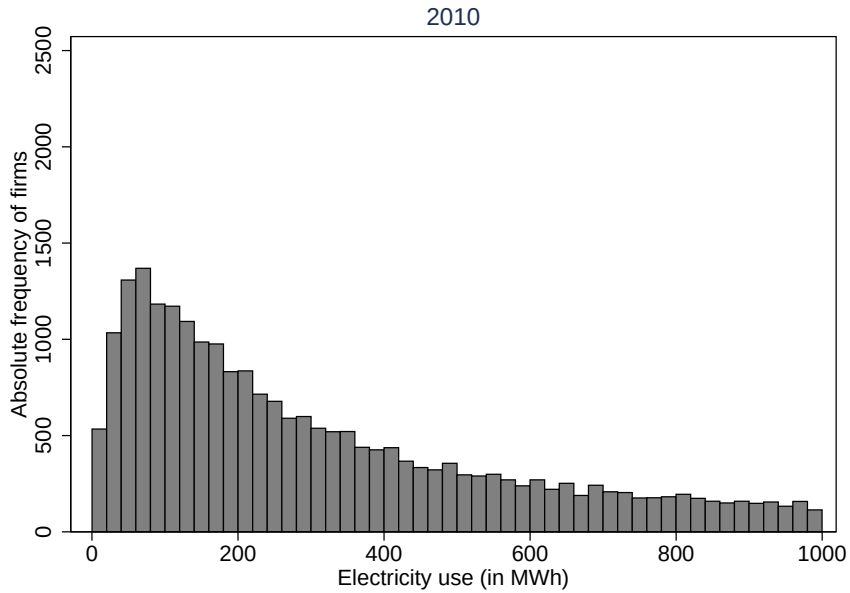
Economic activity & electricity cost shares in 2010

ISIC Rev. 4	Industry	Obs.	Percent	Average EC/TC	Average EC/TR
05	Coal mining	1	0.01	.	.
06	Oil extraction	1	0.01	.	.
08	Other mining	192	2.44	0.002	0.036
09	Mining support services	6	0.08	0.002	.
10	Food products	398	5.07	0.010	0.013
11	Beverages	23	0.29	0.006	0.011
12	Tobacco products	4	0.05	0.013	.
13	Textiles	121	1.54	0.009	0.006
14	Wearing apparel	111	1.41	0.006	0.005
15	Leather products	49	0.62	0.007	0.006
16	Wood and cork	149	1.86	0.008	0.007
17	Paper and paper products	66	0.84	0.012	0.008
18	Print and recorded media	186	2.37	0.005	0.007
19	Coke and refining	4	0.05	.	.
20	Chemicals	117	1.49	0.005	0.013
21	Pharmaceuticals	36	0.46	0.004	0.004
22	Rubber and plastic	250	3.18	0.006	0.006
23	Non-metallic mineral products	621	7.91	0.008	0.013
24	Basic metals	38	0.48	0.005	0.005
25	Fabricated metal products	1,064	13.55	0.006	0.005
26	Computer, electronics and optics	456	5.81	0.005	0.003
27	Electrical equipment	551	7.01	0.005	0.003
28	Machinery and equipment n.e.c.	1,133	15.42	0.006	0.004
29	Motor vehicles	139	1.77	0.008	0.004
30	Other transport equipment	37	0.47	0.005	0.005
31	Furniture	119	1.51	0.011	0.005
32	Other manufacturing	792	10.08	0.007	0.005
33	Repair and installation	1,194	15.20	0.003	0.003
	Total number of observations	7,855		1,546	7,104

Distribution of electricity use in 2010





Notes: Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) - AFiD-Panel Industrial Units and AFiD-Module Use of Energy, own calculations.

Own price elasticities, electricity

- Evidence from comparable studies of industrial electricity demand

Elasticity	Time period	Data	Authors
-1 – -1.7	1977 – 1985	Rep'd cross section AUS	Woodland 1993, *EnergyJ*
-0.6	1983 – 1996	Panel DK	Bjørner et al. 2001, *EnergyEcon*
-0.5	2000 – 2005	Panel ITA	Bardazzi et al.2015, *EnergyEcon*
-1.2	2001 – 2008	Panel IND	Abeberese forthc., *REStat*

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Regression Results - 2010-2012 - Including controls

Dependent variable:	**Panel FE IV excl. self-generation** ln(electricity procurement)		**Panel FE IV incl. self-generation** ln(electricity procurement)		**Panel FE IV incl. self-generation** ln(electricity use)	
	Str. eq.	First stage	Str. eq.	First stage	Str. eq.	First stage
ln(average elec. price)	-1.566***		-1.656***		-1.547***	
	(0.133)		(0.135)		(0.134)	
ln(average netw. charge)		0.219***		0.217***		0.217***
		(0.005)		(0.005)		(0.005)
ln(employees)	0.138***	-0.006**	0.139***	-0.004	0.145***	-0.004
	(0.016)	(0.003)	(0.016)	(0.003)	(0.016)	(0.003)
ln(revenues)	0.102***	0.024***	0.101***	0.024***	0.100***	0.024***
	(0.010)	(0.002)	(0.010)	(0.002)	(0.010)	(0.002)
export dummy	0.022*	0.001	0.022*	0.001	0.024*	0.001
	(0.012)	(0.002)	(0.012)	(0.002)	(0.012)	(0.002)
real property tax	0.001***	0.001***	0.002***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
trade tax	0.002***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	8.781***	3.480***	9.253***	3.483***	8.736***	3.483***
	(0.589)	(0.034)	(0.592)	(0.033)	(0.590)	(0.033)
Plant fixed effects	yes	yes	yes	yes	yes	yes
R^2	0.06	0.29	0.05	0.29	0.05	0.29
Observations	19,585		20,739		20,739	

* p<0.10, ** p<0.05, *** p<0.01. Standard errors are clustered at the plant level.
The dependent variable varies across the columns with columns 1-4 concerning electricity procurement and columns 5-6 electricity use.
The sample varies across the columns with columns 1-2 concerning only plants without self-generation and columns 3-6 including those plants.

Regression Results - 2010-2012 - Self-generation

- Plants with self-generation:336 (2010) $\rightarrow$ 552 (2012)
- Share of total plants: 4.35% (2010) $\rightarrow$ 7.03% (2012)

	Panel FE IV		**Panel FE IV**		**Panel Tobit RE**
Dependent variable:	ln(electricity self-generation)		ln(electricity self-generation+1)		
	Str. eq.	First stage	Str. eq.	First stage	
ln(average elec. price)	3.179**		0.611***		
	(1.470)		(0.176)		
ln(average netw. charge)		0.237***		0.254***	3.295***
		(0.027)		(0.005)	(0.313)
ln(employees)	0.095	0.047***	0.063***	-0.005	1.127***
	(0.217)	(0.016)	(0.024)	(0003)	(0.119)
ln(revenues)	0.141	0.016***	0.024	0.029***	0.297***
	(0.098)	(0.007)	(0.015)	(0.002)	(0.082)
export dummy	0.081	-0.003	-0.151	0.000	-0.019
	(0.109)	(0.008)	(0.018)	(0.002)	(0.113)
Constant	-15.435**	3.859***	-3.514***	3.785***	-29.705***
	(7.130)	(0.148)	(0.861)	(0.033)	(1.745)
Plant fixed effects	yes	yes	yes	yes	no, random effects
R^2	0.07	0.15	0.01	0.17	
Log-likelihood					-5,038.93
Observations	1,159	1,159	20,793	20,793	20,863

* p<0.10, ** p<0.05, *** p<0.01. Standard errors are clustered at the plant level.
Columns 1-2 are for the sample of plants with own electricity generation. Columns 3-5 are for the complete sample. For the latter, the dependent variable has been transformed by adding 1 before taking the logarithm.