Energy Tax Exemptions and Industrial Production

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Motivation

- Many environmental regulations do only **apply to a subset of jurisdictions** (carbon taxes, EU-ETS)
- Concern about **'leakage' of industrial activity and emissions**
- Policy response: **exemption schemes** for energy-intensive and trade-exposed (EITE) industries

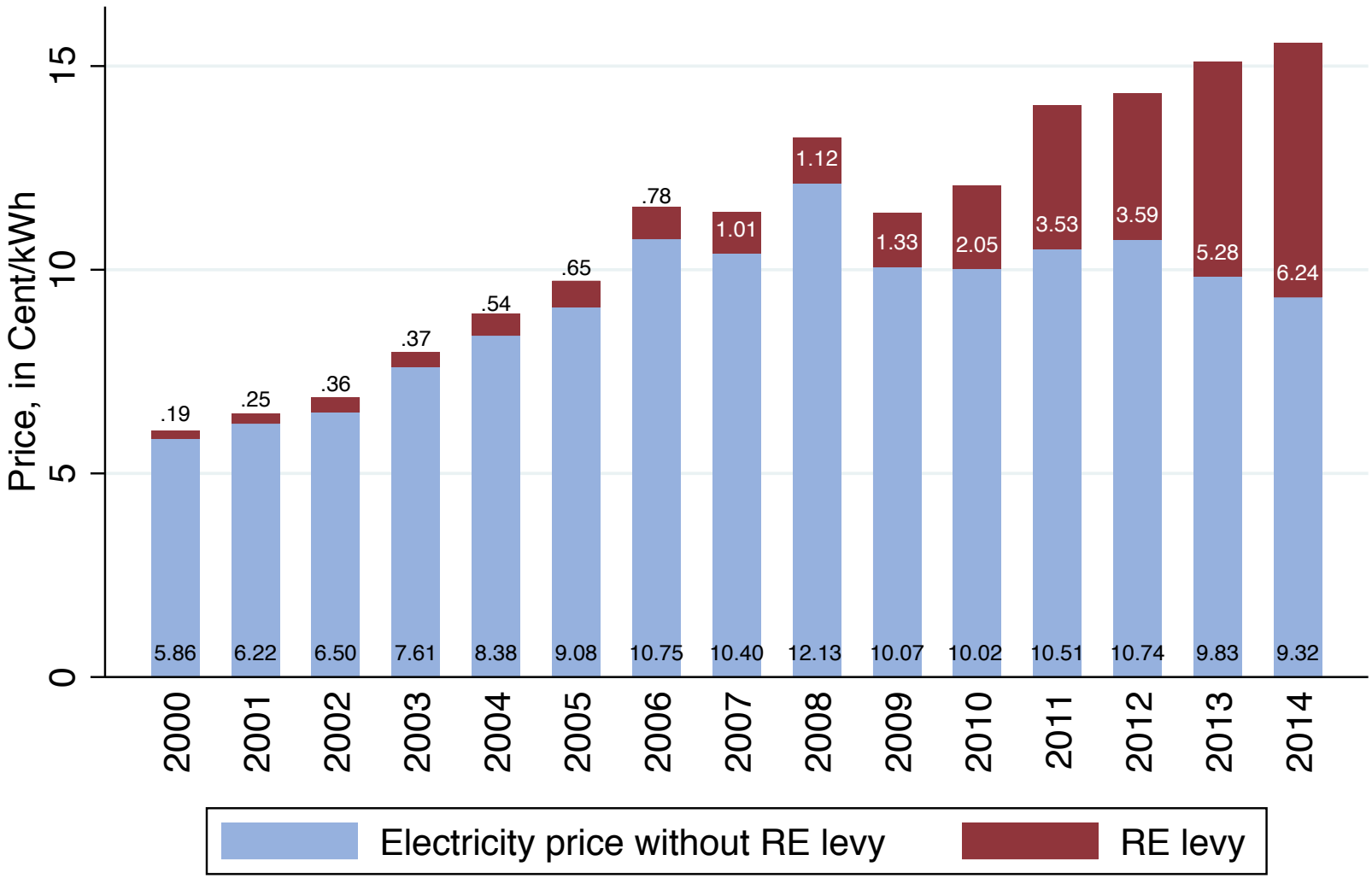
Should EITE industries be protected?

- *Exemptions necessary to sustain domestic production* **vs.**
- *Exemptions undermine incentives for improving energy efficiency and might lead to equity concerns*

Context: Renewable Energy Levy (REL)

- REL (tax on electricity prices) introduced to finance subsidy schemes for renewable energies
- Focus on Germany as a leader in renewable energy deployment with large subsidy scheme
- REL is **paid by all electricity users**, but exemptions for EITE industries
- Increasing deployment of renewable energies has led to a **surge in total subsidy cost** from approximately 8 billion Euros in 2010 to 22 billion Euros in 2014

Electricity Prices in the German Industry

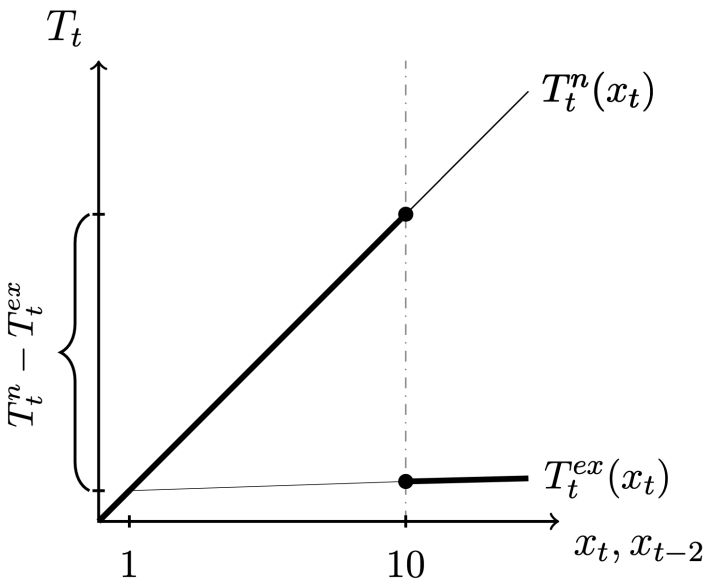


Source: BDEW 2014

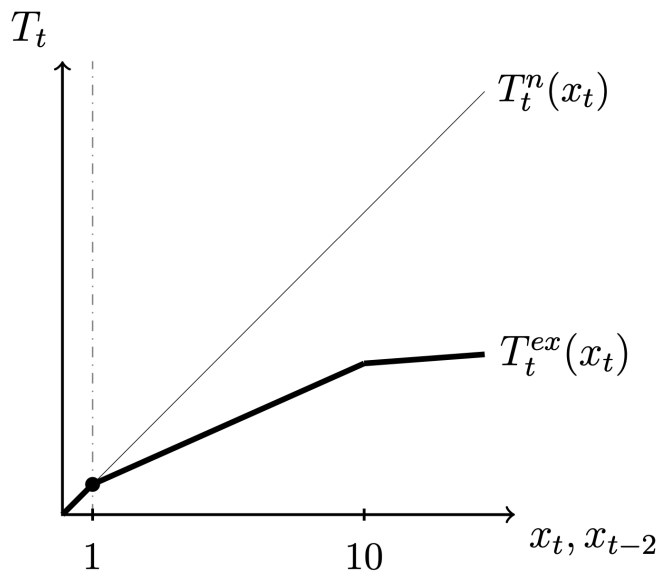
This Paper

- Empirically assess the impact of exemption schemes on **plant-level inputs** and **outputs**
- Contributes to policy design: **'notched' schedule** vs. **'reformed' schedule**, where inframarginal benefits have been largely removed

Notched schedule



Reformed schedule



This Paper

- Empirically assess the impact of exemption schemes on **plant-level inputs** and **outputs**
- Contributes to policy design: **'notched' schedule** vs. **'reformed' schedule**, where inframarginal benefits have been largely removed
  - **Notched policy design:**
    - Natural Experiment: financial crisis (2008/09) induces local randomization around an eligibility cutoff
      → fuzzy Regression Discontinuity (RD) design
  - **Reformed policy design:**
    - Natural Experiment: major policy reform in 2012 expanded exemption eligibility criteria and removed the 'notch'
      → matching Difference-in-Differences (DiD) estimator

Main Findings

Qualitatively, both evaluations yield very similar results:

1. Exempted plants increase electricity use
2. Potential mechanism: fuel substitution
3. No evidence for impact on exemptions on outputs (sales, export share, investment) and employment

Quantitatively, our results differ:

1. **Notched schedule:** $\sim 40\%$ increase in electricity use
2. **Reformed schedule:** $\sim 5\%$ increase in electricity use

Contribution

- Provide evidence that exemption schemes are **not effective** in increasing competitiveness of exempted industry
- Depending on the policy design, **exemptions can lead to distortions of energy input use** with implications for carbon emissions
- Provide empirical estimates for price elasticity from **large exogenous change in electricity prices** in manufacturing sector

Data

- German Manufacturing census (AFiD): 2007-2013
  - Scope: all German manufacturing *plants* with more than 20 employees
  - Production survey: plant-level information on energy use, employment, gross output, exports
  - Cost structure survey: firm-level information on total energy cost and gross value added
- List of REL exempted plants for the years 2010-2013 (BAFA)

Empirical strategy: fuzzy RDD

- **Potential outcomes framework:** changes in outcomes between plants that pay the full levy and plants that are exempted:

$$\alpha_{ATT} = E\left[Y_{it}(1) - Y_{it}(0) | D_i = 1\right]$$

- ATT for compliers at the cutoff, ATT^{RD}, identified as

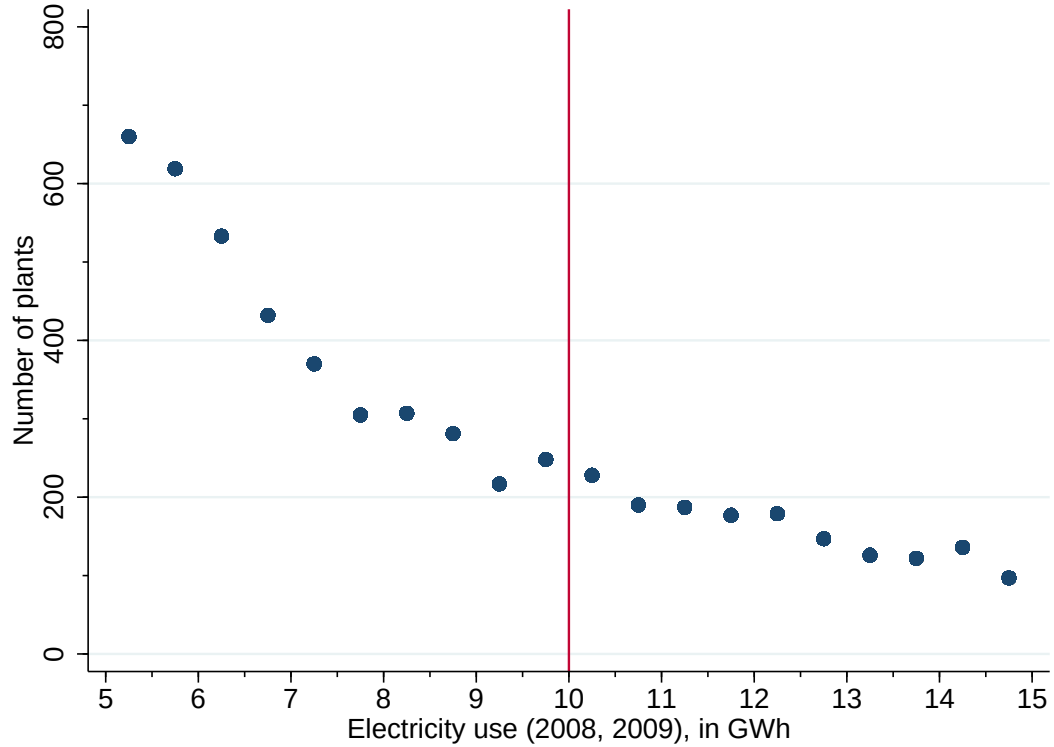
$$ATT^{RD} = \frac{\lim_{\epsilon \downarrow 0} E(Y_i | R_i = c + \epsilon) - \lim_{\epsilon \uparrow 0} E(Y_i | R_i = c + \epsilon)}{\lim_{\epsilon \downarrow 0} E(T_i | R_i = c + \epsilon) - \lim_{\epsilon \uparrow 0} E(T_i | R_i = c + \epsilon)},$$

- **Key assumptions:** Jump in treatment probability at c, treatment affects all plants in same direction, conditional expectations of the potential outcomes, $E(Y_i(j)|R_i)$ for $j \in \{0, 1\}$, continuous at c

RD design

- Exploit **local randomization around 10 GWh threshold** during financial and economic crisis via fuzzy RD design
  - In 2008/09, gross value added in the manufacturing sector plummeted unexpectedly by 20.7 % and led to widespead use of short-term working arrangements
  - Electricity input in manufacturing is highly output dependent: crisis increased cost for potential 'bunching'

Selection above the threshold?



- McCrary's test of continuity:

Year	2008	2009	2010	2011
Test statistic	0.04	0.05	0.37**	-0.15
	(0.15)	(0.16)	(0.16)	(0.14)

Estimation results for the ATT

	ATT^{RD} (1)	Standard errors (2)	n (3)
Panel A: *Electricity & fuel usage*			
Electricity consumption [GWh]	4.037**	1.756	33,032
Log electricity consumption	0.526*	0.301	33,407
Log fossil fuel consumption	0.086	0.500	29,945
Share of total energy mix:			
Electricity [%]	0.187	0.122	33,102
Fossil fuel [%]	−0.232**	0.118	33,077
Panel B: *CO2 emissions*			
Log CO_2, direct	0.175	0.506	29,960
Log CO_2, total	0.685*	0.377	33,268
Panel C: *Competitiveness indicators*			
Log employment	0.153	0.181	32,639
Log sales	0.394	0.299	34,119
Export share	−0.137*	0.081	33,957
1(investment)	−0.166	0.206	35,861
1(investment machinery)	−0.130	0.183	35,861
Log investment	0.847	1.178	25,736

Robustness

- Intra-firm spillovers (SUTVA violations): single-plant firms
  ▸ Spillover
- Placebo RD regression on baseline variables
- Varying bandwidths and treatment of outliers ▸ Bandwidth
- Local polynomial regressions ▸ Local polynomial estimation

Empirical strategy: matching DiD

- Exploit extension in eligibility criteria via matching DiD approach (Heckman, Ichimura, and Todd, 1997)
- The ATT^{DiD} is defined as:

$$ATT^{DiD} = \frac{1}{N_1} \sum_{i \epsilon I_1} \left\{ (Y_{it}(1) - Y_{i0}(0)) - \sum_{k \epsilon I_0} W_{N_0,N_1}(i,k)(Y_{kt}(0) - Y_{k0}(0)) \right\}$$

- I_1 denotes the set of N_1 REL exempt plants
- Weight W with $\sum_{k \epsilon I_0} W_{N_0,N_1}(i,k) = 1$ determines weighting of counterfactual observation k
- **Key assumptions:** Overlap, SUTVA, conditional unconfoundedness

Matching DiD: Pre-treatment trends

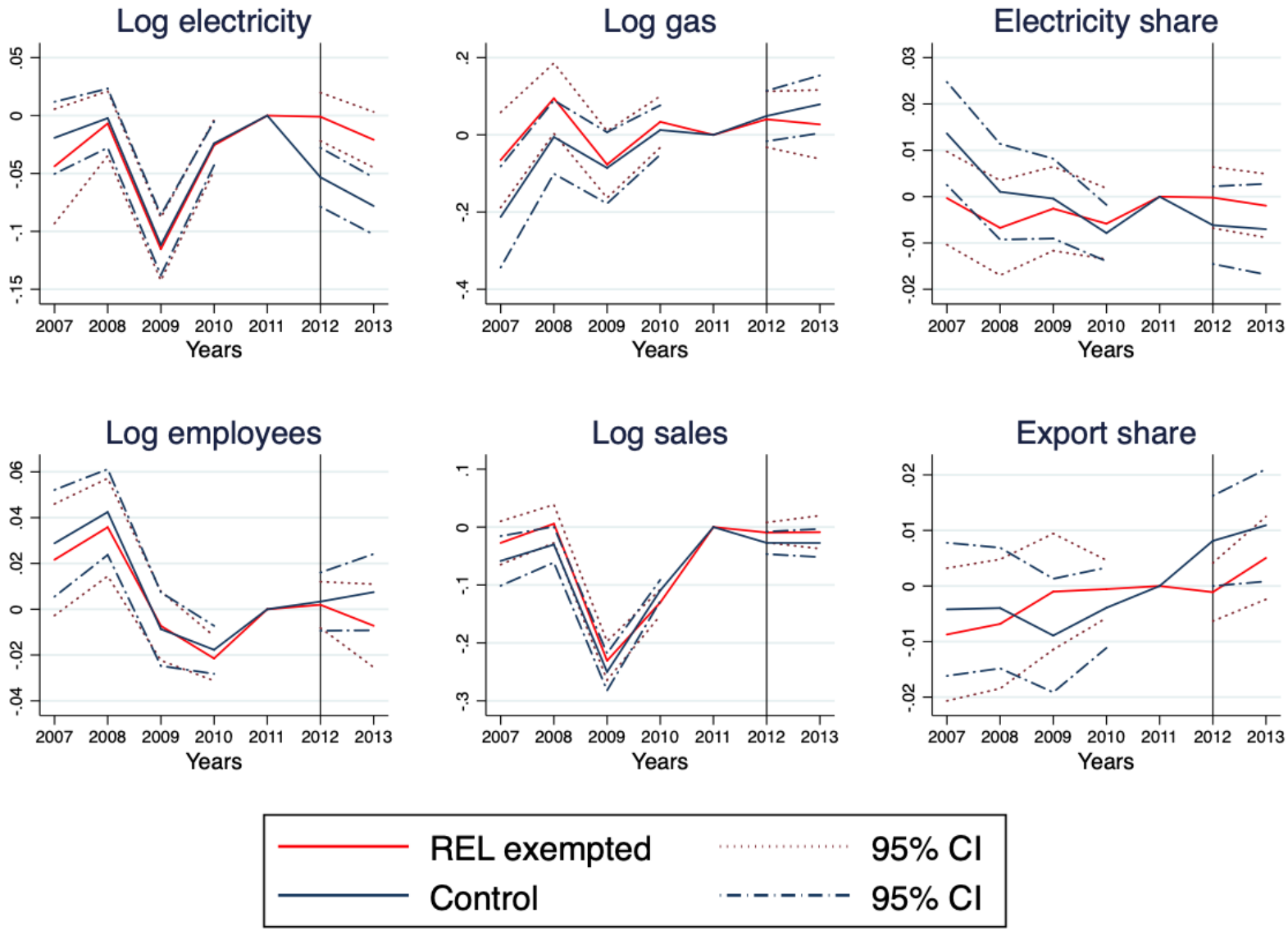


Table: Results Matching DiD Estimates (1:1 matching)

Δ 2013-2011	ATT^{DiD} (1)	SE (2)
Panel A: *Electricity & fuel usage*		
Log electricity consumption	0.057***	0.018
Log fossil fuel consumption	−0.039	0.046
Share of total energy mix:		
Electricity [%]	0.005	0.006
Fossil fuel [%]	−0.005	0.006
Panel B: *CO2 emissions*		
Log CO_2, direct	−0.026	0.046
Log CO_2, total	0.053***	0.018
Panel C: *Competitiveness indicators*		
Log employment	−0.015	0.013
Log sales	0.018	0.020
Export share	−0.006	0.006
1(investment)	−0.011	0.021
1(investment machinery)	−0.011	0.017
Log investment	0.028	0.129
# of observations	916	
# of treated plants	458	

Robustness

- Anticipation of policy change: base year 2010 ▸ Anticipation
- Intra-firm spillovers: single-plant firms ▸ Spillover
- Subsample: 5-10 GWh plants ▸ Sample 1
- Selection into Treatment (growth expectations) ▸ Group DiD
- Balanced sample in electricity and gas use ▸ Sample 2
- Matching: Propensity score based only on electricity intensity (no lags) and economic sub-sectors ▸ Matching

Discussion

- Exemption schemes are **not effective in increasing competitiveness** of exempted industry
  - Total cost of exemption policy in 2013, approx. 4 billion Euros
  - Equity concern for renewable energy financing

- Exemption **policies can distort energy inputs**
  - Impact on CO_2 emissions
  - Back-of-the-envelope: BR leads to approximate cost of 200k Euros (emissions + electricity wholesale price) per bunching plant
  - Total effect: $\sim$ 40m Euros in 2010/11 (200 plants)

- **Caveat:** Focus on medium-sized energy-intensive plants in manufacturing, mostly short-run effects

Conclusion

- This paper analyzes the impact of a large energy tax exemption scheme on the German manufacturing industry
- Using two sources of exogenous variation, we show that:
  - Notched exemption: $\sim 40\%$ increase in electricity use
  - Reformed exemption: $\sim 5\%$ increase in electricity use
  - Exemptions have no impact on competitiveness indicators
- Exemptions are costly and might not be effective in their objective to retain domestic production
- Policy design matters: caution against notched exemption schemes

APPENDIX

Summary statistics (2013)

	Non-exempt plants			EEG exempt plants: 1-10GWh			All EEG exempt plants		
VARIABLE	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.
Plant-level data									
Economic covariates									
Sales, in million €	37.265	453.930	39,045	26.527	69.815	641	79.284	219.216	1,458
Export share (of sales)	0.214	0.263	39,045	0.212	0.262	641	0.281	0.286	1,458
Number of employees	135.879	620.459	38,422	73.300	83.006	645	176.893	251.244	1,454
Investments, in million €	1.229	15.275	39,198	0.775	5.563	639	2.339	7.160	1,444
Average wage per employee, in thd. €	33.695	13.614	38,421	33.577	9.795	645	38.755	14.848	1,454
Energy-related covariates									
Electricity use, in GWh	3.652	48.653	38,917	5.474	4.360	630	52.280	164.919	1,429
Energy use (w/o electricity), in GWh	15.939	631.243	39,049	9.574	18.800	638	120.379	602.199	1,443
Own electricity generation, in %	0.089	0.285	40,755	0.085	0.279	659	0.129	0.335	1,482
Electricity use per gross output	3.244	423.100	37,913	2.364	37.007	622	1.737	24.771	1,419
Electricity share in total energy	0.518	0.259	38,917	0.599	0.310	630	0.558	0.316	1,429
Gas share in total energy	0.297	0.292	38,917	0.281	0.307	630	0.281	0.301	1,429
Oil share in total energy	0.134	0.237	38,917	0.050	0.136	630	0.035	0.115	1,429
Coal share in total energy	0.005	0.063	38,917	0.010	0.086	630	0.031	0.134	1,429
Renewables share in total energy	0.047	0.161	38,917	0.061	0.194	630	0.094	0.229	1,429
Total CO_2 emissions, in 1,000 t	5540	181444	39,049	4707	4983	638	50328	181140	1,443
Direct CO_2 emissions, in 1,000 t	3862	175915	39,049	1692	4064	638	22876	139819	1,443
CO_2 intenisty of energy use, in g per kWh	407.699	121.206	38,917	415.643	132.297	630	395.483	141.136	1,429
Electricity use (t-2), in GWh	3.768	46.610	36,693	5.135	2.350	608	56.096	192.672	1,431

Back of the Envelope

- EEG reform 2012 led to approximately 5.2 TWh of additionally privileged electricity, representing 200 million Euros of subsidies to the energy-intensive manufacturing industry
- In 2013, total of 1,700 exempt plants receive subsidies of approximately 4 billion Euros
- Without exemptions, EEG levy approximately 1 cent / KWh lower for all electricity consumers

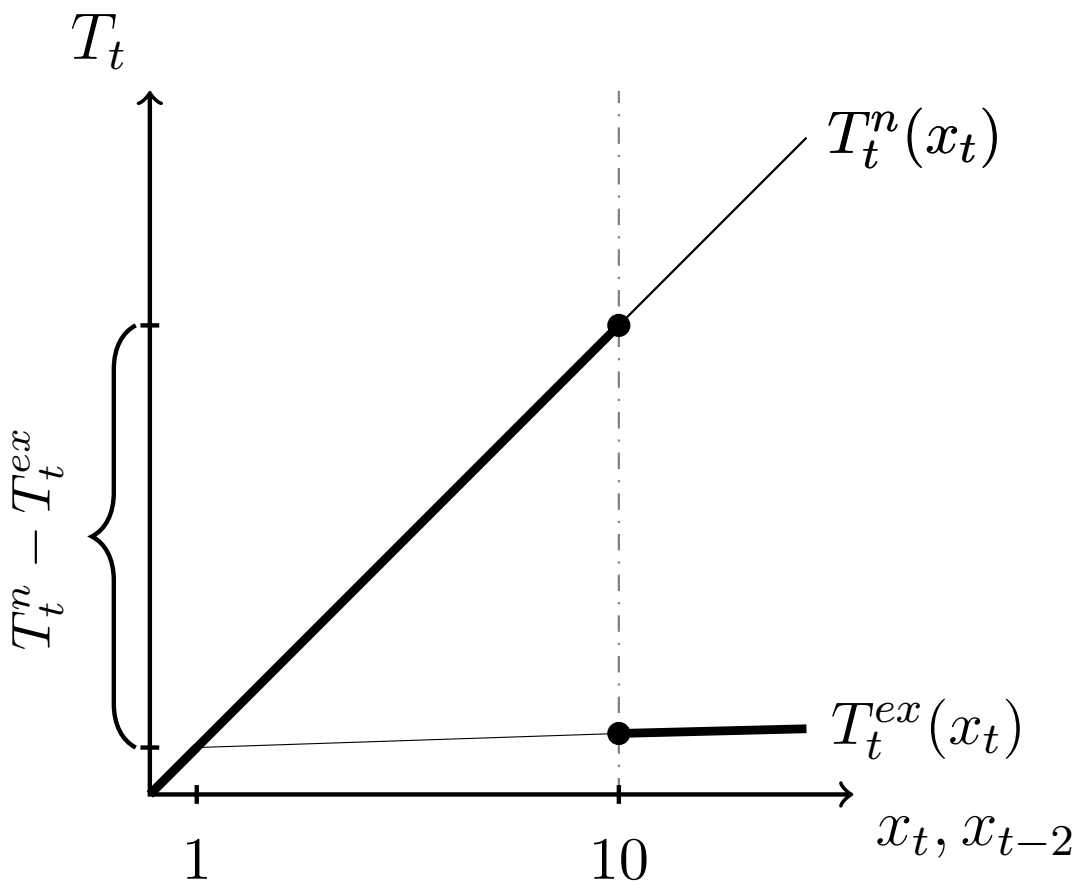
REL exemptions prior to 2013

Eligibility is determined by two cutoff rules:

1. electricity use at the **plant level** is larger than **10 GWh**
2. the share of electricity cost to gross value added at the **firm level** is larger than **15 %**

- Application timeline for exemption:
  - to be exempt in year t
  - plants apply in year $t-1$
  - with data from year $t-2$

REL exemption schedule prior to 2013



Implication, if exempted:

- below 1 GWh:
  pay 100% of levy
- between 1 and 10 GWh:
  pay 0.05 cent per kWh
- above 10 GWh:
  pay 0.05 cent per kWh

→ **Notched schedule**

REL exemption schedule from 2013

Eligibility extended substantially by changing cutoffs:

1. Electricity use cutoff reduced from **10 to 1 GWh**
2. Share of electricity cost to gross value added cutoff reduced from **15 % to 14 %**

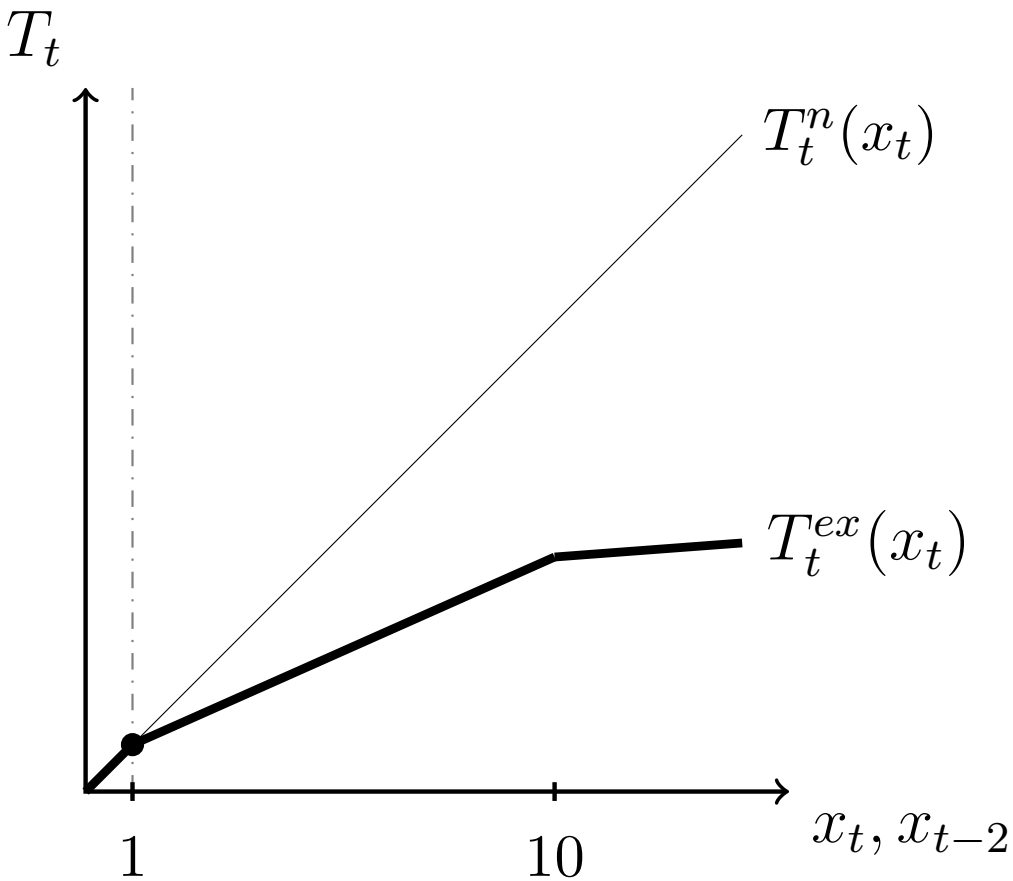
Implications of the reform:

- Increased the number of exempt plants from 683 to 1,663; yet left total amount of exempted electricity largely unchanged
- Eliminated the tax notch at 10 GWh

Timing of the reform:

- 'EEG 2012' enacted in late 2011
- For plants to be exempted in 2013, needed to apply in 2012, based on data from 2011

REL exemption schedule from 2013



Implication, if exempted:

- below 1 GWh:
  pay 100% of levy
- between 1 and 10 GWh:
  pay 10% of levy
- above 10 GWh:
  pay 1% of levy

→ **Notch no longer present**

Input Choices and Policy Design

- Tax exemptions under the **notched policy design** can impact production input choices in two ways:
  - Exemption reduces marginal tax rate for all exempted firms $\rightarrow$ **marginal price response** (in absence of notch).
  - Exemption in current period works as **'subsidy for bunching'**: lower prices today make it profitable for more firms to increase their electricity consumption above the eligibility threshold
- Test for impact of REL exemptions under both policy designs to distinguish **marginal price response** from **net bunching response**

Decomposition of Responses

- Use the two sets of empirical estimates to distinguish between **the marginal price response (MPR) and the net bunching response (BR)**

- The treatment effect of exempting firms from the electricity tax is then:

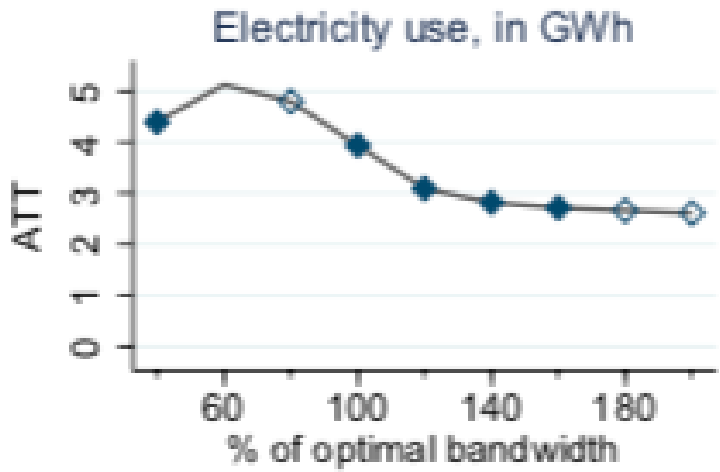
$$TE = MPR_{\text{no notch}} + \Delta BR,$$

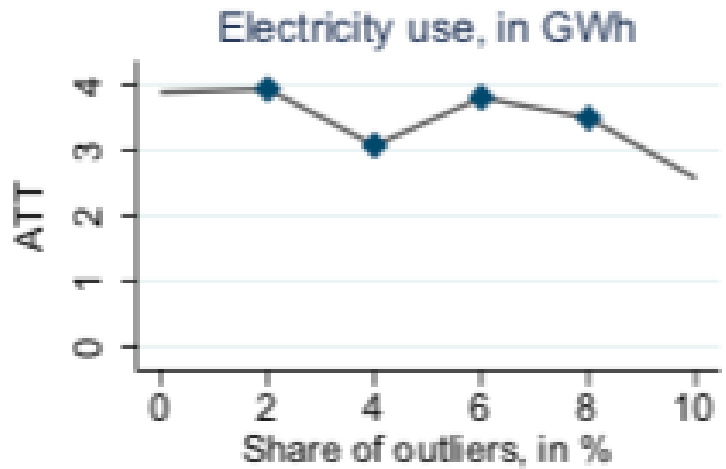
where ΔBR denotes the net bunching response to getting exempt. ▸ Model Details

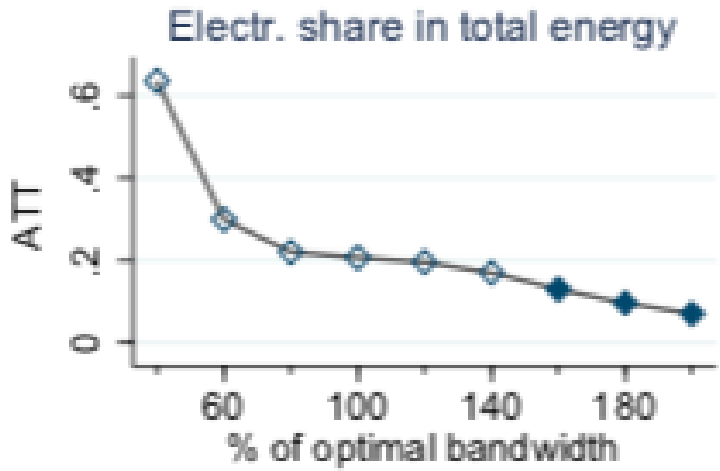
Decomposition of Effect Sizes

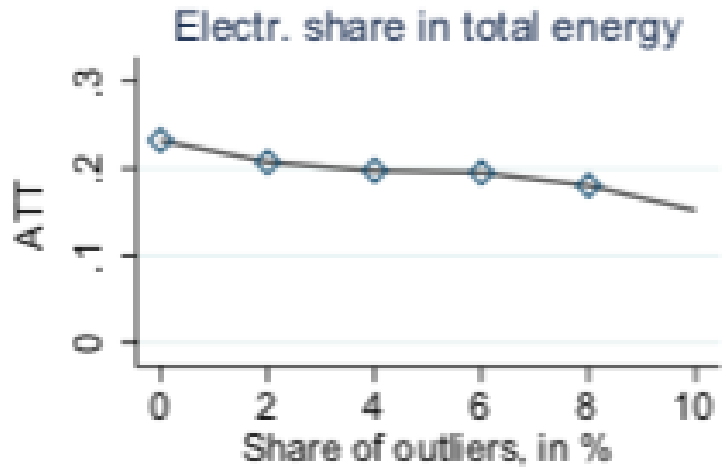
Estimand	Estimated Term from Model	ATT	ΔPrice	Elasticity
ATT^{RD} (10 GWh)	(1): $MPR + BR$	40.4%	21.1%	-1.92
ATT^{DiD} (1-10 GWh)	(2): MPR	5.7%	31.4%	-0.18
	(1)$-$(2) $= BR$	34.7%		-1.73

Robustness 1: Bandwidth and Outliers









Back

Robustness 2: Local polynomial estimation

- local polynomial regressions might better capture the CEF

	ATT (electricity use)	Std. errors	# of obs.
Second order polynomials	4.92**	2.08	1,380
Third order polynomials	5.93*	3.39	1,380
Fourth order polynomials	5.05	3.95	1,380

Notes: Estimation by 2SLS where the variable of passing the threshold, Z_i is used as an instrument for the treatment variable T_i. Observations are clustered at the firm level. *, **,*** denote significance at the 10 %, 5 %, 1 % level, respectively.

Back

Robustness 3: SUTVA

- Does intra-firm decision making drive the results?
- Exclude all firms with multiple plants

ATT (electricity use)	Std. errors	# of obs.
3.851	6.329	27,868

Notes: Observations are clustered at the firm level. *, **,*** denote significance at the 10 %, 5 %, 1 % level, respectively.

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Model

Let firms have the following profit function:

$$\pi = y(\psi x, z) - qz - px - T(x),$$

where x: taxed production input, z: composite untaxed input, $y(\cdot)$: production function, $\psi \in [\underline{\psi}, \bar{\psi}]$: firm's productivity with respect to x.

A government implements a notched tax schedule $T(x)$, which is defined as follows:

$$T(x) = \begin{cases} tx - A \text{ if } x \geq \hat{x} \\ tx \qquad\quad \text{if } x < \hat{x}, \end{cases}$$

where t: per-unit tax rate of x, A: subsidy that a firm obtains when its consumption of x surpasses a predefined threshold value $\hat{x}$.

Model

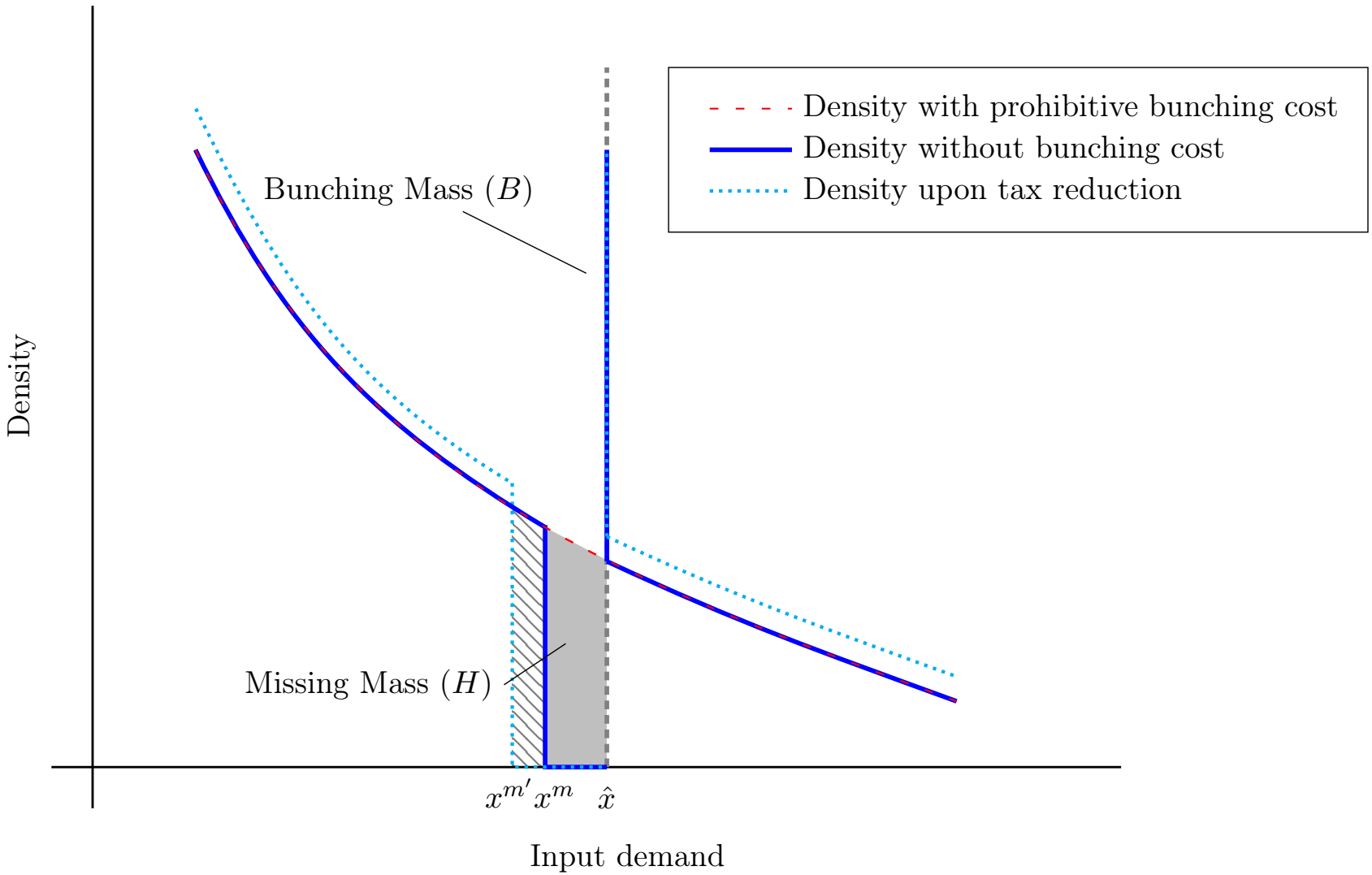
The first derivative of average consumption x^* w.r.t. t^{ex}:

$$\frac{\partial x^*}{\partial t^{ex}} = \underbrace{\int_0^{\infty} \frac{\partial x^c}{\partial t^{ex}} g(\psi) d\psi}_{\text{Marginal price response}} + \underbrace{\int_{\psi^{m'}}^{\psi^m} (\hat{x} - x^c)\, g(\psi) d\psi - \int_{\psi^{m'}}^{\psi^{\hat{x}}} \frac{\partial x^c}{\partial t^{ex}} g(\psi) d\psi}_{\text{Net bunching effect of notch}}.$$

- Exempting plants under a notched schedule works as a **subsidy for bunching**.

▸ Back

Response to exemption in a notched schedule



Test for parallel pre-treatment trends

VARIABLE	Treat mean	Specification 1 Control mean	Specification 1 Control p-value	Specification 2 Control mean	Specification 2 Control p-value
Differences: 2011-2010					
Electricity	.026	.024	0.876	.058	0.132
Sales	.130	.111	0.124	.109	0.236
Employment	.025	.020	0.543	.023	1
Export share	.001	.003	0.572	0.001	0.989
Wage	.032	.027	0.536	.032	0.987
Electricity share	.003	0.011	0.147	.017	0.011**
Differences: 2010-2009					
Electricity	.098	.10	0.904	.091	0.749
Sales	.108	.144	0.025**	.129	0.181
Employment	-.0105	-.0025	0.304	-.004	0.443
Export share	.001	.004	0.564	.006	0.321
Wage	.052	0.035	0.268	.036	0.322
Electricity share	-.004	-0.008	0.467	-0.003	0.857

Note: Pre-treatment differences for group of treated firms (EEG exempt in 2013) and two distinct control groups, based on nearest neighbor matching. T-test for equality of means in growth rates 2011 and growth rates 2010. * p<.1 ,** p<.05, and ***p<.01.

Table: Propensity score: Logit regression - Specification 1

Exempt 2013	beta	std err.
electricity	3.005***	(0.556)
lag electricity	.680**	(0.319)
lag 2 electricity	.445*	(0.259)
lag 3 electricity	.348*	(0.211)
sales	-.548**	(0.239)
employment	.638	(0.923)
wage	4.197	(3.255)
electricity × electricity	-.448**	(0.173)
sales × sales	.015	(0.042)
employment × employment	-.341**	(0.111)
wage × wage	-.855*	(0.480)
Export share	-.323	(0.675)
Export share × Export share	-.267	(0.868)
Constant	Y	
Observations	9064	
Pseudo R^2	.42	
2-digit sector FE	17	

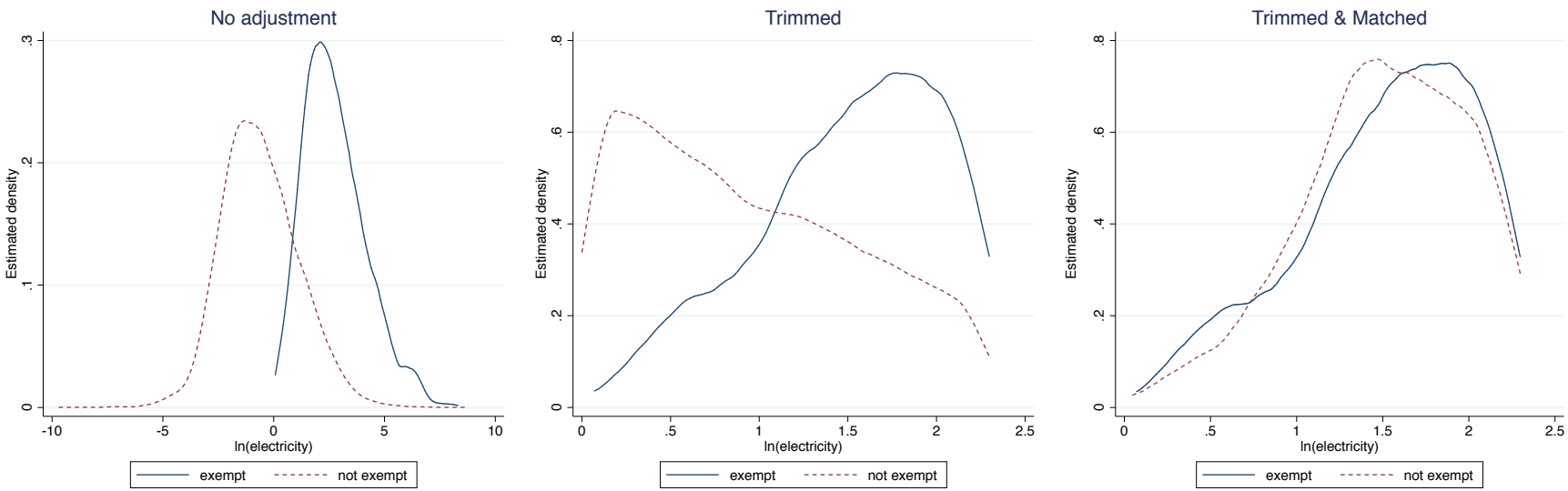
Note: Main dependent variable: EEG exempt 2013. Plants with 1-10 GWh electricity consumption in 2011. All dependent variables refer to the base year, 2011. Logit regression. Lower case variables in logs. Regression controls for manufacturing sub-sectors with 2-digit specific fixed-effects. $p < 0.1$ (*), $p < 0.05$ (**), $p < 0.01$ (***).

Table: Propensity score: Logit regression - Specification 2

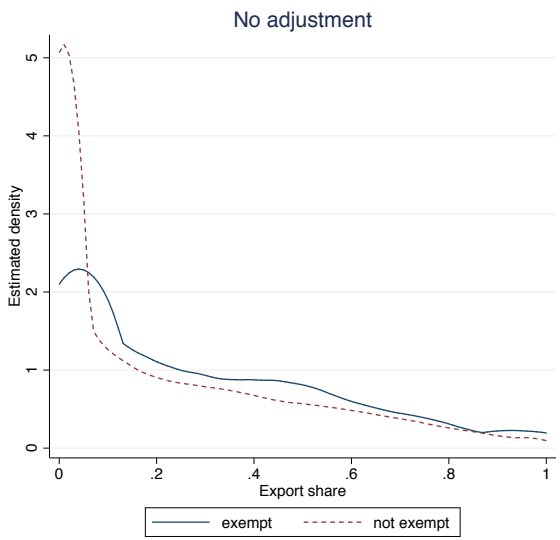
Exempt 2013	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5
electricity	1.897**	3.141***	1.959*	1.514	1.626***
	(0.952)	(0.693)	(1.143)	(1.426)	(0.318)
lag electricity	0.15	0.282	1.287	0.698	0.817**
	(1.187)	(0.509)	(1.107)	(1.853)	(0.351)
lag 2 electricity	0.079	-0.128	-0.238	-0.376	1.359***
	(1.306)	(0.481)	(0.769)	(1.424)	(0.433)
lag 3 electricity	0.376	-0.144	0.358	1.33	0.317
	(1.079)	(0.226)	(0.87)	(0.835)	(0.376)
sales	0.377**	-1.139***	-2.229***	-0.456*	-1.38***
	(0.164)	(0.206)	(0.349)	(0.246)	(0.153)
employment	-2.46***	-1.422***	-0.736**	-2.542***	-2.063***
	(0.209)	(0.216)	(0.341)	(0.327)	(0.24)
Observations	1419	1881	973	867	4069
Pseudo R^2	0.4	0.3	0.4	0.35	0.51

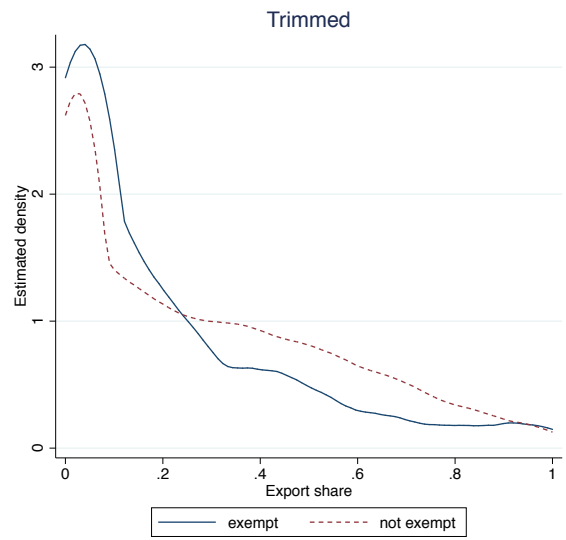
Note: Main dependent variable: EEG exempt 2013. All independent variables refer to the base year. Subsectors redefined according to mean energy intensity (WZ 2008) sector 1: food (WZ 10,11), sector 2: chemicals & pharmaceuticals (WZ 19,20,21,22), sector 3: paper & cement (WZ 17,23), sector 4: metal, electrical equipment, machinery and cars (WZ 24,25,26,27,28,29,30,33), and sector 5: textiles, leather, wood processing and miscellaneous (WZ 13,14,15,16,18,31,32). Logit regression. BBGG algorithm, SE iterated! $p < 0.1$ (*), $p < 0.05$ (**), $p < 0.01$ (***).

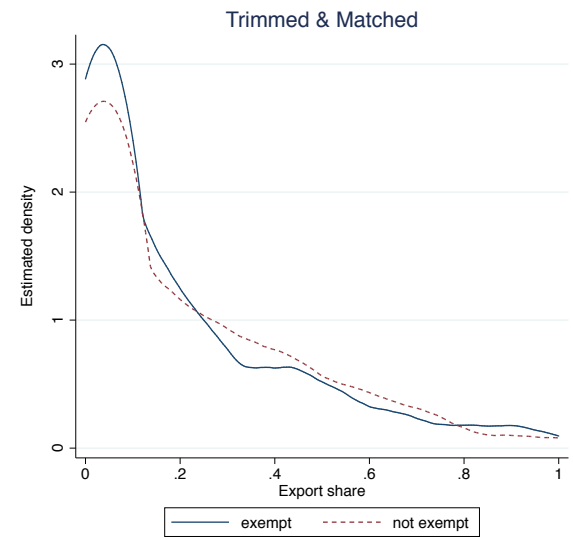
Trimming & Matching: log electricity



Trimming & Matching: Export share

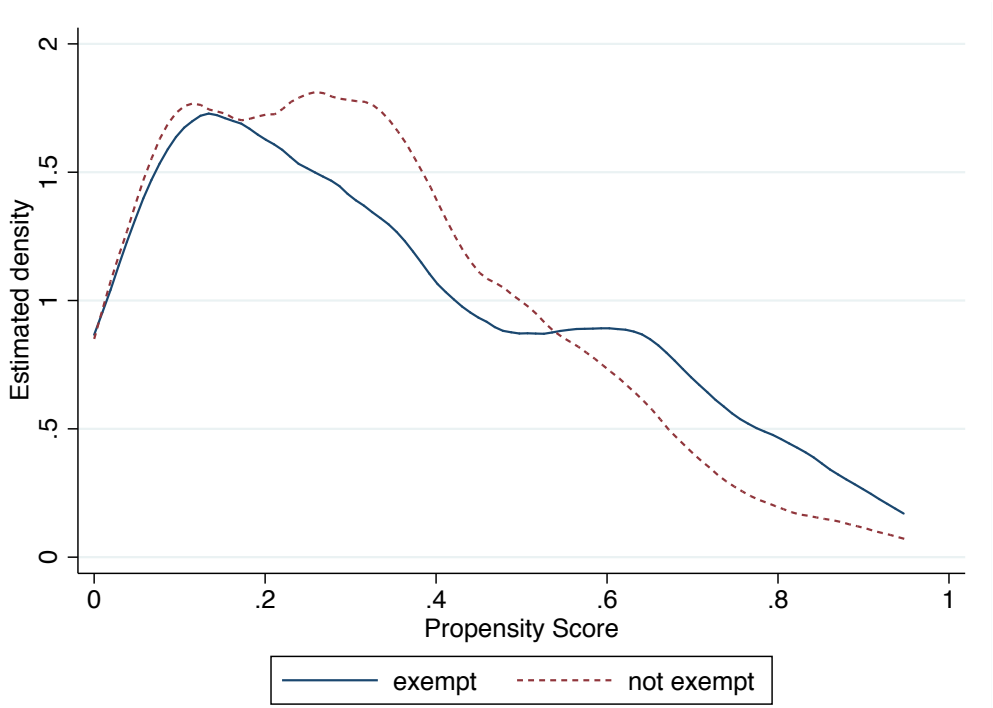






Overlap: Propensity score

- Existence of both treated and controls in all data cells



Electricity prices in the German industry

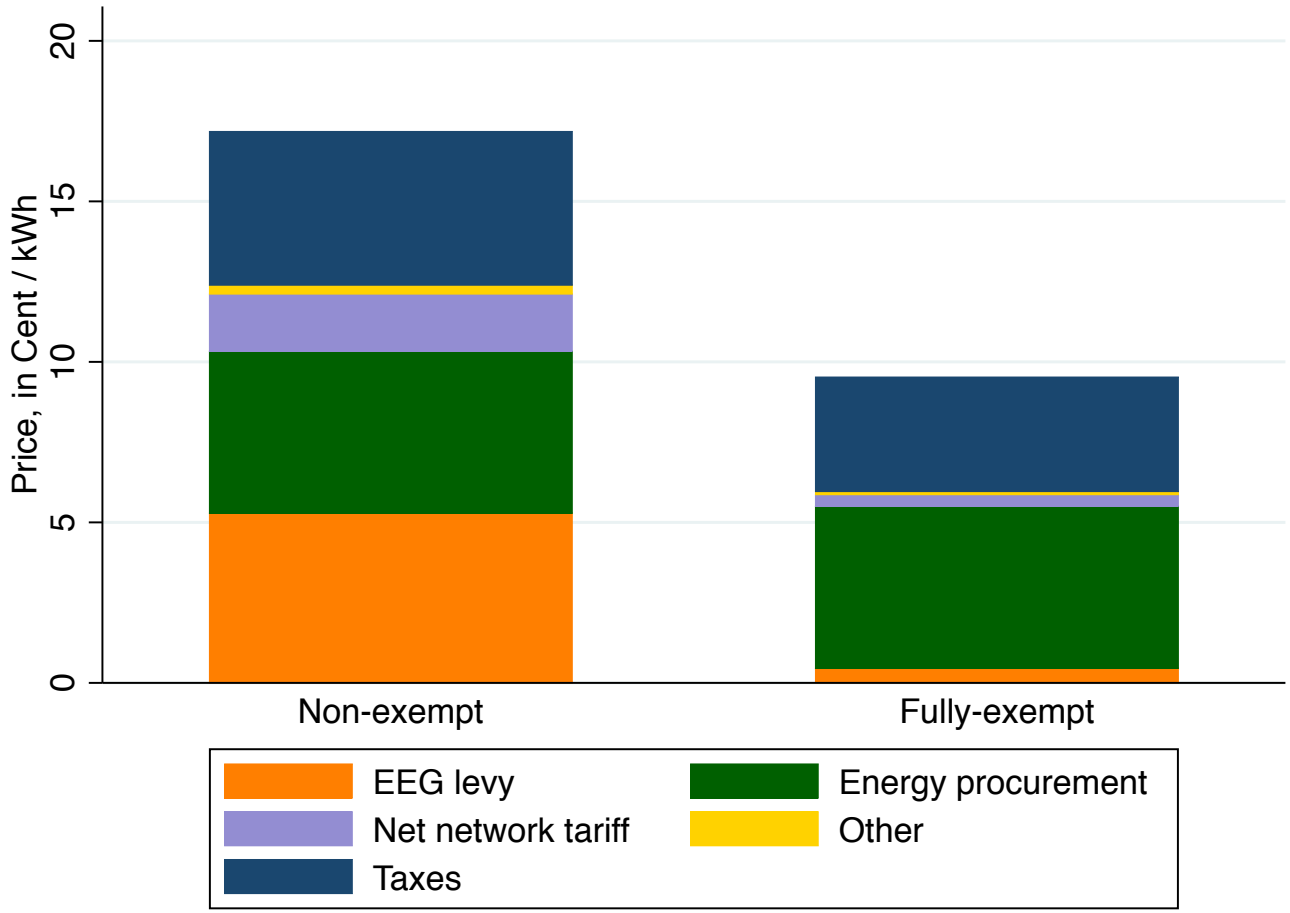


Figure: Average electricity price in the German industry 2013. Source: survey of the federal network agency. N = 206.

Table: Balance of covariates: Group DiD

VARIABLE	Treat mean	Control mean	T-test t-statistic	T-test p-value
Differences: 2011-2010				
Electricity	.056	.059	0.76	0.95
Sales	.113	.114	-0.08	0.933
Employment	.038	.041	-0.54	0.586
Export share	.005	.003	0.90	0.369
Wage	.033	.032	0.30	0.762
Electricity share	.017	.018	-0.48	0.628
Investment	.321	.677	-2.75	0.006***
Own production	.012	.005	1.48	0.139
Differences: 2010-2009				
Electricity	.115	.104	0.85	0.394
Sales	.145	.151	-0.73	0.466
Employment	-.011	-.000	-2.59	0.01**
Export share	.004	.007	-1.05	0.292
Wage	.057	.055	0.74	0.460
Electricity share	-.003	-.006	0.79	0.428
Investment	-.003	-.102	0.76	0.449
Own production	.012	.012	0.06	0.953

Robustness: base year 2010

	(1)	(2)	(3)	(4)
Matching algorithm	1:1	1:20 cal	1:1	1:20 cal
Panel A: *Electricity and gas use*				
Electricity use	0.057*	0.033*	0.025	0.034*
	(0.031)	(0.017)	(0.022)	(0.019)
Gas use	-0.081	-0.074	-0.067	-0.066
	(0.064)	(0.058)	(0.086)	(0.059)
Own electricity generation	0	-0.004	-0.015	-0.008
	(0.017)	(0.011)	(0.017)	(0.011)
Panel B: *Fuel inputs & carbon emissions*				
Electricity share in total energy	0.017**	0.012*	0.008	0.008
	(0.008)	(0.007)	(0.008)	(0.005)
Gas share in total energy	-0.014	-0.005	-0.016	-0.009
	(0.012)	(0.008)	(0.01)	(0.008)
Oil share in total energy	-0.004	-0.001	0.013*	0.006
	(0.01)	(0.006)	(0.008)	(0.007)
Total CO_2 emissions	0.042	0.028*	0.045**	0.041***
	(0.028)	(0.016)	(0.021)	(0.014)
Direct CO_2 emissions	-0.078	-0.06	-0.004	-0.005
	(0.05)	(0.044)	(0.059)	(0.039)
Observations	908	2,384	918	2,375
# treated plants	454	454	459	439
# control plants	454	1,930	459	1,936

▸ Robustness

Robustness: base year 2012

	(1)	(2)	(3)	(4)
Matching algorithm	1:1	1:20 cal	1:1	1:20 cal
Panel A: *Electricity and gas use*				
Electricity use	0.026	0.027**	0.05*	0.041**
	(0.017)	(0.014)	(0.026)	(0.017)
Gas use	-0.044	-0.039	-0.034	-0.043
	(0.044)	(0.044)	(0.058)	(0.041)
Own electricity generation	-0.004	-0.009	-0.013*	-0.017***
	(0.014)	(0.007)	(0.007)	(0.006)
Panel B: *Fuel inputs & carbon emissions*				
Electricity share in total energy	0.012*	0.011**	0.02**	0.014**
	(0.007)	(0.005)	(0.008)	(0.006)
Gas share in total energy	-0.015**	-0.009*	-0.014*	-0.011**
	(0.008)	(0.005)	(0.007)	(0.005)
Oil share in total energy	0.007	0	-0.005	-0.003
	(0.006)	(0.004)	(0.003)	(0.003)
Total CO_2 emissions	0.02	0.013	0.026	0.021
	(0.017)	(0.013)	(0.022)	(0.015)
Direct CO_2 emissions	-0.036	-0.051	-0.059	-0.062
	(0.035)	(0.033)	(0.038)	(0.03)
Observations	1,060	2659	1,058	2674
# treated plants	530	530	529	505
# control plants	530	2,129	529	2,169

▸ Robustness

Robustness: Single-plant firms

	(1)	(2)	(3)	(4)
Matching algorithm	1:1	1:20 cal	1:1	1:20 cal
Panel A: *Electricity and gas use*				
Electricity use	0.077**	0.049**	0.056	0.062**
	(0.034)	(0.021)	(0.039)	(0.025)
Gas use	-0.09	-0.069	-0.093	-0.055
	(0.078)	(0.071)	(0.091)	(0.07)
Own electricity production	-0.024	-0.021	-0.019	-0.019
	(0.016)	(0.014)	(0.016)	(0.013)
Panel B: *Fuel inputs & carbon emissions*				
Electricity share in total energy	0.025**	0.013*	0.015	0.011
	(0.011)	(0.007)	(0.01)	(0.008)
Gas share in total energy	-0.011	-0.005	-0.012	-0.004
	(0.011)	(0.008)	(0.011)	(0.009)
Oil share in total energy	0.001	0.002	0.002	0.002
	(0.01)	(0.007)	(0.008)	(0.007)
Total CO_2 emissions	0.046	0.032*	0.009	0.049**
	(0.032)	(0.018)	(0.032)	(0.02)
Direct CO_2 emissions	-0.037	-0.033	-0.023	0.001
	(0.065)	(0.054)	(0.065)	(0.048)
Observations	738	1,817	732	1,738
# treated plants	369	369	366	347
# control plants	369	1,448	366	1,391

▸ Robustness

Robustness: 5-10 GWh sample

	(1)	(2)	(3)	(4)
Matching algorithm	1:1	1:20 cal	1:1	1:20 cal
Panel A: *Electricity and gas use*				
Electricity use	0.028	0.055*	0.079**	0.047**
	(0.031)	(0.032)	(0.034)	(0.023)
Gas use	-0.184*	-0.111	-0.085	-0.082
	(0.101)	(0.079)	(0.093)	(0.083)
Own electricity production	-0.012	-0.002	-0.02	0.007
	(0.033)	(0.016)	(0.019)	(0.018)
Panel B: *Fuel inputs & carbon emissions*				
Electricity share in total energy	0	0.001	-0.003	0.001
	(0.009)	(0.007)	(0.008)	(0.007)
Gas share in total energy	-0.007	-0.016	-0.02	-0.021**
	(0.013)	(0.01)	(0.015)	(0.01)
Oil share in total energy	0.001	0.01	0.009	0.011
	(0.009)	(0.008)	(0.01)	(0.009)
Total CO_2 emissions	0.007	0.035	0.06	0.04*
	(0.033)	(0.031)	(0.037)	(0.023)
Direct CO_2 emissions	-0.062	-0.067	-0.005	-0.029
	(0.094)	(0.058)	(0.067)	(0.064)
Observations	506	827	498	885
# treated plants	253	253	249	240
# control plants	253	574	249	645

▸ Robustness

Robustness: balanced energy sample

	(1)	(2)	(3)	(4)
Matching algorithm	1:1	1:20 cal	1:1	1:20 cal
Panel A: *Electricity and gas use*				
electricity	0.042*	0.038*	0.03	0.042*
	(0.025)	(0.02)	(0.023)	(0.024)
gas	-0.051	-0.055	-0.081	-0.046
	(0.066)	(0.055)	(0.058)	(0.059)
Own electricity production	-0.026*	-0.022*	-0.026*	-0.019
	(0.014)	(0.012)	(0.013)	(0.013)
Panel B: *Fuel inputs & carbon emissions*				
Electricity share in total energy, in %	0.013*	0.011**	0.013*	0.009
	(0.008)	(0.005)	(0.007)	(0.007)
Gas share in total energy, in %	-0.016	-0.015*	-0.027**	-0.015*
	(0.01)	(0.008)	(0.009)	(0.008)
Oil share in total energy, in %	-0.006	0.002	0.008	0.003
	(0.005)	(0.005)	(0.006)	(0.006)
total co_2	0.02	0.017	0.012	0.03
	(0.024)	(0.018)	(0.02)	(0.022)
fuel co_2	-0.056	-0.057	-0.063	-0.031
	(0.056)	(0.043)	(0.047)	(0.047)
Observations	696	1756	694	1745
# treated plants	348	348	346	327
# control plants	348	1,408	348	1,418

▸ Robustness

Robustness: Matching on 3-digits sectors

	(1)	(2)	(3)	(4)
Matching algorithm	1:1	1:20 cal	1:1	1:20 cal
Panel A: *Electricity and gas use*				
Electricity use	0.075***	0.051***	0.034	0.043*
	(0.024)	(0.018)	(0.034)	(0.024)
Gas use	-0.086	-0.057	-0.057	-0.072
	(0.063)	(0.054)	(0.075)	(0.067)
Own electricity production	-0.012	-0.01	-0.02	-0.036**
	(0.012)	(0.011)	(0.016)	(0.014)
Panel B: *Fuel inputs & carbon emissions*				
Electricity share in total energy	0.012	0.01*	0.013	0.006
	(0.008)	(0.006)	(0.009)	(0.007)
Gas share in total energy	-0.021**	-0.006	-0.001	-0.008
	(0.01)	(0.007)	(0.011)	(0.009)
Oil share in total energy	0.008	0	-0.002	0.005
	(0.008)	(0.005)	(0.009)	(0.007)
Total CO_2 emissions	0.058**	0.031**	0.007	0.033*
	(0.023)	(0.015)	(0.028)	(0.018)
Direct CO_2 emissions	-0.013	-0.029	-0.105**	0.005
	(0.049)	(0.041)	(0.048)	(0.047)
Observations	1,016	2545	1,008	1866
# treated plants	508	508	504	369
# control plants	508	2,037	504	1,497

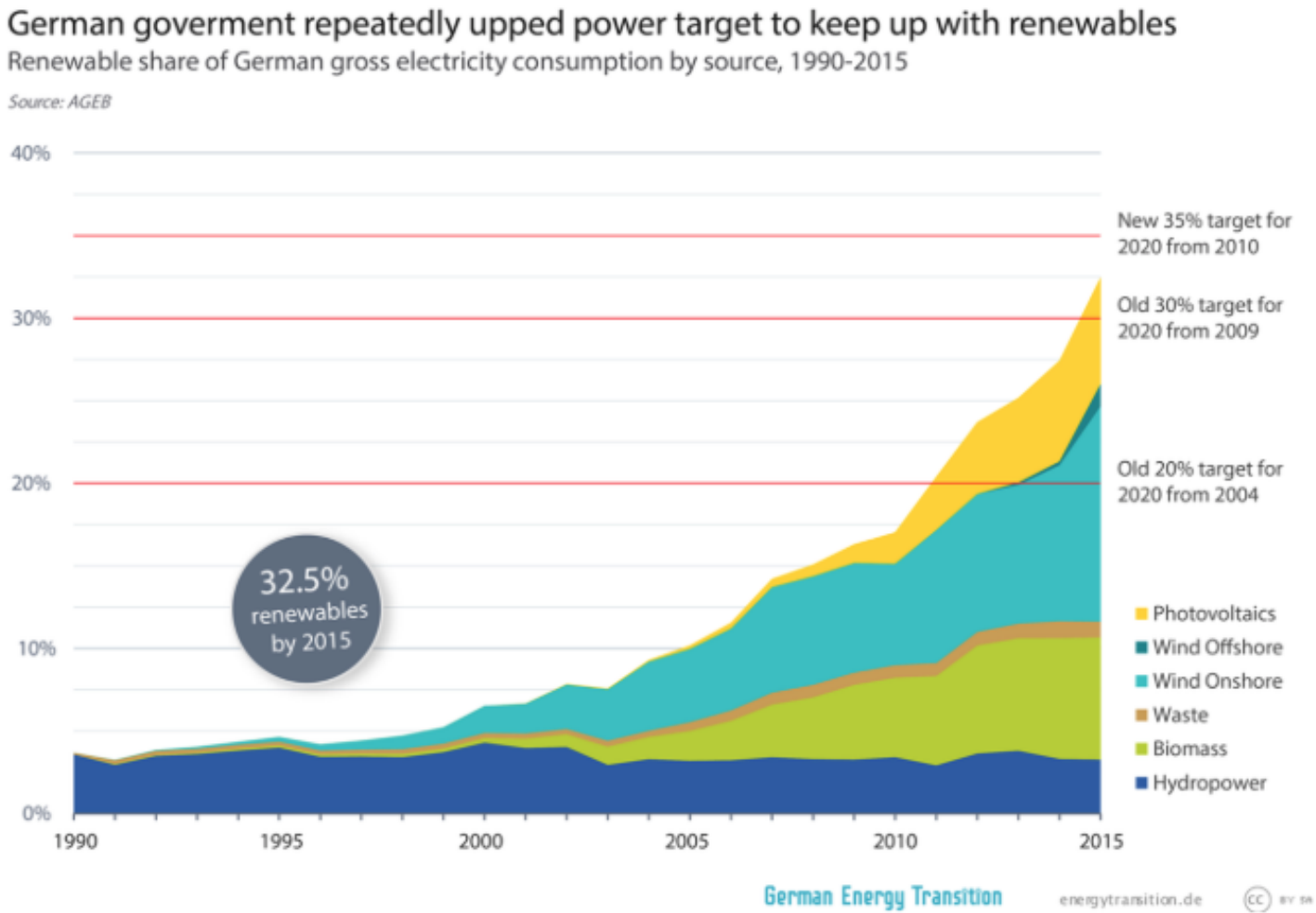
▸ Robustness

Robustness: Matching elec-to-sales ratio

	Specification (1)	(2)
Matching algorithm	1:1 cal	1:20 cal
Panel A: *Electricity and gas use*		
Electricity use	0.063***	0.062***
	(0.02)	(0.014)
Gas use	-0.064	-0.044
	(0.067)	(0.049)
Own electricity production	-0.018	-0.008
	(0.014)	(0.009)
Panel B: *Fuel inputs & carbon emissions*		
Electricity share in total energy	0.013*	0.009*
	(0.007)	(0.005)
Gas share in total energy	-0.007	-0.011*
	(0.007)	(0.005)
Oil share in total energy	-0.003	0
	(0.006)	(0.005)
Total CO_2 emissions	0.046**	0.046***
	(0.018)	(0.013)
Direct CO_2 emissions	-0.041	0.008
	(0.052)	(0.036)
Observations	1,040	4163
# treated plants	564	564
# control plants	476	3,599

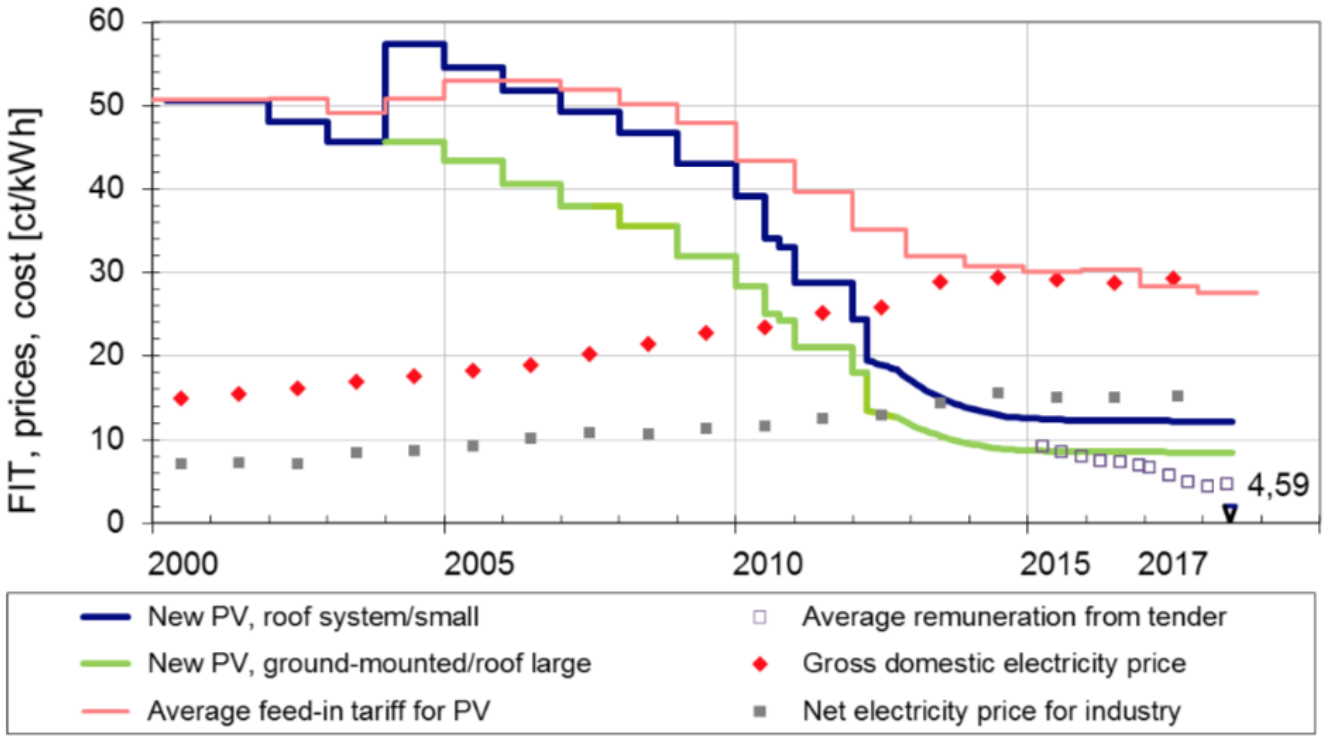
▸ Robustness

Share of Renewables in German Electricity Mix



▸ Policy

Feed-in-Tariffs and Electricity Prices

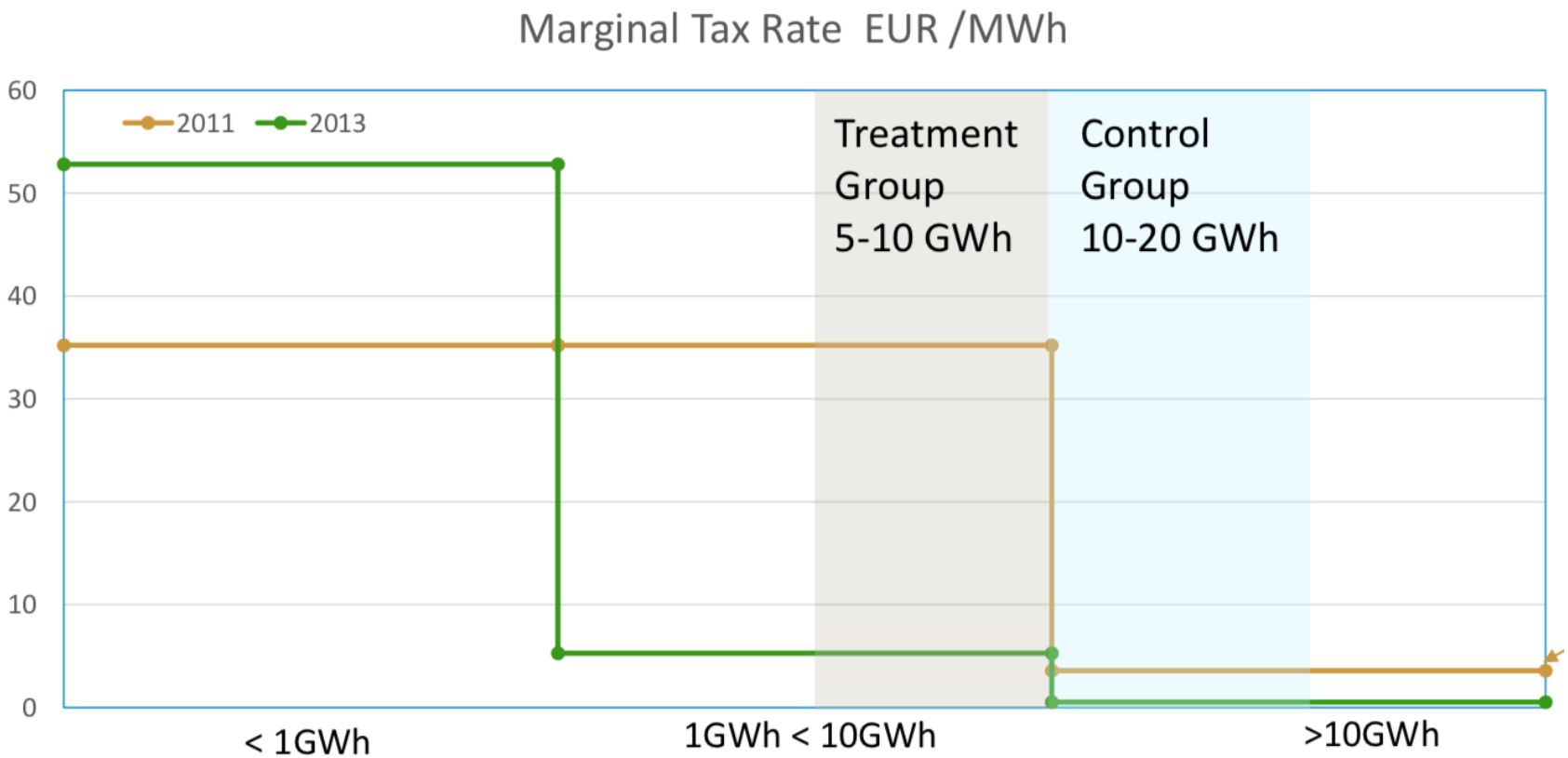


▸ Policy

Selection into Treatment

- While plants need to fulfill the eligibility criteria to be exempt, program participation is voluntary
- Especially small plants *might find it profitable not to apply* if administrative burden is large
- Matching DiD allows us to take into account selection based on time-invariant unobservable heterogeneity
- Issue remains if plants select into treatment based on *growth expectations*
- Use policy change as **'natural experiment'** to identify a lower bound for the main treatment effect

Policy reform as natural experiment



Group Difference-in-Differences

$$\Delta Y_i = \alpha_0 + \alpha_{ITT} Z_i + \varepsilon_i$$

- Focus on similar groups: 5-10 GWh (treated) and 10-20 GWh (control) electricity consumption in 2011
- $\Delta Y_i = Y_{it} - Y_{it'}$ denotes the difference in outcomes 2013 - 2011
- Z_i is a treatment indicator
- $\hat{\alpha}_{ITT}$ is the lower bound intention-to-treat for the true $\hat{\alpha}_{ATT}$
- **No selection concerns, yet: less precise**

DiD: Pre-treatment trends

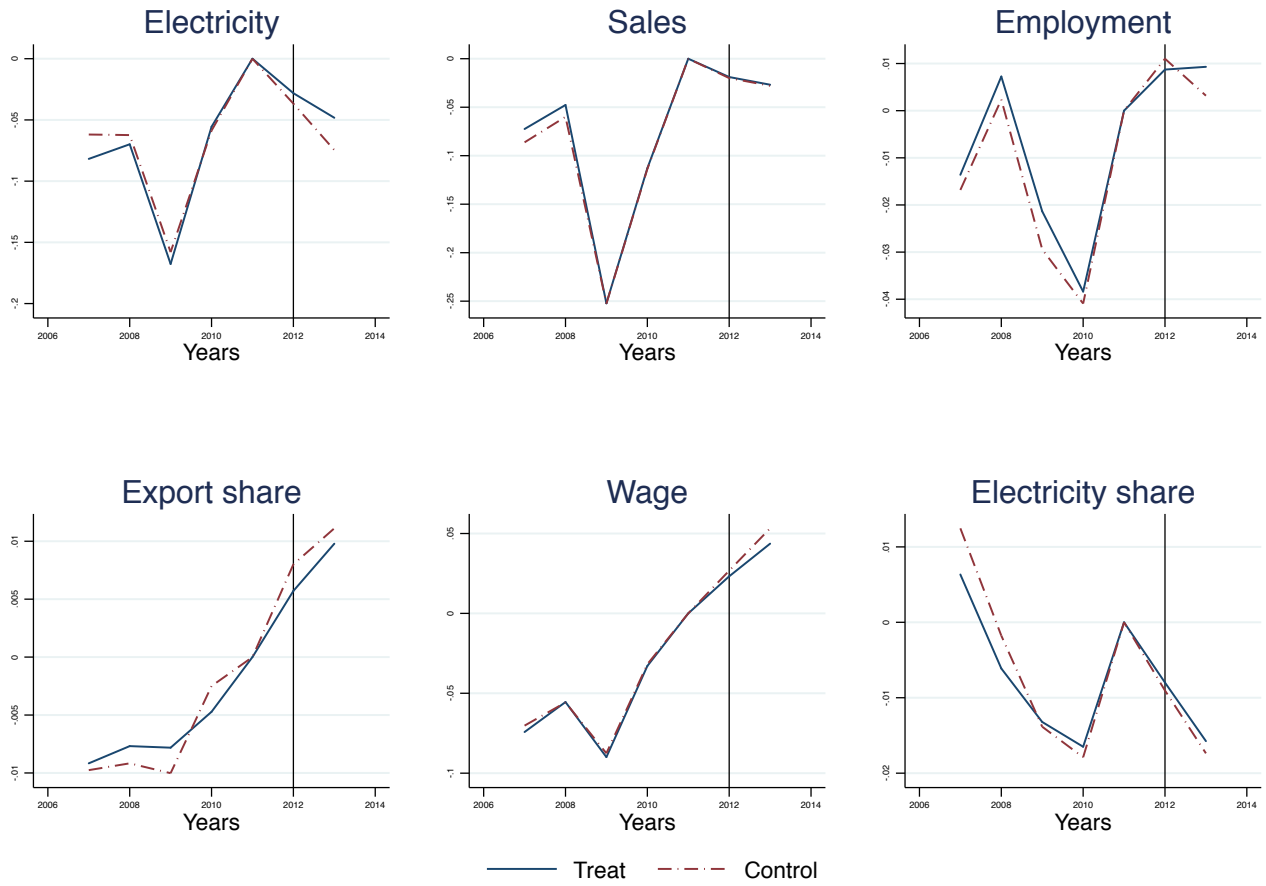


Figure: Pre-treatment trends for eligible group (5-10 GWh electricity consumption in 2011) and control group (10-20 GWh electricity in 2011). Individual variables are normalized with respect to the base year 2011.

Group DiD: main results

Table: Results: difference-in-difference (groups)

OUTCOME	α_{ITT}	std err.
Panel A: *Electricity use*		
Electricity use	0.026*	(0.016)
Electricity share	0.002	(0.003)
Own electricity production	0.002	(0.007)
Panel B: *Competitiveness indicators*		
Employment	0.006	(0.007)
Sales	0.001	(0.013)
Export share	-0.001	(0.003)
Investment	-0.131	(0.237)
Obervations	3,585	
Constant	Yes	

▸ Robustness