The effect of Network Charges on German Manufacturing Plants

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Abstract

Climate policy often implies increasing energy costs. Due to incomplete regulation across the globe, concerns about employment effects play an important role in the policy debate. Using micro data on network charges and the official plant census data for Germany we study the impact of rising electricity costs on plant performance in German Manufacturing. Electricity network charges are determined through regulation in Germany. Network charges make up a substantial share of final electricity prices and are largely exogenous to manufacturing plants. We find evidence of negative own-price elasticities for electricity and negative impacts on hours worked suggesting that higher electricity costs may reduce overall production.

Keywords: Network charges, Electricity Use, Firm Performance, Climate Policy, Manufacturing

JEL-Classification: D22, L60, Q41, Q48

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1 Introduction

The challenge posed by climate change is considerable. The world set an ambitious target in Paris at the 21st Conference of the Parties meeting in 2015. Since then, little has happened and global greenhouse gas emissions continue to increase. While a solution in terms of pricing the climate externality either through emissions trading or a tax on greenhouse gas emissions is available, failure to implement globally coordinated policies continues to hold back the policy response across the globe. Unilateral action therefore comes with a risk of incurring costs in terms of loss of competitiveness or jobs due to stricter regulation than that implemented by trading partners. There is also the risk of leakage as emissions may shift from regulated to unregulated economies reducing the share of global emissions addressed by regulation. Such concerns about competitiveness impacts and leakage have played a substantial role in deterring unilateral policy efforts. As a result, climate policies that are introduced often come with exemptions for trade-intensive or energy-intensive sectors.

The extent to which concerns regarding leakage and competitiveness losses are valid has been studied in several instances. However, typically a quasi-experimental design is used in which specific features of the policy under study determine the research design and the definition of treatment and control groups as specific subsets of the data. One example is the research on firms regulated under the EU Emissions Trading Scheme (EU ETS) or firms eligible for specific exemptions or reduced tax rates. The affected firms tend to be large and belong to specific sectors. In consequence, the external validity of this existing research is limited.

In this paper we study the effect of electricity network charges on German manufacturing plants. Electricity network charges make up approximately 20-30 percent of the electricity price faced by plants. The German network charges are plausibly exogenous to the individual plant as the level is determined through regulation by the Federal Network Agency. Network charges depend on maintenance costs, network expansion, etc. As a result there is substantial variation both across time and space. We recover the effect of network charges on electricity consumption and hours worked in German manufacturing plants using the manufacturing census data. Our preliminary findings indicate that higher electricity network charges reduce electricity consumption and total hours worked in a both economically and statistically significant way.

Our paper contributes to several strands of literature. First, it adds to the literature on the causal effect of price instruments on energy demand and firm performance. Martin *et al.* (2014) found that a moderate energy tax reduced electricity intensity in manufacturing in the United Kingdom. For Germany, existing literature has focused on a kink in the electricity tax (Flues and Lutz, 2015), exemption from the Renewable Energy Surcharge (Gerster, 2017) and the EU ETS (Petrick and Wagner, 2014). As a result, the impact of energy costs is fairly well-known among very small and very large users of electricity, but rather poorly understood for the wide majority of manufacturing plants. The relevance of assessing the impact of electricity costs on the majority of manufacturing plants is also made apparent through the EU ETS: Several studies have found evidence of cost pass-through in the power generation sector (e.g. Alexeeva-Talebi (2011), Fabra and Reguant (2014)). This implies that all plants consuming electricity are indirectly regulated under the ETS. An assessment of the costs and benefits of the ETS should therefore also take this indirect effect into account, which has so far not been quantified for Germany in an ex post analysis.

In terms of employment, Kahn and Mansur (2013) compare concentrations of employment in manufacturing in low and high energy price counties. They find that energy intensive industries are more likely to be located in counties with low energy prices. For Germany, the paper by Cox *et al.* (2014) examines the impact of sectoral level electricity prices on employment. Their findings suggest that higher electricity prices lower production. However, the data used for their analysis contained very little information on the plant beyond employment variables. In contrast, our data set is very detailed with regard to the plant's revenues, energy use and investment behavior, and we take advantage of a more disaggregated source of variation in electricity prices.

Our paper also contributes to the literature on own-price elasticities in industrial production. Abeberese (2017), Bardazzi *et al.* (2015) and Boyd and Lee (2016) study own price elasticites in the manufacturing sector in India, Italy and the United States. They find elasticities ranging from -0.5 to -1.2. The price data available for these studies typically derive from the firm's reported electricity costs or variation at the state level. In contrast, our study is based on network level variaton in an important component of electricity prices.

The paper is structured as follows: Section 2 describes the network structure and regulation of network charges in Germany. Section 3 introduces the data and discusses the research design. Section 4 reports and discusses our results. In section 5 we conclude.

2 Background on electricity prices and networks

The final price of electricity is composed of (1) costs of generation and supply; (2) taxes, levies and surcharges; and (3) network charges. There is competition in generation on the wholesale market. The International Energy Agency (IEA) describes the German energy-only electricity market as efficient and liquid in its 2013 country review (International Energy Agency (IEA), 2013). In other words, for generation of electricity the marginal price is decisive. Taxes, levies and surcharges play a rather important role in Germany making up approximately 40% of final electricity prices depending on the consumption band. Germany has an electricity tax, the Renewable Energies Act (EEG) surcharge, the Combined Heat and Power (CHP) surcharge, and the Section 19 surcharge all of which are imposed at the national level. In addition there is the concession fee which is determined at the municipal level. Individual customers still face different prices due to exemptions and reduced rates applicable to specific groups. The network charges vary at the network level and account for up to 30 % of the final electricity price. In Figure 1 the evolutoin of electricity prices in Germany according to Eurostat is displayed for different consumption bands. Due to exemptions and lower charges for large electricity users the prices generally decline as consumption increases. For all consumption bands prices are increasing until 2014 afer which they flatten off or decline. The increase in prices is mainly due to increases in taxes and levies, and network charges. Over the period a general decline in the component attributed to generation and supply can be observed in particular after 2008/2009. This decline in wholesale prices is likely driven at least in part by the expansion in renewable energy sources over the period.

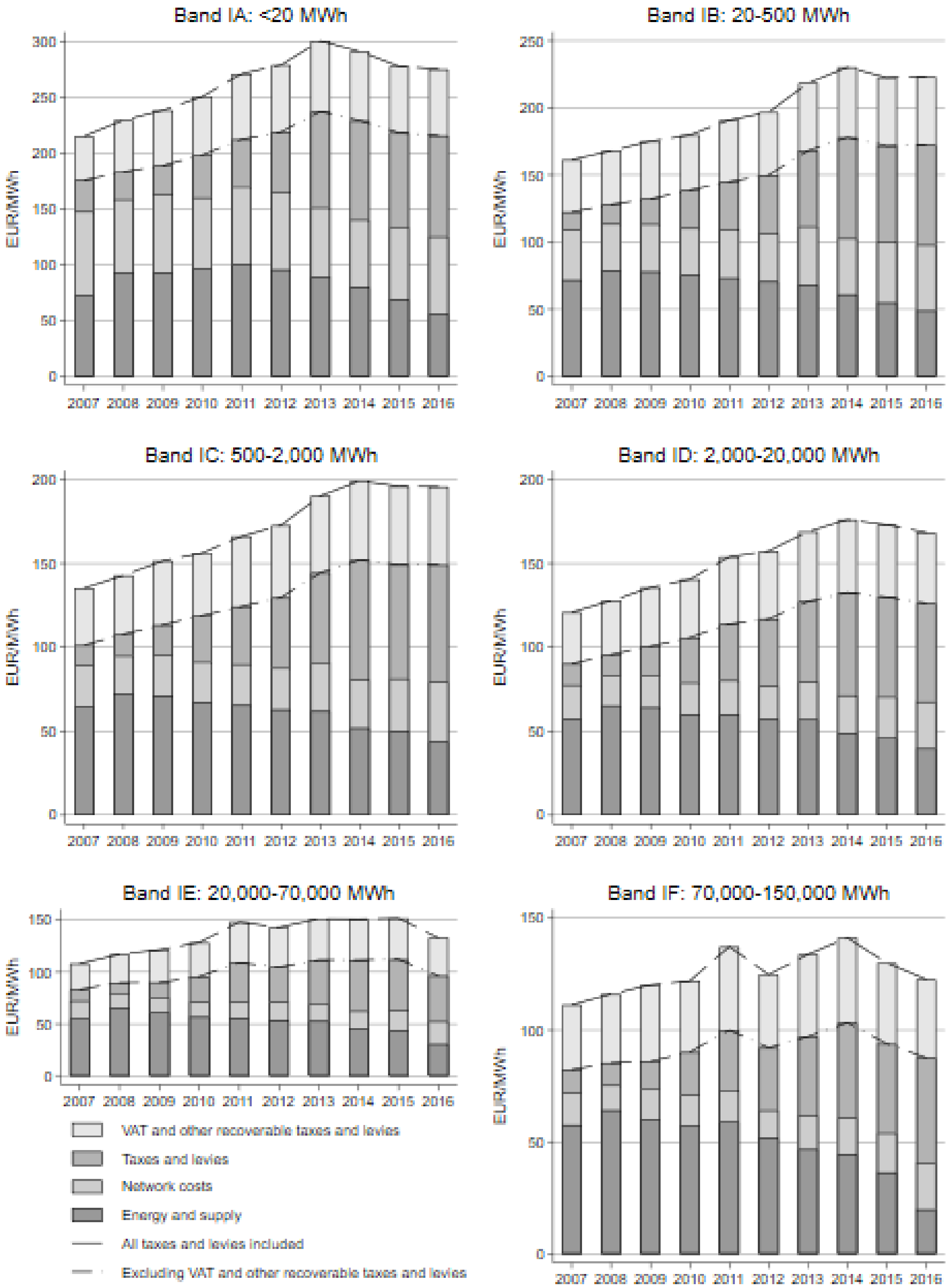
The German retail market for electricity is characterised by competition such that customers can choose their own provider. In 2011 approximately 1,100 different electricity suppliers were active in Germany and 54% of the customers had chosen a supplier other than the incumbent (Federal Network Agency (BNetzA) and Federal Cartel Agency (BKartA), 2013).

In addition to variation over time and across consumption bands, there is important regional variation within Germany in electricity costs. This variation derives from the network charges. In this study we focus on variation in network charges for identification of plant responses to rising electricity costs.

2.1 Electricity networks

There are four Transition System operators (TSOs) operating the extra high voltage networks and around 800 Distribution System Operators (DSOs) responsible for the low, medium and high voltage networks in Germany. Both transmission and distribution networks are natural monopolies. Electricity network operations are regulated in Germany by the Federal Network Agency (*Bundesnetzagentur*) to reduce monopoly profits and inefficiencies in network operation. Prior to 2005 the electricity market was characterized by vertically integrated utilities (generation, transmission and distribution as well as retail and supply) with regional monopolies. With the 2005 amendment to the Energy Act came unbundling of electricity generation and network operations. The Federal Network Agency was also established with this act to regulate network charges. Starting in 2005 the TSOs and in 2007 the DSOs were under a cost plus regulation in which the network operator could recover costs plus a markup through the network charges. In 2009 this regulation was replaced by the current incentive regulation based on benchmarking. Since 2009 each DSO has been assigned a specific revenue cap based on benchmarking of the cost structure and efficiency requirements. Every year the network charges are published for the coming year according to the revenue cap. Drivers of variation in network charges across DSOs include a variety of cost components of which the most important are: Network operation, i.e. maintenance, infrastructure investments and connection of new plants and installations; system support services such as redispatch and balancing power; and finally transmissions losses. Every customer in the network area pays a network charge which depends on the voltage level, metering and volume procured from the network.

The structure of the network charges faced by each plant depends on the volume of procurement from the network, the (peak) load, and the hours of usage. The different categories into which plants are classified are shown in table 1. Once the tariff becomes a three part tariff, the number of hours of use annually plays an important role in deter-



Source: Eurostat time series nrg_pc_205 and nrg_pc_205_c.

Figure 1: The development of electricity prices for different consumption bands

Table 1: Structure of network charges

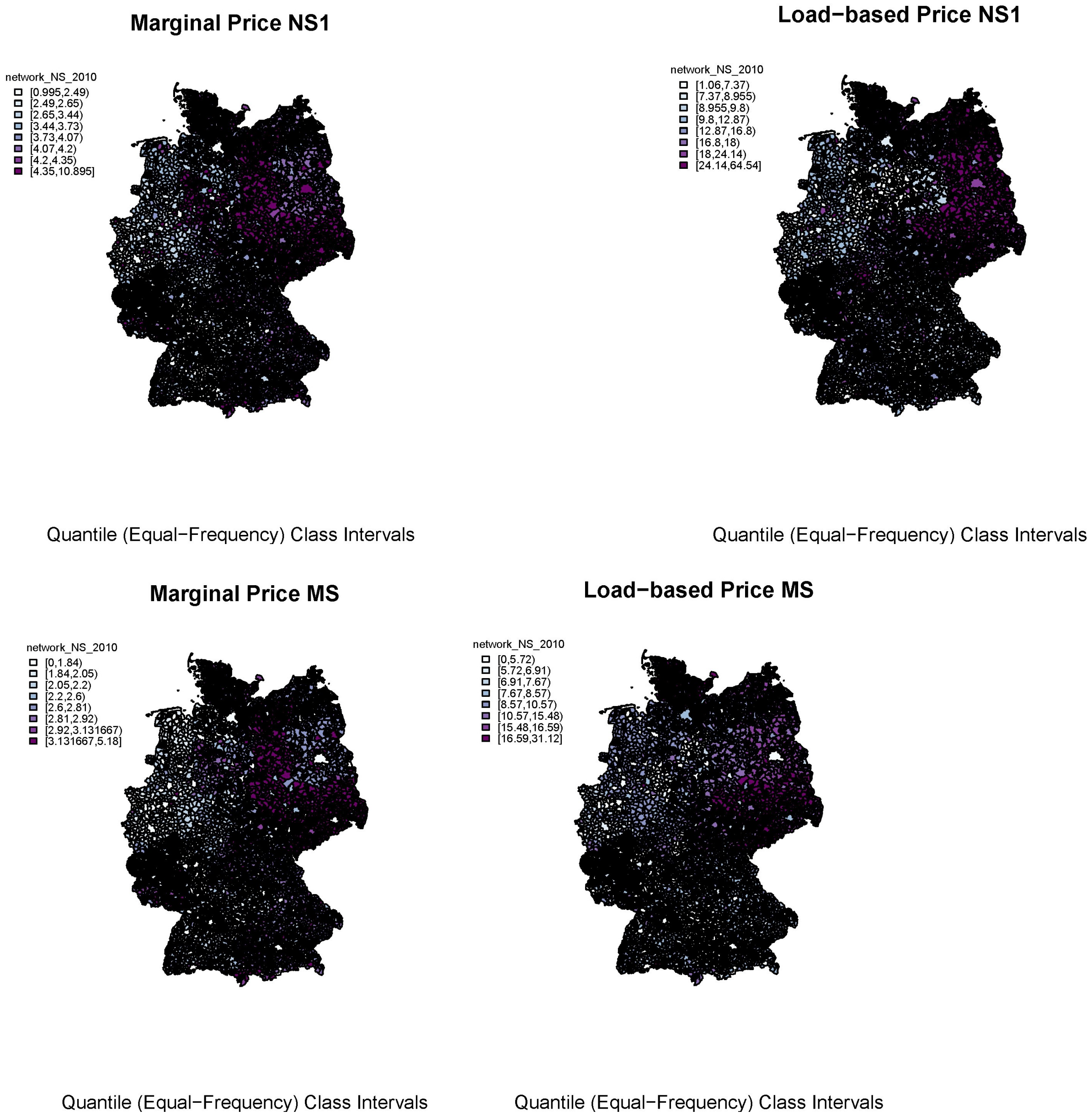
Customer group	Standard load profile (SLP)	Interval-metered (RLM)	Individual charges (§19)
Annual procurement	$\leq$ 100 MWh	$>$ 100 MWh	$>$ 10 GWh,
			min. 7,000 hours of use
Transmission level	Low and medium voltage	Low, medium and high voltage	Medium and high voltage
Tariff structure	Two-part tariff	Three-part tariff	Eligible for reduced
"Arbeitspreis"	Price per unit (EUR/MWh)	Price per unit (EUR/MWh)	network charges
"Grund-/Leistungspreis"	Base price per year (EUR/a)	Peak load price (EUR/MW*a)	
		Tariff varies by hours of use:	
		$\leq$ or $>$ 2,500 hours/a	

Notes: Based on the Electricity Network Charge Regulation. In addition to these categories, there are reduced charges for plants with atypical usage patterns. These are plants whose peak load lies in time periods during which the network is under pressure and so their usage assists the network operator in avoiding congestion.

mining the tariff structure by dividing the plants into tariff group 1 (below 2,500 hours) or 2 (above 2,500 hours). To make this distinction clearer, 2,500 hours is achieved by a plant operating 6 days a week and 8 hours a day all year round (52 weeks). In other words, plants with regular double shifts (16 hour work days) will be in group 2, whereas a plant with a single shift and a 40 hour work week will be in group 1.

There is substantial variation in network charges as can be seen in Figure 2. Drivers of this variation inclue expansion of renewable energy installations which must be connected to the network as well as maintenance and changes in the customer base. Higher network charges apply to many of the states belonging to the former Eastern Germany. However, there is also substantial variation at a small spatial scale.

To compare network charges over time we calculate average network charges for three hypothetical manufacturing plants in the medium voltage network and plot the kernel distribution for odd years from 2005 until 2013 in Figure 3. Clearly, there is substantial variation over time in the network charges faced by plants. In the later years, the network charges are higher than in the earlier part of the period and much more heterogeneous. The network charges in the low voltage network evolve in a qualitatively similar manner. Determinants of variation in network charges are further discussed in Graevenitz *et al.* (2011).



Own calculations.

Figure 2: Regional variation in network charge components in the low and medium voltage networks

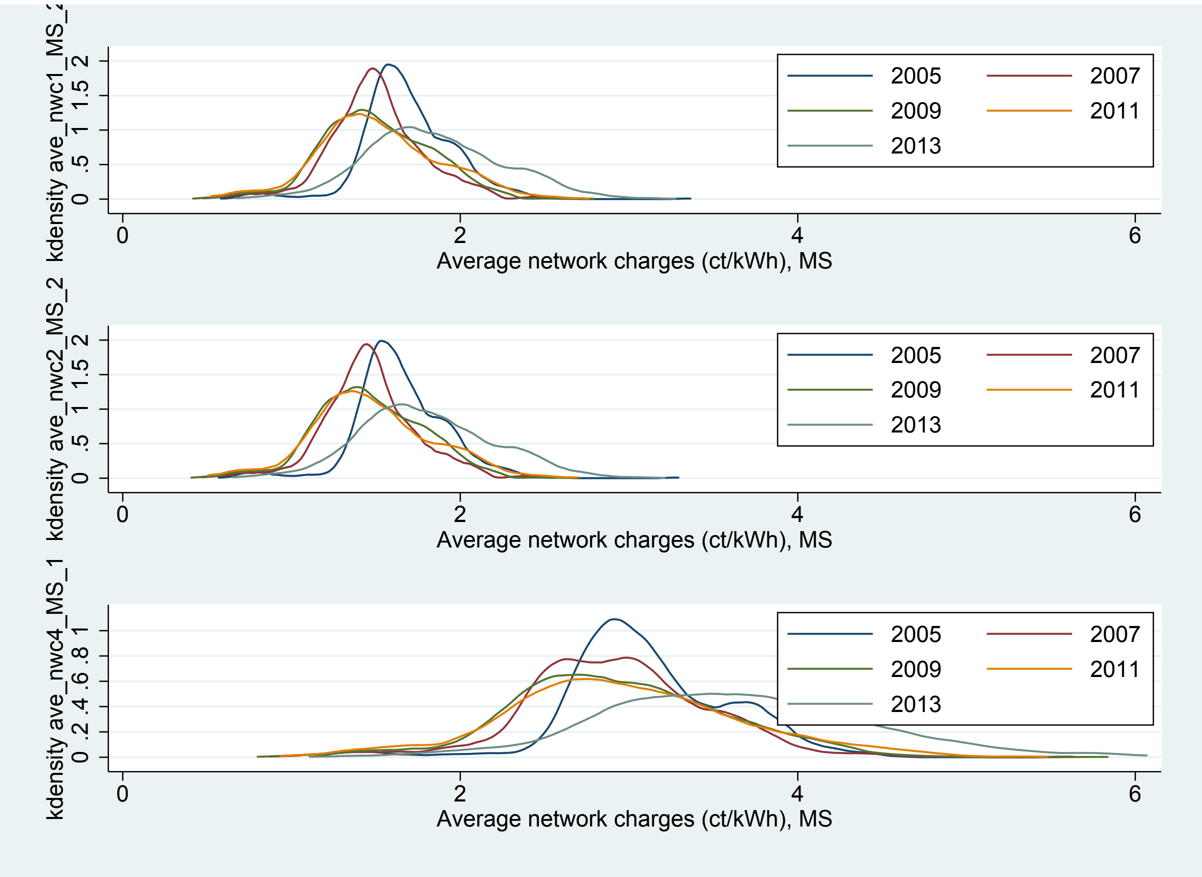


Figure 3: The development of average network charges, medium voltage

Source: Own calculations. The upper panel shows average network charges for a hypothetic copper plant consuming 5,100 MWh per year with a peak load of 850 kW and shift work (Group 2). The medium panel shows a hypothetical chemical plant with 950 MWh use per year and a peak load of 152 kW and shift work. The bottom panel shows a hypothetical plant with 250 MWh per year and a peak load of 125 kW and no shift work (Group 1).

3 Data

3.1 Data Sources

In order to analyse the impact of network charges on German manufacturing plants, we combine comprehensive administrative plant-level data on the one hand with data on network charges on the other hand. These two data sets are described in more detail in the following.

The first main data source we make use of in this paper are the official micro-level data from the Federal Statistical Offices of the Bund and the Länder, the so-called AFiD panels (*"Amtliche Firmendaten für Deutschland"*: Official Firm Data for Germany). Specifically, we make use of the panels "industrial plants", "energy use" and "structure of earnings".

The panel "industrial plants" contains information on the number of employees per plant, the hours worked, the value of output, exports and further variables on the economic activities of plants. The AFiD panel collects this information from four individual sources: the "monthly reports on manufacturing, mining and quarrying plants", the "annual report of manufacturing, mining and quarrying plants", the "investment survey for manufacturing, mining and quarrying plants" and the "quarterly production survey for manufacturing plants". Participation in these surveys is mandatory for all industrial plants in the German manufacturing sector with more than 20 employees. We have data available from 1995 to 2014.

The panel "industrial plants" is supplemented with the panel "energy use" that contains information on the energy use of industrial plants, e.g. on the consumption of different fuels, electricity procurement, or electricity self-generation. We use information on plants' electricity procurement and on total hours worked from those two panels as dependent variables, respectively. We apply a log-transformation to both of those variables in the regressions.

Finally, in order to assign specific network tariffs to a given plant (for the tariff structure, see Table 1), we use the "structure of earnings survey" from AFiD. This survey contains information on whether the plant uses work models like shift work, night work or Sunday work. We use this information to distinguish plants with more or less than 2,500 annual operating hours, respectively. A detailed discussion of the assignment of network charges to a plant is postponed to section 3.2. The structure of earnings survey however differs from the aforementioned two AFiD panels in two important aspects: First, the survey is not conducted every year: We have data available from this AFiD panel for 2001, 2006, 2010 and 2014. Second, not all plants with more than 20 employees are required to take part in the survey. Instead, the panel consists of a stratified sample of plants, where the strata are given by the federal states, the sectors and the plant's size class with respect to their number of employees. Plants with more employees are more likely to be sampled, and plants with more than 1,000 employees are always sampled. To keep the burden for manufacturing plants as small as possible, participation in the survey is rotated: If possible, plants that take part in the structure of earnings survey in one year do not have to participate in the next one. The deliberate rotation leads to the samples of two years overlapping as little as possible. Since in the bigger employee size classes, all plants have to participate in the survey, this rotation particularly affects plants with fewer employees.[1] Each year the survey is conducted, around 15-20% of observations in the universe of AFiD data (consisting in all manufacturing plants with more than 20 employees) report in the structure of earnings survey.

Since we need information on the manufacturing plants' shift work to properly assign network tariffs to the plants, we limit our attention to those plants that took part in the structure of earnings survey at least once. Section 3.4 gives an overview of our estimation sample and how it relates to the complete AFiD sample containing the universe of manufacturing plants with more than 20 employees. This leaves us with a panel of around 12,000-16,000 plants per year.[2]

The second main data source we draw on in this paper is a data set on network charges provided by the ene't GmbH. While network operators are required by law to annually publish the network charges for each network area, the data set from the ene't GmbH contains the compiled information on all network charges between 2005 and 2014. The data set contains information on the network charges for all three voltage levels (low, medium and high voltage level), for both standard and interval-metered load profiles and for the different price components (per unit price, base price and peak load price).

[1]Table 5 in the Appendix gives an overview of the pattern of the plants reportings in the structure of earnings survey

[2]We drop observations with implausible reportings of e.g. energy use. Information on the data cleansing procedure can be found in the appendix.

Information on network charges are available both on the level of postal codes and on the level of municipalities. We merge the network charge information to the administrative micro-data by municipality codes.

Since information on network charges is only available from 2005 onwards, our estimation sample consists of observations from the period 2005-2014. However, we include information from the structure of earnings survey in 2001 to assign network tariffs to the plants.

3.2 Assigning specific network charges to a given plant

As described in Section 2, the network charges a plant has to pay depend on a number of factors, such as the network and voltage level a plant is connected to, its peak load and the amount of electricity procured. Unfortunately, we do not observe all of those factors which makes it impossible for us to calculate the exact network charges a plant has to pay. In the following, we outline how we deal with these challenges and which assumptions we need to make.

The size of network charges crucially depends on the network area. As shown in Figure 2, there is substantial spatial variation involved in network charges. We are able to uniquely identify the network a plant is connected to for around 50-60% of the sample (depending on the year). The map in Figure 5 in the Appendix shows where we can uniquely identify a network and where there are multiple networks within a municipality in the low voltage level. In case there is no unique assignment of a network possible, we calculate the average network tariffs from all networks available at a plant location. For robustness checks, we exclude all observations where no unique assignment is possible.

Moreover, network charges vary depending on whether plants are in the standard load profile, the interval-metered load profile or are eligible for reduced network charges (see Table 1 for the composition of network charges). Arguably, most plants in our data use registered load metering, since only few plants either procure less than 100 MWh or more than 10 GWh. We drop the plants with a procurement of less than 100 MWh and focus on the plants with registered load metering.

For those plants, total network charges depend on the electricity procurement (through the price per unit) and the peak load used (through the peak load price). Since we do not have any information on a plant's peak load, we are unable to calculate the total network charges payable. Therefore, we focus on the components of the network charges themselves (i.e. we look at how increases in the per unit and the peak load price affect economic outcomes, respectively, rather than analysing how they react to increases in average network tariffs). While plants may respond to average rather than marginal prices (for evidence on households, see Ito 2014), the individual price components of network charges are what policy makers can manipulate.

The price components within the interval-metered profile vary depending on whether the annual hours of use of the net exceed 2,500 hours or not. We approximate the annual hours of use by distinguishing plants that conduct shift work, night work or Sunday work and plants that do not.[3] Due to the small overlap between the samples in the structure of earnings survey, we do not confine ourselves to observations of the survey, but rather keep all plants in our estimation sample that reported in the survey at some point. This means that for most plants, we only know for a single moment in time whether they were conducting shift, night or Sunday work, and therefore need to make some assumptions on the operating hours in the remaining years. We assume that if a plant reported (no) shift work once, it was doing (no) shift work for the whole time period it is present in the data. If a plant reported several times in the structure of earnings survey, we do linear interpolation between the reporting years.[4] For those plants which we do observe multiple times, only very few change their status with regard to shift work over time.

Finally, network charges vary across the different voltage levels. We do not observe whether plants are connected to the low, medium or high voltage level. The bulk of manufacturing plants should be connected to the low or medium voltage level, since the

[3] A plant without any such work models is operating for 8 hours a day, 6 days a week and 52 weeks per year, i.e. 2,496 hours annually. Only plants with multiple shifts or night work, i.e. operating more than 8 hours per day, or Sunday work, i.e. operating 7 days a week, exceed the threshold of 2,500 annual hours of use of the net.

[4] One could of course use characteristics that are observable across the whole time period of the sample, like the number of employees or energy use, to explain in probit or logit regressions whether a plant is conducting shift/Sunday/night work or not. The estimated coefficients could then be used to predict the presence/absence of shift, night and Sunday work also in years in which the plants did not take part in the structure of earnings survey. However, testing this approach we found that we tend to overestimate the presence of shift/night/Sunday work significantly. Therefore, the assumption of the plants sticking to the work models they reported once and doing linear interpolation, respectively, is an assumption just as well and moreover more transparent.

high voltage level serves only largescale consumers like railway operators or suppliers like power plants. Therefore, we focus our attention to the low and medium voltage levels. Since we cannot accurately assign plants to the low or medium voltage level, we run our regressions on both low voltage network tariffs (implicitly assuming that all plants are connected to the low voltage level) and on medium voltage network tariffs (implicitly assuming that all plants are connected to the medium voltage level) and compare the results.

While we try to assign network charges to the manufacturing plants in our sample as accurately as possible, undoubtely we suffer some measurement error stemming from the assumptions we make: We will misclassify parts of the plants according to their annual hours of use of the net (below or above 2,500 hours per annum). Measurement error could be particularly prevalent for plants in group 2 (i.e. with annual hours of use of the net exceeding 2,500), since we wrongly assign the plants with an annual electricity procurement of more than 10 GWh that are eligible for reduced network tariffs to group 2. Also, we misclassify parts of the plants according to the voltage level they are connected to. Network charges on the low and medium voltage level are rather strongly correlated so that measurement error is unlikely to be extreme.[5] Under the assumption of classical measurement error, our estimates are subject to attenuation bias and should be considered a lower bound on a possible effect.

3.3 Research design

Our research design aims to utilize the variation within plants over time in network charges. Unfortunately, we cannot identify which voltage level a plant is connected to. We therefore estimate a standard reduced form regression with plant fixed effects described in equation 1:

$$y_{ijt} = \alpha_i + \beta_1\, MP1_{ijt} + \beta_2\, LP1_{ijt} + \beta_3\, MP2_{ijt} + \beta_4\, LP2_{ijt} + \pi_{st} + \varepsilon_{ijt} \qquad (1)$$

where i indicates the plant, t the year, and j the electricity network area. $MP1$ and $MP2$ refer to the marginal prices faced by group 1 and 2 (i.e. depending on the plant's

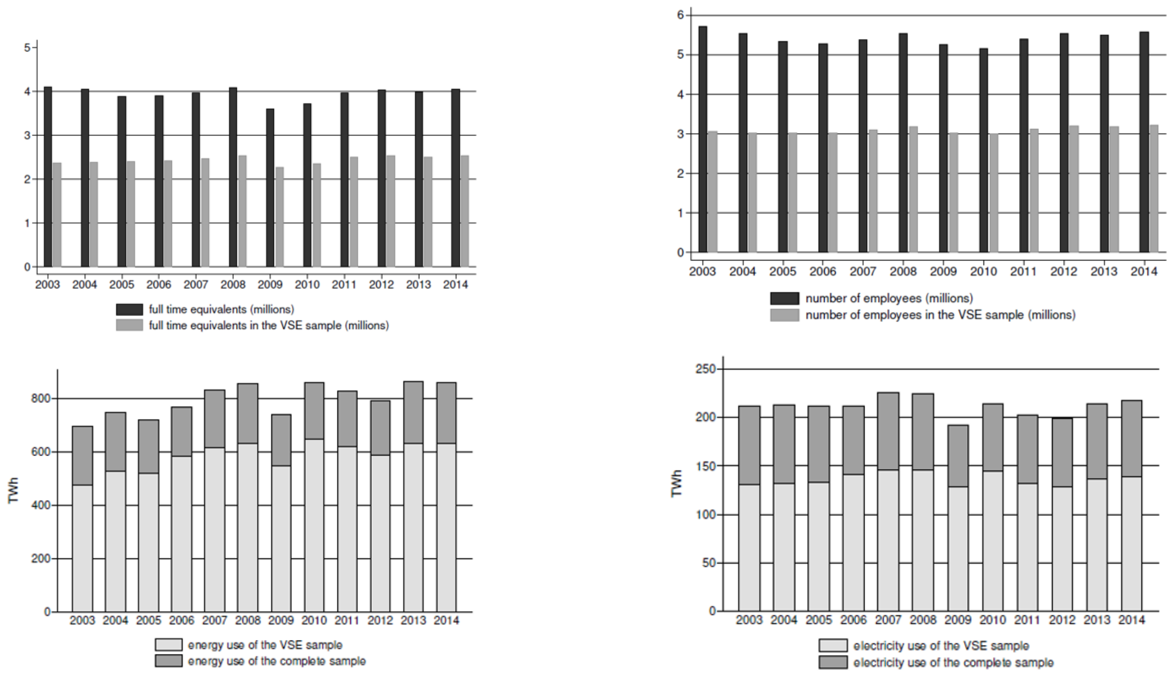
[5]The correlation between e.g. the low and medium voltage per unit prices for plants with an annual use of below 2,500 hours in our estimation sample is around 0.5-0.7 in each year; for the peak load price, the correlation is approximately 0.55-0.85.

operating hours) $LP1$ and $LP2$ are the load-based prices. We run separate regressions for the low and medium voltage network charges. Subscript s denotes the sector, so π_{st} non-parametrically captures sector specific time trends. We cluster errors at the level of the county as a proxy for the network in the main specification. We have done robustness checks with regard to the clustering and our findings hold.

3.4 The estimation sample

As noted in the previous section, our estimation sample consists of all plants in the AFiD panel between 2005 and 2014 that reported in the structure of earnings survey at least once between 2001 and 2014. We denote this sample the VSE sample (VSE - *VerdienstStrukturErhebung* - Structure of earnings survey) This leaves us with a panel of around 12,000-16,000 plants per year, while the AFiD universe of all plants with more than 20 employees in the manufacturing sector in Germany consists of around 40,000 plants per year. However, whilst we lose many plants in our analysis in absolute terms, our sample covers large shares of the AFiD universe in terms of variables of significant economic importance: As shown in Figure 4, our sample covers around 55% of the employees in the German manufacturing sector each year, around 60% of full time equivalents, roughly 65% of electricity use and roughly 70% of total energy use. Those numbers show that with our sample, we capture an important part of the economic activity in German manufacturing, especially with regards to energy statistics. The numbers reflect the fact that in the structure of earnings survey, larger plants with more employees (and higher energy uses) are overrepresented.

Table 2 presents the summary statistics of the variables we use in our estimation.



Own calculations.

Figure 4: Coverage of key variables of the estimation sample as compared to the full AFiD universe

Table 2: Summary statistics of key variables in 2009 (top panel) and 2014 (bottom panel)

	NS-1-AP	**NS-2-AP**	**NS-1-LP**	**NS-2-LP**	**MS-1-AP**	**MS-2-AP**	**MS-1-LP**	**MS-2-LP**	**log electricity use**	**log hours worked**
p10	2.5775	0.825	6.72	34.50208	1.76	0.29	4.315	31.86	11.2923	11.41083
p50	3.529167	1.431944	10.82	63.6475	2.29	0.525	8.07	53.93	13.66785	12.26063
mean	3.555349	1.486466	12.46244	64.26108	2.345249	0.581066	8.660918	52.89386	13.78804	12.43174
p90	4.591667	2.3	22.385	95.145	2.97	0.9358333	14.05	68.29833	16.44377	13.71739
sd	0.8611315	0.5197744	6.176449	22.32365	0.5550992	0.2478748	3.71937	13.92703	2.014251	0.9427895
p10	3.084167	1	8.96	44.36	2.172857	0.4114286	6.953333	46.02	11.29384	11.49165
p50	4.15	1.62	15.19167	80.035	2.975	0.74	12.4	69.58	13.72033	12.35233
mean	4.159978	1.679516	18.78404	80.82929	2.990096	0.7914403	13.95825	68.97191	13.84517	12.5249
p90	5.28	2.47	32.205	113.73	3.88	1.36	22.83556	92.77	16.55264	13.80948
sd	0.8523594	0.5723599	9.916429	24.20838	0.6530322	0.3571383	6.577795	18.12808	2.063467	0.9467531

Notes: Own calculations. NS and MS are abbreviations for low and medium voltage levels, respectively. 1 and 2 indicate the network prices for plants with an annual use of the net of below or above 2,500 hours, respectively. AP and LP are abbreviations for the per unit price and the peak load price.

4 Results

4.1 The effects of metwork charges on electricity consumption

Table 3 depicts our estimates of the effects of network charges on the electricity consumption of German manufacturing plants. Column (1) contains the results from running equation 1 using network charges from the low voltage level and column (2) from using network charges from the medium voltage level. In the regressions, we exploit the within-plant variation in network charges over time for 13,783 German manufacturing plants. On average, plants are present in our sample for 8.54 years, which yields a sample size of 117,830 observations. Standard errors are clustered at the county level.

Table 3: The effects of network charges on electricity consumption of German manufacturing plants

	Low voltage level	**Medium voltage level**
	(1)	(2)
Network price per unit, group 1	-0.0158 (0.0001)***	-0.0131 (0.0218)**
Network peak load price, group 1	-0.0008 (0.1005)	0.0004 (0.5477)
Network price per unit, group 2	-0.0033 (0.4906)	-0.0005 (0.9585)
Network peak load price, group 2	-0.0039 (0.0064)***	0.0001 (0.4329)
N	117.830	117.830
R^2	0.0353	0.0349

Notes: The regressions include observations from 2005–2014. The dependent variable is the logarithm of electricity use per plant. The reported numbers are the coefficients from a panel fixed effect regression of log electricity prices on network prices with plant and sector-year fixed effects, using standard errors clustered at the county-level. p-values are in parentheses. Group 1 refers to plants having annual hours of use of the net of below 2.500, group 2 with above 2.500. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. Column (1) contains results using network charges from the low voltage level. Column (2) reports results for network prices from the medium voltage level.

As can be seen in Table 3, network charges have a statistically significant negative effect on plants' electricity consumption: We find significant negative effects of the per unit network price in both voltage levels for those plants with an annual use of the net of below 2,500 hours (*group 1*). The coefficients suggest that a one cent increase in the per unit network price for those plants is associated with a decrease in electricity consumption of around 1.6% in the low voltage level and around 1.3% in the medium voltage level. While this might seem a large effect at first sight, note that average and median per unit network price for electricity purchasers with an annual use of the net of below 2,500 hours amounts to around 4 cents in the low voltage level and 2-2.5 cents in the medium voltage level (see summary statistics in Table 2). Thus, a one cent increase is equivalent to a 25% or 40-50% increase in the per unit network price, respectively, which is a large change. In terms of total electricity prices, a one cent increase corresponds to an increase of around 4-5%. With this in mind, the size of our estimates seem plausible.

Interestingly, it seems that the plants with more than 2,500 operating hours (*group 2*) do not react to the per unit network price, but rather to the peak load price: For those plants, a one euro increase in the peak load price in the low voltage level is associated with a statistically significant decrease of electricity use of around 0.04%. Since the peak load price is not directly translatable into a price per kilowatt hour, it is difficult to assess the plausibility of the size of this effect. Given that a one euro increase in the peak load price is equivalent to an increase of around 1.1-1.4%, it makes sense that the estimated effect is smaller than the one observed for the per unit price for the plants with an annual use of below 2,500 hours. Yet, it is striking that we find an effect at all: Standard economic theory would predict that firms respond to marginal prices only, not to fixed costs. However, our result is in line with Puller and West (2013) who state that "(c)asual empiricism suggests that utility customers are better informed about their total monthly expenditures on gas/electricity rather than the marginal price [...]." For households as well, Ito (2014) found responses to average prices rather than marginal prices. The statistically significant effect we find for the peak load price points in the same direction for German manufacturing plants. However, we do not find a statistically significant effect in the medium voltage level.

4.2 The effects of network charges on hours worked

Table 4 presents the results from estimating equation 1 using the logarithm of labour input, i.e. total hours worked in a manufacturing plant, as a dependent variable. Again, column (1) reports the results for the low voltage level and column (2) for the medium voltage level. Since we only have the hours worked for manufacturing plants with more than 50 employees available throughout the estimation period, the number of observations differs from the one we used in the previous section: Here, we use information on 10,899 German manufacturing plants who report on average for 8.43 years, resulting in a sample of 91,902 observations. Standard errors are clustered at the county level.

Table 4: The effects of network charges on hours worked in German manufacturing plants

	Low voltage level	**Medium voltage level**
	(1)	(2)
Network price per unit, group 1	-0.0118 (0.0036)***	-0.0387 (0.5006)
Network peak load price, group 1	0.0004 (0.4018)	0.0005 (0.5195)
Network price per unit, group 2	0.0023 (0.6077)	-0.0017 (0.8556)
Network peak load price, group 2	-0.0002 (0.0549)	0.0003 (0.1184)
N	91.902	91.902
R^2	0.0590	0.0586

Notes: The regressions include observations from 2005–2014. The dependent variable is the logarithm of hours worked use per plant. The reported numbers are the coefficients from a panel fixed effect regression of log electricity prices on network prices with plant and sector-year fixed effects, using standard errors clustered at the county-level. p-values are in parentheses. Group 1 refers to plants having less than 2.500 operating hours annually, group 2 are plants with more than 2.500 operating hours. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. Column (1) contains results using network charges from the low voltage level. Column (2) reports results for network charges from the medium voltage level.

While we do not find statistically significant effects for any of the price components of network charges in the medium voltage level, we do find a negative effect of network charges on hours worked in the low voltage level. The pattern is similar to the effects of network charges on electricity consumption: The plants with an annual use of the net of below 2,500 hours (*group 1*) respond to the per unit network price, while the plants with an annual use of the net of above 2,500 hours (*group 2*) rather respond to the peak load price. In particular, we find that for the plants without shift/night/Sunday work, a one cent increase in the per unit network price leads to a decrease in the hours worked of around 1.2%. For the plants that exceed an annual use of the net of 2,500 hours, a one euro increase in the peak load price is related to a decrease in the hours worked of around 0.02% – even though the effect is only marginally significant. Overall, the effects are smaller than what we find with respect to electricity consumption, indicating that the hours worked might be more difficult to adjust for manufacturing plants as compared to electricity consumption. The sign of the effect however seems to suggest that labour input and electricity are complements rather than substitutes: If prices for one of those input factors increase, demand for the other decreases. These findings are in line with previous findings by Cox *et al.* (2014) who find that the dominant effect of electricity price increases is to decrease production. The effect we find is pretty large: While Marin and Vona (2019) do not find any significant effect of energy prices on aggregate employment, using data on 14 European countries and 15 industrial sectors over the period 1995-2011, Deschenes (2010) finds a statistically significant effect of electricity prices on full-time equivalent employment in the US; his estimates however are somewhat smaller, as he finds that a 1 percent increase in electricity prices leads to a change in full-time equivalent employment that ranges from -0.16 to -0.10%. Hence, for a 4-5% increase in electricity prices, his estimates predict a decrease in employment of 0.8% at maximum. The employment effects of electricity prices remains ambiguous and merit futher analysis.

4.3 Sectoral heterogeneity in the effects of network charges

The previous sections reported results of the effects of network charges on electricity consumption and hours worked in the manufacturing sector as a whole. However, the manufacturing sector is quite heterogeneous: It comprises both sectors in which the electricity intensity (i.e. the kWh of electricity consumed per euro of output) is quite high, as e.g. the manufacture of food products, the textiles industry or the manufacture of computer, electronic and optical products, and sectors in which electricity plays only a minor role, as e.g. the manufacture of electrical equipment or the manufacture of furniture. To take these differences into account, we modify equation 1 and introduce interaction terms of the network charge variables with two-digit sectors. We find substantial heterogeneity in the effects of network charges in the different sectors.[6] In particular, we find that the negative effects of network charges on electricity consumption are concentrated in the sectors "manufacture of computer, electronic and optical products" (NACE code 26) and "machine construction" (NACE code 28) in the low voltage level. Those are also the sectors for which we find a significant negative effect of network charges on total hours worked.[7] In the medium voltage level, we also find significant negative effects of network charges on the hours worked in sector 26. Note that this sector is among the top five sectors with respect to electricity intensity so that a strong reaction of this sector to increases in electricity prices seems plausible.

[6] Due to confidentiality requirements, the exact regression results cannot be depicted in this paper at this moment.

[7] We do only interpret results in sectors where we have at least 1.000 observations available.

4.4 Robustness checks

In order to check the robustness of our results to changes in the assumptions we made, we run various additional regressions:

First, we exclude all plants from our estimation sample that took part in the structure of earnings survey only in 2001: 2001 is relatively far away from our estimation sample ranging from 2005 to 2014; it might be problematic to classify plants into doing shift/night/Sunday work or conducting none of those work models in 2014 based on the classification of 2001. In a similar vein, we exclude all observations where reporting in the structure of earnings survey dated back more than four years: The farther away the reporting year has been, the larger is the probability that the plants changed their work models and switched in or out of doing shift/night/Sunday work. Our results are robust to those specifications.

Moreover, we run our regressions excluding all observations from 2009: It is well known that many manufacturing firms in Germany responded to the economic crisis by introducing short-time work. Therefore, in 2009, arguably many plants usually operating for more than 2,500 hours per year could have reduced hours, leading to a different network tariff applying in 2009. We check whether this potential misclassification of manufacturing plants in 2009 in the network tariff structure affects the results. This is not the case.

Finally, we also check whether the significance of the results changes when we cluster standard errors at the level of the high voltage level network areas instead of at the county level. In 2010, there were only around 50 high voltage level network areas as compared to roughly 420 counties. Thus, clustering at a more aggregate level should diminish the significance of the results. We choose to cluster on the levels of the high voltage level network areas (rather than on the low or medium voltage level networks), since the costs of the high voltage level networks are passed on to the medium and low voltage level networks, so that all plants located in the same high voltage level network area might be affected by changes in network charges to some degree in the same way (see Figure 6 in the Appendix for an overview of the structure of the network charges). Again, the results are not affected.

5 Conclusion

Climate policies like the European Union Emission Trading Scheme or the Renewable Energy Surcharge in Germany tend to result in increasing electricity prices. Given that climate change regulation does not apply worldwide but remains a largely unilateral issue, concerns about job losses and decreases in international competitiveness have been raised. As the German manufacturing sector is both an important pillar of the German economy and export-dependent, it is of crucial interest to policy makers of how manufacturing plants react to increasing electricity prices. In this paper, we shed light on the responses of German manufacturing plants to changes in exogeneous variation in electricity prices using a unique combination of administrative micro level data with information on network charges.

Exploiting within-plant variation in network charges over time, we find that manufacturing plants react to rising network charges by both reducing electricity consumption and labour input as measured by the hours worked. Results however display large degrees of heterogeneity across sectors within manufacturing. More research is needed to identify the channels by which increasing network charges reduce labour input in the German manufacturing sector.

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References

Abeberese, A. B. (2017). Electricity Cost and Firm Performance: Evidence from India. *The Review of Economics and Statistics*, **99** (5), 839–852.

Alexeeva-Talebi, V. (2011). Cost pass-through of the EU emissions allowances: Examining the European petroleum markets. *Energy Economics*, **33**, S75 – S83, supplemental Issue: Fourth Atlantic Workshop in Energy and Environmental Economics.

Bardazzi, R., Oropallo, F. and Pazienza, M. G. (2015). Do manufacturing firms react to energy prices? Evidence from Italy. *Energy Economics*, **49**, 168–181.

Boyd, G. A. and Lee, J. M. (2016). Measuring Plant Level Energy Efficiency and Technical Change in the U.S. Metal-Based Durable Manufacturing Sector Using Stochastic Frontier Analysis. *US Census Bureau Center for Economic Studies Paper No. CES-WP- 16-52*.

Cox, M., Peichl, A., Pestel, N. and Siegloch, S. (2014). Labor demand effects of rising electricity prices: Evidence for Germany. *Energy Policy*, **75**, 266–277.

Deschenes, O. (2010). Climate Policy and Labor Markets. *NBER Working Paper*, **16111**.

Fabra, N. and Reguant, M. (2014). Pass-through of emissions costs in electricity markets. *American Economic Review*, **104** (9), 2872–99.

Federal Network Agency (BNetzA) and Federal Cartel Agency (BKartA) (2013). *Development in Electricity and Natural Gas Markets in Germany, Monitoring Report 2012*. Bonn.

Flues, F. and Lutz, B. J. (2015). The effect of electricity taxation on the German manufacturing sector: A regression discontinuity approach. *ZEW discussion papers No. 15-013*.

Gerster, A. (2017). *Do Electricity Taxes Matter? Quasi-Experimental Evidence from German Manufacturing*. Working paper, Social Science Research Network.

Graevenitz, K. v., Lutz, B. and Massier, P. (2011). *Prices as Climate Policy: Assessing the Causal Effect of Electricity Prices on German Manufacturing Plants*. Discussion Papers unpublished, ZEW.

International Energy Agency (IEA) (2013). *Energy Policies of IEA Countries Germany 2013 Review*. Paris.

Ito, K. (2014). Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing. *American Economic Review*, **104** (2), 537–63.

Kahn, M. E. and Mansur, E. T. (2013). Do local energy prices and regulation affect the geographic concentration of employment? *Journal of Public Economics*, **101**, 105–114.

Marin, G. and Vona, F. (2019). Climate policies and skill-biased employment dynamics: Evidence from EU countries. *Journal of Environmental Economics and Management*, **98**.

Martin, R., de Preux, L. B. and Wagner, U. J. (2014). The impact of a carbon tax on manufacturing: Evidence from microdata. *Journal of Public Economics*, **117**, 1–14.

Petrick, S. and Wagner, U. J. (2014). *The impact of carbon trading on industry: Evidence from German manufacturing firms*. Working paper, Social Science Research Network.

Puller, S. L. and West, J. (2013). Efficient retail pricing in electricity and natural gas markets. *American Economic Review*, **103** (3), 350–355.

6 Appendix

Data cleansing for the AFiD data

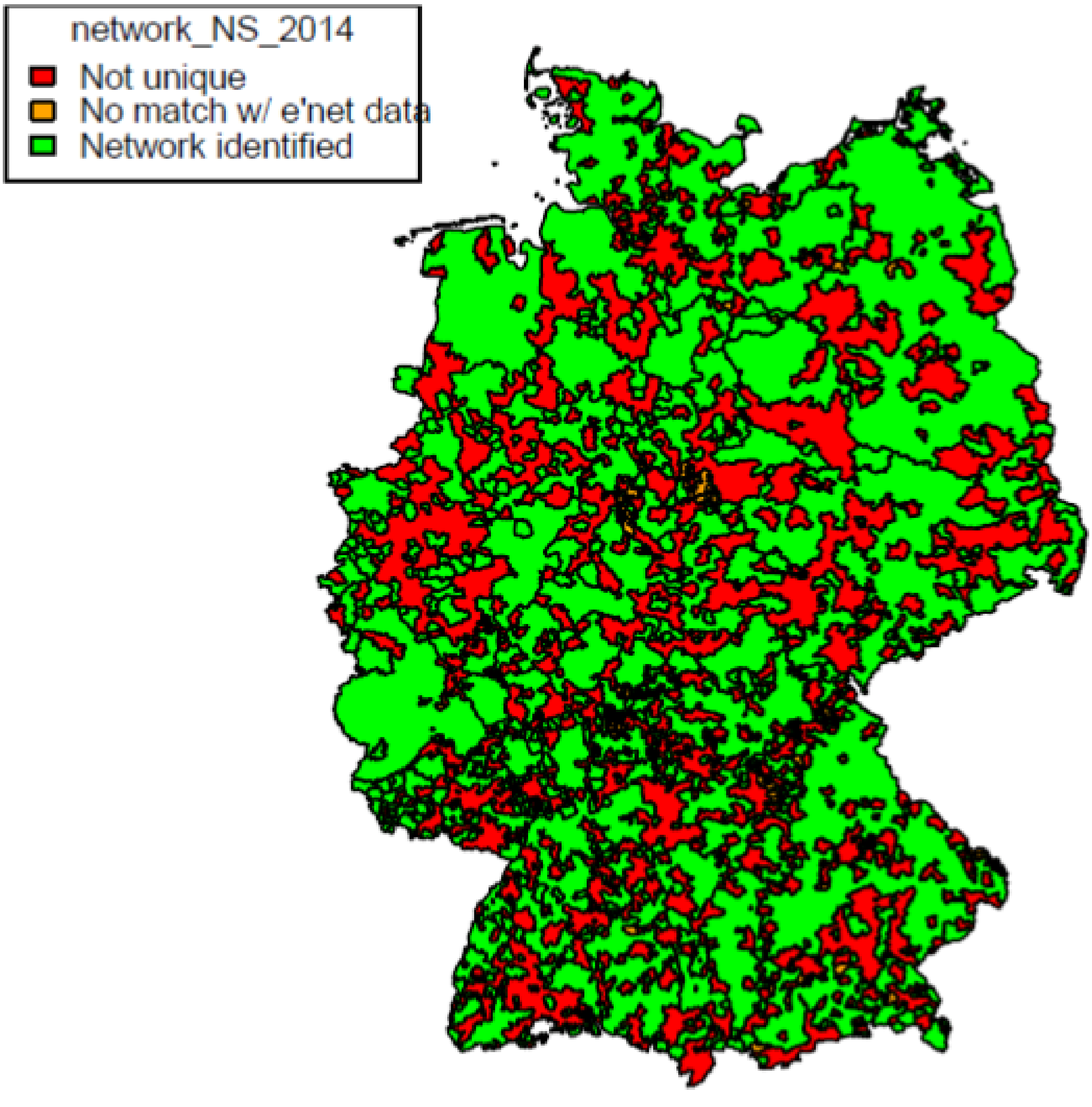
While the research data centres and the statistical offices conduct various quality controls with the data, the large amount of data makes it impossible to check every data point for inconsistencies and to correct all inaccuracies. Therefore, we adopt a separate data cleansing procedure:

Table 5: Reporting patterns in the structure of earnings survey between 2006 and 2014

Own calculations.

Reporting Pattern	**Number of plants**	**Percent**
Reporting in all years	596	2.84
Reporting in 2010 and 2014	436	2.08
Reporting in 2006 and 2010	370	1.76
Reporting in 2006 and 2014	982	4.67
Reporting only in 2014	6.372	30.33
Reporting only in 2010	5.991	28.52
Reporting only in 2006	6.261	29.80
Total	21.008	100

We exclude all observations that report a negative energetic fuel use and those observations where our calculated measure of total energy use is below zero. Moreover, we drop all firms in which one plant reports the energy statistics for several plants within the firm. While we can identify the firms in which one plant reports the energy data for several plants, we cannot properly allocate the fuel and electricity use across the plants which is why we do not consider those firms. Furthermore, we drop all observations where the electricity share from our calculated measure of total energy use exceeds 1, and all observations that report electricity self-generation from fossil fuels while at the same time reporting no consumption of fossil fuels. Lastly, we drop outliers in terms of fuel use, where outliers are defined as plants where one standard deviation of fuel use within the plant is bigger than 100 times the median fuel use of the plant.



Source: Low voltage networks as defined by merging ene't data to municipality shape files.

Figure 5: Unique assignment of low voltage level network areas to municipalities in 2014

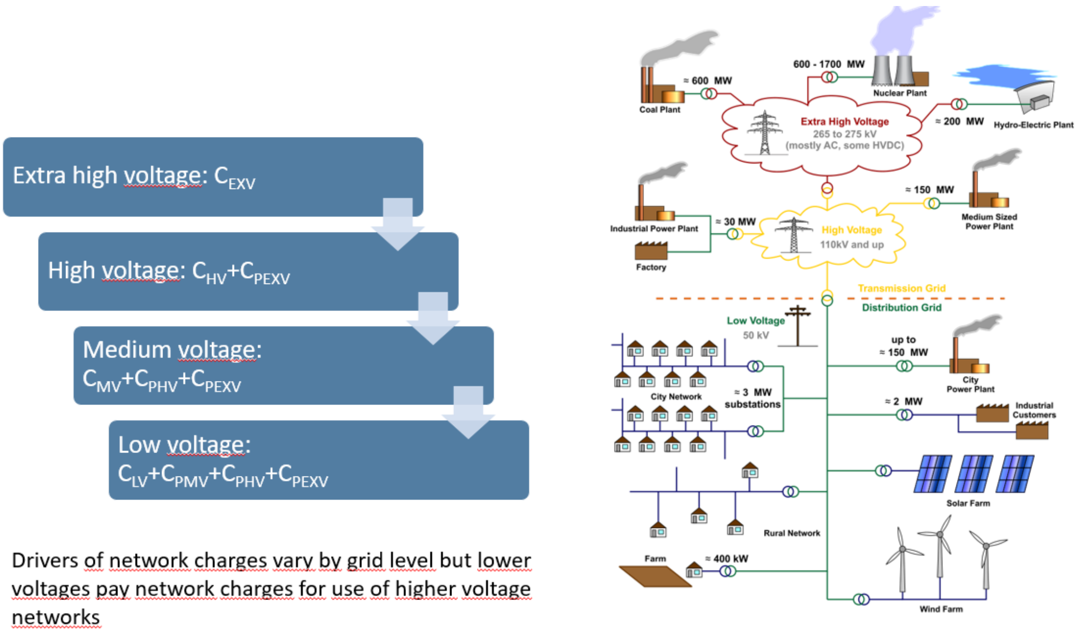


Figure 6: The structure of network charges