Regional electricity price effect on industry location

Sweden's 2011 electricity market split

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Abstract:

In November 2011, a reform split the Swedish electricity market into four price zones and made it possible for different parts of the country to have different electricity prices. For industries where electricity constitutes a large share of production costs, it may be preferred to be located in a zone where electricity prices are lower. The purpose of this thesis is to investigate if splitting the country into four electricity price zones has resulted in new patterns for where electricity-intensive industries are located. We expect the reform to have a negative impact on the number of companies in the southern, more expensive price zones relative to the northern zones. The difference-in-differences method is used to find the effects in four industries: the chemical, steel- and metalworks, metal goods, and rubber- and plastic goods industries. Few results are significant, but those that are, show negative effects in the southern parts of Sweden relative to the north. There are significant effects found in the steel/metal industry in zone 3 and the metal goods industry in zone 4. We consider the results to not provide enough evidence to prove that the reform had a general effect on where firms locate. One of the discussed possible explanations is that firms may value other factors higher than electricity price when deciding location, such as natural resources, labour and infrastructure.

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Introduction

Since 2011, Sweden has had four electricity price zones. Instead of one spot price on the electricity market for the whole country, it has since November 2011 been possible for different parts of Sweden to have different electricity prices depending on demand. This is something we have become acutely aware of in 2022 with spikes in electricity prices in the whole country, but especially in the south of Sweden.

The northern half of the country is characterised by a lower demand for electricity than what is produced, and the southern half, where a majority of the population lives, is characterised by a relatively high demand for electricity. Due to limitations in the electricity transmission system, prices between electricity zones differ. For industries with production that require large amounts of electricity, the possibility of price differences between areas may be an important factor to take into account, as increases in electricity price could lead to higher production costs. For this reason electricity-intensive industries may prefer to be located in a zone with electricity surplus, where electricity prices tend to be lower.

The purpose of this thesis is to investigate what splitting the country into four electricity price zones has meant for industry location; more specifically, if this reform has resulted in new patterns for where electricity-intensive industries are located.

The structure of the thesis is as follows: first, a review of previous literature on this topic, followed by background information about the Swedish electricity market. Thereafter, theory on production cost and comparative advantage between regions is presented. We also introduce the difference-in-differences method which was used for the analysis. After that, results on the relative effect of electricity zones on firm location are presented along with a conclusion, leaving ideas for future research.

2 Related research

One of the earlier studies on industry location choice, by Carlton (1983), compares three industries in the United States with different levels of electricity intensity to investigate what factors play a significant role in firm location decision making. The results show that electricity prices have a strong effect on industry location (Carlton 1983). Another one of the earlier studies proves different results. Nijkamp and Perrels (1988) investigate if regional electricity price differences in The Netherlands expose a pattern in firm location. To analyse this, they divide the country into four areas with significantly different price levels, to see if firms tend to locate or relocate to an area with lower electricity price. The results show almost no effect of regional electricity price differences on firm location patterns.

Bae (2009) studies how firms respond to regional electricity prices in the United States. Firms that have the possibility to relocate may move to a state with lower electricity prices, as a response to higher electricity costs. Since firms may respond differently due to differences in mobility, three groups were studied: electricity-intensive firms with high or low mobility, and firms that do not use a lot of electricity for production. The results show that electricity-intensive firms of both high and low mobility tend to not relocate. Instead, they substitute away electricity when prices are high. It is also discussed that firms may not relocate due to high moving costs and other regional factors that play a role in firm location. Khan and Mansur (2013) find a relationship between electricity price and firm location decisions for some manufacturing industries like primary metals. This relationship is not found among non-manufacturing industries.

For the electricity generation industry, the direction of location choice is opposite to that of manufacturing. Sweden's 2011 electricity market split has been evaluated by Lundin (2022). With a difference-in-differences approach (similar to the one used in this thesis), he finds that the split caused 18 percent of wind power construction projects with large developers to move in planning from zones 1 and 2 with lower electricity price to zones 3 and 4 with higher price. Smaller developers did not shift locations; probably because they are locally bound.

Indirect evidence of manufacturing industry location tending towards low cost electricity areas is found in a study of foreign direct investments (FDI) by Barteková & Ziesemer (2018). They find that European Union countries with higher electricity prices attract less FDI. This potentially affects or is affected by industry location.

Overall, the literature on electricity price and firm location is inconclusive. Although, it seems more common to not find electricity price as a determinant for where manufacturing firms locate. Literature on the Swedish electricity market split is limited, and we find no study on how the market split may have affected manufacturing firms' location choices. Therefore, this thesis could contribute with knowledge about the reform effects on Swedish industries. The varying results of this literature review give no clear indication of what the effects of the reform may be.

3 Background: The Swedish electricity market

The Swedish electricity market was split into four electricity price zones (sometimes called bidding areas) on November 1, 2011. This was done to comply with European Union laws and efforts to create a more integrated electricity market (Energimarknadsinspektionen 2014).

Since the deregulation of the electricity market in 1996, the spot prices for electricity have been decided on the Nord Pool market. Nord Pool is a common market for the Nordic countries, and the spot prices are decided based on supply and demand. Before the 2011 reform there was one spot price for the whole country; now there are four. Prices are decided for each price zone every hour for the next day. This is called the day-ahead market (Nord pool n.d).

Spot prices differ between zones because of limitations in transmission capacity. Since demand for electricity is higher in the south, electricity from northern Sweden has to be transported. There are limitations in how much electricity that can be moved through the transmission system, and when demand for electricity in a zone is higher than what the transmission system can handle (also called bottlenecks), the spot prices between electricity zones diverge, creating higher prices in the zone with higher demand (Energimarknadsinspektionen 2014). Splitting the electricity market into four zones has therefore helped to expose where those limitations are, which gives indications to where investments should be made in the transmission system (Svenska kraftnät 2022).

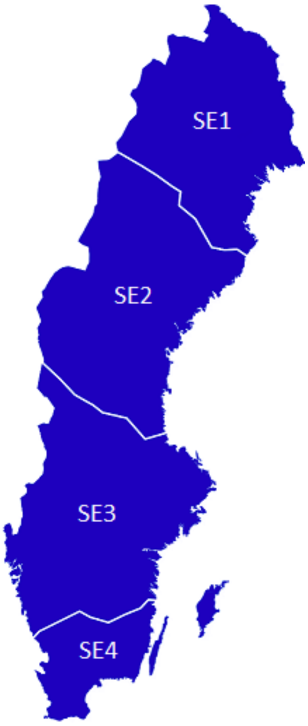

Figure 1. The four Swedish electricity price areas (SCB 2022b, modified).

Figure 1 shows a map of the electricity price zones in Sweden. The price zones from north to south are called SE1, SE2, SE3, and SE4. As previously stated, there is an electricity surplus in the north (SE1 and SE2) and electricity deficiency in the south (SE3 and SE4). Anticipating the market split, prices were expected to become higher and fluctuate more in the south. However, price differences were small until 2018. SE1 and SE2 have had the same spot price for most of the time. Until 2019, SE3 only had slightly higher spot prices than the northern price zones. And SE4, the most southern and connected to continental Europe, was not much more expensive until 2018.

Bottlenecks in the electricity transmission system make the prices in zones 3 and 4 more sensitive to being tied to German electricity spot prices (Energimarknadsinspektionen 2014). This partly explains why the southern half of Sweden has been the most affected by the 2022 electricity crisis. Further, in a recent assessment of electricity generation capacity relative to demand, SE4 had the lowest relative capacity in Europe (less than 100%) and SE1 and SE2 had the highest relative capacity in Europe (more than 300%) (ENTSO-E 2022, p. 12).

Figure 2, found below, illustrates average yearly electricity spot prices for each price zone. It is visible that the prices are similar, but SE4 tends to be the zone with the highest electricity spot price. Figure 2 also shows that spot prices in SE3 have been 95 percent of prices in SE4, and prices in SE1 and SE2 have been 86 percent of prices in SE4.

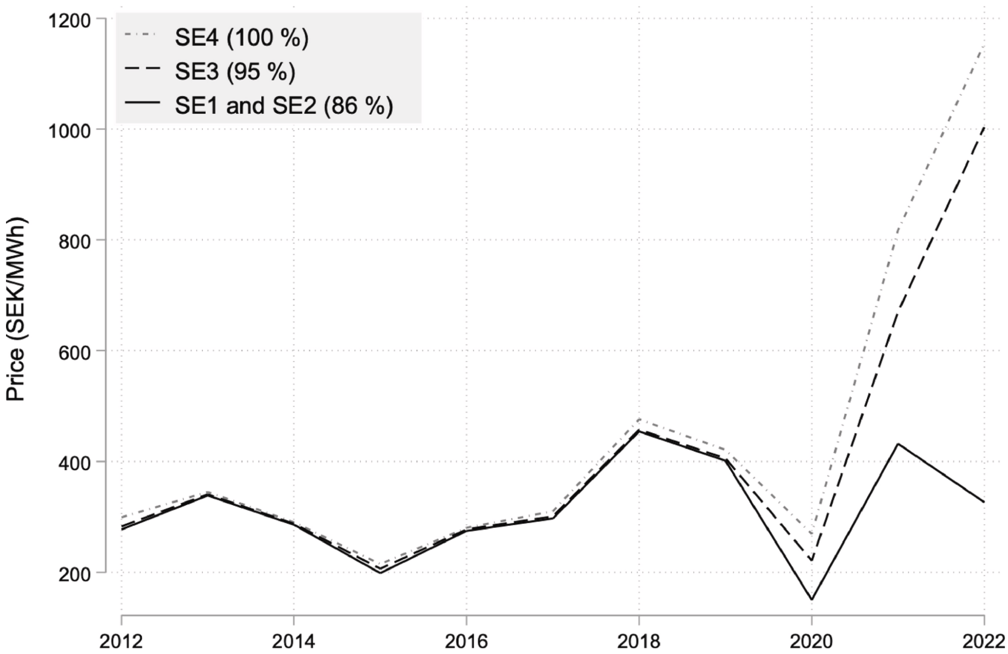

Figure 2. Average yearly electricity spot prices by zone (Lundin 2022, p. 4).

4 Theory: Production cost and comparative advantage

In this section, we present theory about why electricity price affects industry location and other industry performance indicators.

The theory of production cost is concerned with profit maximisation by optimising costs and production quantities. Electricity is one of several input factors to production (others include labour and capital). When electricity price is raised, then the variable cost of production increases[1]. All else equal, the production supply curve shifts left/up (see figure 3) (Frank & Cartwright 2016). This is particularly significant in electricity-intensive production where electricity constitutes a larger share of production inputs. With imperfect competition and product differentiation, the product price could be raised to P_1 in the figure. With perfect

[1] Some companies have fixed rate electricity contracts (SVT 2022). We consider this a variable cost because the fixed rate over time reflects the underlying electricity spot price. Furthermore, per definition, fixed costs remain when production is stopped. We could not find statistics for the contract time of companies in Sweden; fixed rate contracts for households range from 1-3 years (SCB 2023).

competition, price would be fixed at P_0 and production output would have to be limited to less than Q_1.

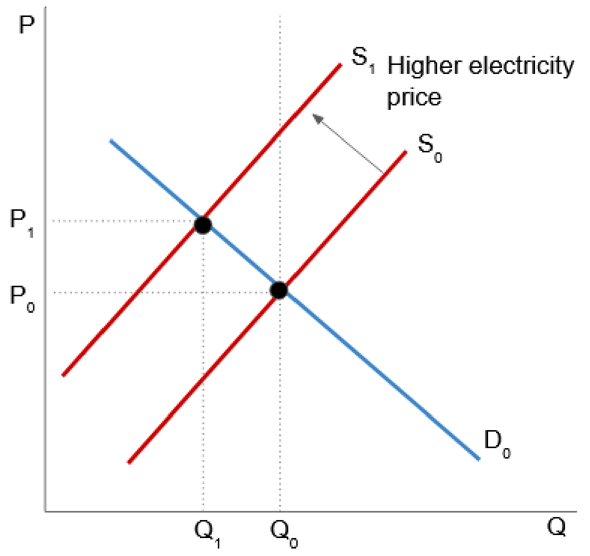

Figure 3. Production supply curve shift.

Without transmission limitations, the law of one price for identical goods would apply to electricity (Feenstra & Taylor 2017) and make all zones have the same spot price. Transmission limitations make electricity regionally bound to a degree, which is manifested in different zonal prices. The potential effects of regional differences in electricity price can be explained with the Heckscher-Ohlin model on comparative advantage. In both international and domestic trade, and thus competition, regions have comparative advantage over other regions in producing and exporting goods that intensely use factors of production found in abundance in that region (Feenstra & Taylor 2017). For example, labour, raw materials, and electricity. To be competitive, industries will tend to locate in regions that afford enough comparative advantage in key input factors (e.g. Kahn & Mansur 2013).

Electricity abundance and low electricity prices play a significant role for some industries. For example, electricity cost per production cost can be 12-16% for textiles, 20-25% for electric furnace steel, and 30-50% for aluminium and chemicals (BLS & Tractus 2016, in Elliot, Sun & Zhu 2019, p. 567). Indeed, Sweden and other countries give electricity-intensive industries big reductions in energy tax on electricity as well as exemptions from other electricity related fees (European Commission 2022; Energimyndigheten 2019).

In the long run, all production factors can be changed (Frank & Cartwright 2016; Perloff 2020) and electricity-intensive industries and startup investments may tend to move production to lower-cost electricity zones (e.g. Kahn & Mansur 2013). However, electricity-intensive industries may have other factors than electricity that influence location. For example, data-centres prefer a cold climate for cooling and metal producers prefer proximity to mines. Generally, key considerations include labour supply, transport and service infrastructure, cost of land, and materials supply (Nijkamp & Perells 1988). As outlined earlier in our research review, electricity price effect on industry location shows mixed results due to such multi-factor considerations.

In the short run, fixed costs of manufacturing facilities such as investments in buildings and machines can prevent industry movement (Frank & Cartwright 2016; Perloff 2020). There are many ways such bound companies may be affected by and respond to higher electricity prices. For example, they may lower manufacturing output (Kwon et al. 2016a; Gonese, Hompashe & Sibanda 2019) and consequently reduce jobs (Bijnens, Konings & Vanormelingen 2022), increase energy efficiency (Bae 2009; Kwon et al. 2016b; Ratner & Ratner 2016), or switch manufacturing to another type of product (Elliot, Sun & Zhu 2019). Hence, electricity-intensive industries in the southern price zones may have to increase energy efficiency and decrease manufacturing output.

In summary, electricity-intensive industries that are not bound to other resources and investments, and cannot increase energy efficiency, should tend to locate production in electricity zones with lower cost or expected lower cost. This implies the following hypothesis for our study: We expect the number of firms in electricity-intensive industries to decrease in the southern, more expensive price zones relative to the number of firms in the northern zones.

5 Method

5.1 Difference-in-differences (DiD)

5.1.1 Approach

To analyse the effects of the market split reform, we use the difference-in-differences method (DiD). DiD is an approach used to evaluate effects of e.g. a reform or event (treatment). By comparing a group that has been exposed to treatment (treatment group) with a group that has not (control group), one can find the treatment effect; assuming that exposure to treatment is the only thing that differs between the groups. In our analysis, treatment is the reform, and the electricity zones are either treatment or control groups.

DiD rests on an assumption of parallel trends, i.e. all groups would have identical trends without exposure to treatment. By verifying parallel trends of control and treatment groups in years prior to treatment, it is confirmed that the groups are suited for DiD analysis. Figure 4 illustrates actual parallel trends before treatment, actual diverging trends after treatment, and a dotted assumed parallel trend without treatment.

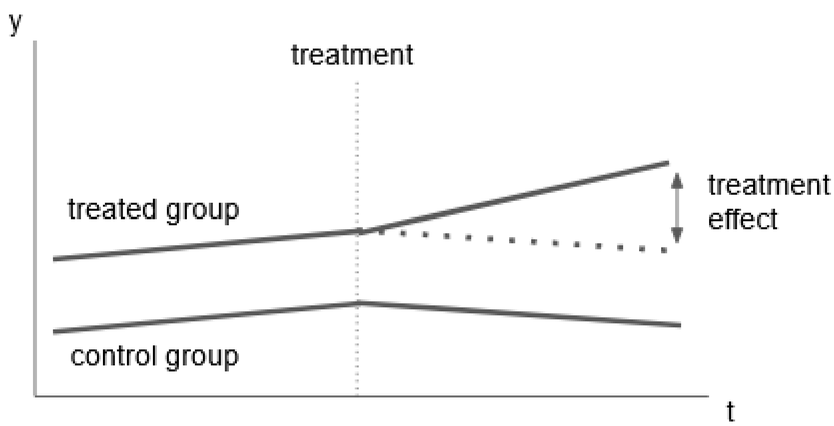

Figure 4. Basic difference-in-differences curves.

The two treatment groups in our DiD are the higher price electricity zones 3 and 4. Due to the small differences in electricity price between zones 1 and 2 they are combined into one control group. Usually in a DiD, the control group has not been exposed to treatment. That is not the case in this study since the control group zones exist as a result of the reform and are affected by the change in relative prices between zones. We can still use zones 1 and 2 as a control group because we are interested in relative effects between zones. Our results do not state the treatment effect compared to no treatment. They state the effects in the southern zones (SE3 and SE4) relative to the effect in the north (SE1 and SE2). Our approach is similar to Lundin (2022) who investigates wind power investments with a DiD, and uses the northern zones as control group and southern zones as treatment group.

The market split was implemented in November 2011. We define the whole year 2011 (and thus the yearly observations for 2011) to be before treatment, and observations for 2012 and later are defined as after treatment.

5.1.2 Our DiD model

We use regression with panel data to estimate our DiD model. Our basic model:

$$Y_{it} = \alpha + \beta_1 \boldsymbol{zone}_i + \beta_2 post_t + \delta(\boldsymbol{zone}_i \times post_t) + \varepsilon_{it}$$

Y_{it} is the outcome variable that represents the number of companies in county *i* in year *t*. α is a constant. $Zone_i$ is a vector of dummy variables for electricity price areas SE3 and SE4, which take the value zero for observations in SE1 and SE2 as they are the base group. $Post_t$ is a dummy variable that is switched on for all years after the treatment year 2011. $Zone_i \times post_t$ is a vector of two interaction variables, which is only activated (1x1) for treated zones in post years, making δ the coefficient of interest. This coefficient captures the relative effect on the treated group after treatment year, and will therefore provide the treatment effect.

The coefficient β_1 adds a constant difference between the control group and the treated group. The coefficient β_2 represents a common time trend for all groups in the post years (i.e. the parallel trend). These are not coefficients of interest. The coefficient of interest δ adds a zone-specific time trend in post years.

Below is the equivalent model without vector notation:

$$Y_{it} = \alpha + \beta_1 zone3_i + \beta_2 zone4_i + \beta_3 post_t + \delta_1(zone3_i \times post_t) + \delta_2(zone4_i \times post_t) + \varepsilon_{it}$$

Our main model adds a county fixed effect:

$$Y_{it} = \alpha + \beta_1 \boldsymbol{zone}_i + \beta_2 post_t + \delta(\boldsymbol{zone}_i \times post_t) + \lambda_i + \varepsilon_{it}$$

The county fixed effect λ_i is intended to account for all county-specific variation and thus remove its effect from the coefficient of interest.

We do not add a time fixed effect in the same way because the first $post_t$ regressor works as a time fixed effect for each year in the post period. It accounts for the common time trend in post years. If we added a conventional time fixed effect, the statistical software would omit one of them due to collinearity. The coefficients of interest calculate the same values with and without a conventional time fixed effect, but since $post_t$ does not cover the pre-period there are small differences in p-values. Our results are robust to either approach, i.e. significance does not change.

County and time fixed effects are powerful at soaking up omitted variable effects but "cannot control for omitted variables that vary both across entities and over time." (Stock & Watson, 2020, p. 381)

Our model with controls added:

$$Y_{it} = \alpha + \beta_1 \boldsymbol{zone}_i + \beta_2 post_t + \delta(\boldsymbol{zone}_i \times post_t) + \lambda_i + \beta_3 \boldsymbol{control}_{it} + \varepsilon_{it}$$

Control variables are typically crucial to include so that their effect is not attributed to the variable of interest, i.e. omitted variable bias. $Control_{it}$ is a vector of control variables. Considering urbanisation and that southern Sweden is more densely populated than the north, we included county population size as a control variable. However, it is a poor control due to simultaneity. Large population size may lead to more companies locating in the region, but at the same time more companies may lead to more people locating in the region.

We did not have time to include more controls. We considered a business climate index, an aggregate catch-all measure, with an understanding that part of its rating would be attributed to electricity price. Considering more specific controls, Nijkamp & Perells (1988, p. 109) point to various factors that influence firm location choice such as raw materials access, transport conditions and facilities, specialised labour access, and beneficial public regulations.

5.2 Data

The main data used is publicly available from the Statistics Sweden database of industry key figures (SCB 2022a). We have used annual measurements on the number of firms in various industries in all of the 21 Swedish counties between 2008 and 2021. This data allows us to analyse how the number of companies in a certain industry has changed over time in each county. The analysis uses data on the following industries: chemical industry, steel- and metalworks industry, metal goods industry, and the rubber- and plastic goods industry. Why these industries are analysed is explained later in this section.

The electricity price zones were not divided based on county borders, but on the transmission system. Since the data is on a county level and some counties exist across two electricity price zones, we have assigned each county to the zone of which they cover the largest geographical area. As a result, there is a possibility that some companies in the analysis are affected by prices of another electricity zone than they have been assigned to. However, most counties only exist within one zone, and the ones who do not, cover only a small part of another price zone. A list of which zone each county has been assigned to is provided in Appendix A.

5.2.1 Missing observations

The data from Statistics Sweden has some missing values for two reasons. First, when there are fewer than five companies in an observation. Second, when observations are unavailable or unsure. Hence, we must assume that missing values can represent any value.

We excluded industries with many missing values, for example the metal mining industry. Three of the analysed industries had missing data and we are comfortable with the scope and handling of this. To replace missing values with best guess values, also called imputation, we applied (per county) four basic methods that are commonly used: linear interpolation, last value carried forward, mean, and zero constant (Molnar, Hutton, & Fergusson 2008; Williams 2015; Roy 2019). In Appendix B, we describe these methods and how we applied them, together with all missing values and imputations.

To minimise instances of missing data, we chose to include companies of all sizes. This means that companies range from heavy manufacturing with many employees to consulting companies in that industry sector with only one employee. These small companies add uncertainty to our analysis as their electricity intensity and entry/exit patterns may differ from large companies. In other words, the companies in our dataset may have heterogeneous responses to treatment (Stock & Watson 2020, p.500). We hope they tend to gravitate around and correlate with larger companies, or at least not develop in opposite directions.

Also partly to avoid missing data, we chose industries at a rather high level of classification. Companies in Sweden are multi-level classified according to their type of business. The current classification standard SNI 2007 is based on five digits, where one digit is the highest aggregation. We chose industries at the 2 digit level, while for example Carlton (1983) and Bae (2009) use more disaggregate levels. Maybe a more disaggregate level would enable us to select industry niches with a larger proportion of companies that are electricity-intensive.

5.2.2 Chosen industries

The strongest effect of the electricity market reform is expected to be found in industries that use a lot of electricity. For this reason, data on electricity-intensive industries has been used. The definition of an electricity-intensive firm is, according to the electricity certificate law: a manufacturing industry that "uses or is expected to use on average at least 190 megawatt hours of electricity for every million Swedish crowns of the value added from the electricity-intensive production" (Energimyndigheten 2019). Since our data does not provide information on how much electricity is used by the firms, we have chosen industries for the analysis based on the following conditions: the industry has relatively high electricity costs compared to other industries (Energimyndigheten 2022), is highly represented among firms granted electricity tax reduction in 2021 (European Commission 2022), and achieves parallel pre-trends. This is a way to choose industries with large numbers of electricity-intensive firms, but does not guarantee that all firms in our data set are electricity-intensive.

Table 1 describes the analysed industries with their SNI code (classification for the type of business), along with mean and standard deviation.

Variable	Description	Mean (std. dev)
Steel/metal	Number of firms in the industry for steel and metal works (SNI 24)	14.14 (9.24)
Metal goods	Number of firms in the industry for metal goods (SNI 25)	248.79 (200.08)
Chemical	Number of firms in the chemical industry (SNI 20)	22.23 (28.21)
Rubber/plastic goods	Number of firms in the industry for rubber and plastic goods (SNI 22)	42.97 (43.49)

Table 1. Outcome variables, description, mean and standard deviation.

5.3 Parallel pre-trends verification

One basic method to verify that the parallel trends assumption holds for the chosen industries is a visual check of pre-treatment curves. Figure 5 below illustrates the number of companies between 2008-2021 in the analysed industries, in the treatment (3, 4) and control zones (1-2). The graphs are necessary to decide if the pre-trends between zones before 2012 are parallel enough for the DiD method. The curves for each chosen industry look roughly parallel before treatment.

A more precise method to verify parallel trends in the pre-treatment period is a placebo regression (e.g. Karlsson, Nilsson, & Pichler 2014). We ran such a regression that analysed the four years 2008-2011 (i.e prior to the real treatment) with a placebo treatment placed in 2010; this gave two untreated and two treated years. If trends are not parallel, the placebo treatment will be attributed as causing that divergence. This will result in significant coefficients from the placebo regression that indicate that the parallel trends assumption is violated and that the industry data is not suited for DiD. However, with only four observation years, the standard errors will be large and unlikely to give significant effects.

Results from the placebo regression are found in Appendix C. None of the coefficients of interest are significant, which indicates that there are parallel pre-trends, and confirms that the industry data is suited for DiD analysis.

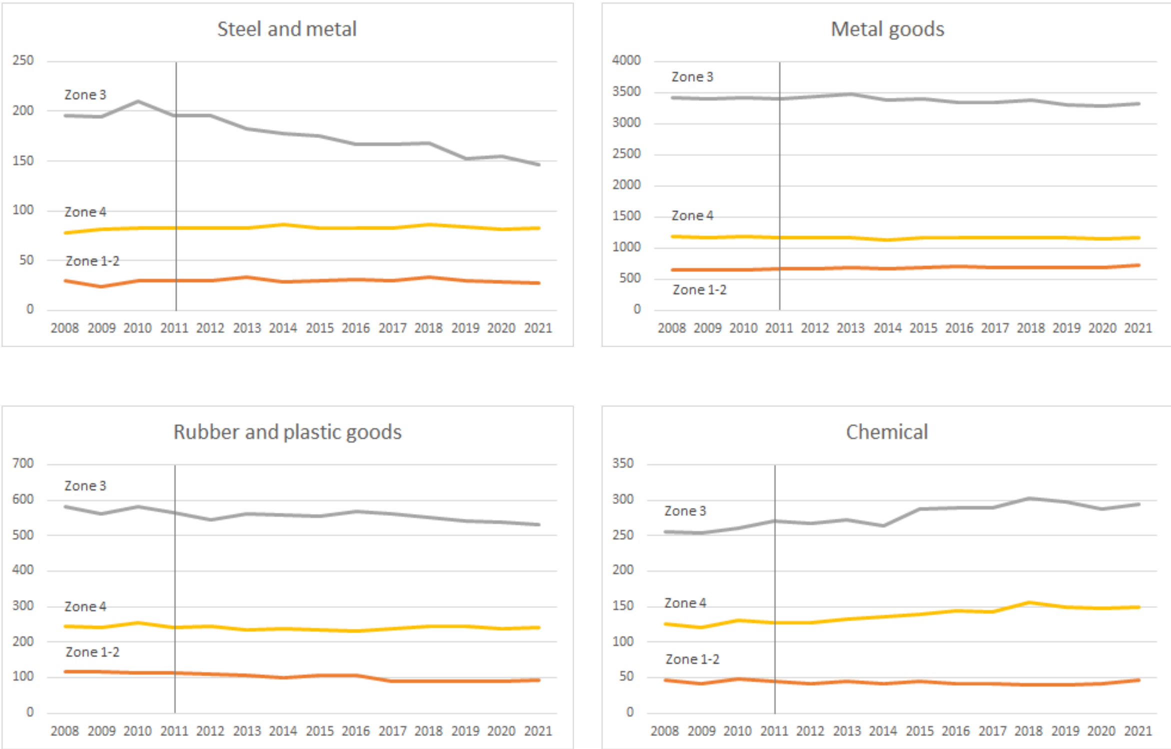

Figure 5. Trend curves for number of companies in each industry.

6 Results

The coefficients of interest are for interaction variables *zone 3 x post* and *zone 4 x post*. They indicate relative development after treatment in each zone compared to zone 1-2, i.e. zone-specific time trends in post years. In so far as fixed effects and control variables remove omitted variable bias, and parallel trends assumption holds, the coefficients of interest show the relative effect of different electricity price zones on firm location.

This effect can be interpreted as the tendency of industries to locate in particular zones. It does not show relocation because a treatment zone can experience a relative increase or decrease in the number of companies without that being related to change in the control zone. Suggesting a relocation effect requires additional findings, such as identifying opposite movements in zone trend curves and tracking company mobility with more detailed data.

	Steel/metal	Metal goods	Rubber/plastic goods	Chemical
Zone 3 x post	-3.217*** (0.002)	-11.659* (0.067)	1.098 (0.409)	2.908 (0.106)
Zone 4 x post	0.04 (0.967)	-10.78** (0.019)	1.92 (0.205)	3.86 (0.111)
Constant	14.655*** (0.000)	249.381*** (0.000)	44.464*** (0.000)	20.583*** (0.000)
FE (yes/no)	yes	yes	yes	yes
R^2	0.019	0.073	0.015	0.043
Observations	294	294	294	294

Table 2. Results of the main specification.

Observations for each county are autocorrelated and therefore we use robust clustered standard errors. p-value in parenthesis, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Zone 3 x post and *zone 4 x post* are the coefficients of interest, showing treatment effects for the analysed industries in electricity zones SE3 and SE4. Significant effects at the at least 5% significance-level are found for the steel/metal industry in zone SE3 and the metal goods industry in zone SE4. The steel/metal industry in SE3 has a negative effect of -3.217 firms per year, and the metal goods industry in SE4 has a negative effect of -10.78 as a result of the reform.

None of the interaction coefficients for rubber/plastic goods and chemical industries are significant. This indicates, even though all those coefficients are positive, that we cannot interpret the effects as other than zero. The electricity market split seemingly has had no effect on these industries' location choice.

The post-treatment trend curves (Figure 5) have subtle movements that cannot really explain the coefficients. The steel/metal industry decline in zone 3 is not accompanied by an increase in zones 1-2, and thus does not suggest relocation. The metal goods industry gap between zone 4 and zones 1-2 looks to close slightly, but too little to suggest relocation. The rubber/plastic goods industry in zone 3 looks to trend relatively negatively but is not significant. The chemical industry zones 3 and 4 trend relatively positively but are not significant.

The R^2 values are very small, ranging from 0.019 to 0.073. This means that our model is poor at predicting the dependent variable. However, we are not developing a predictive model and small R^2 values can be fine in social science models that identify treatment effects (Stock & Watson 2020; ResearchGate 2023).

The regression execution omitted independent zone 3 and zone 4 dummies due to collinearity with counties that they were derived from. Coefficients for zone dummies would, if not omitted, give intercepts for each zone trend when summed with the constant (which would be intercept for zone 1-2). The omittance means that the constant has no useful meaning in our analysis. However, intercepts are not variables of interest in this study.

6.1 Alternative specifications

We included fixed effects (FE) in all regressions and, given their crucial function and the few control variables, we did not see any point in excluding FE as a robustness check.

The population control is only significant for the chemical industry (at 1% level) and its coefficients are extremely small. Nevertheless, R^2 is between 0.2 and 0.8 higher with population. With population, the interaction coefficients change very little, except for the chemical industry where coefficients are insignificant in all specifications. The constant changes a lot for the chemical industry but this is the only insignificant constant. Considering this and simultaneity between population and number of companies, we have excluded population from our main regression. Without such issues, controls should typically be included in the main regression.

7 Discussion

Like the economic theory discussion suggests, the significant results are negative. Firms should choose to locate in regions where the production input costs are low. Before the reform, when electricity spot prices were the same for the whole country, electricity costs would not have mattered for firm location decisions, but since the reform, the lower electricity prices in zones 1 and 2 may have given these areas regional comparative advantages. Since zones 3 and 4 have higher electricity prices, negative effects (i.e negative coefficients) are expected for significant values in these zones.

Similarly to the reviewed literature on firm location and electricity prices, the results are inconclusive. There are some significant results, but for most industries and price zones, no significant effects are found. This could be interpreted as electricity price not being an important factor for firm location and that there are other factors that play a bigger role in where firms decide to locate. Firms could for example be tied to a geographical area due to its resources such as forests or mines. Although a firm may have electricity-intensive production, it will not necessarily affect its location decisions if the production is resource-bound. We do however find a significant effect on the steel/metal industry in one zone. Similar results are also found by Khan and Mansour (2013) who find that location of the primary metals industry is affected by electricity price. Other examples of region-specific factors are regional policies that benefit the particular industry, infrastructure, and even historical ties between the industry and region (Nijkamp & Perrels 1988).

The results may also depend on the differences between industries. Although the industries chosen for the analysis are all deemed to value electricity as an important factor for location, some industries may also be in particular need of certain skilled labour that is found to a larger extent in a certain area. The chemical industry, for example, is one of the industries in the analysis with the highest electricity use (Energimyndigheten 2022); however there is no significant effect in either of the southern zones. Perhaps the need for skills that may be easier to find near large cities (Stockholm, Gothenburg in SE3) is stronger than the effect of electricity prices.

In table 3 below, we outline the results in related literature concerning our studied industries and compare this to our results. Our study confirms the findings of Nijkamp and Perrels (1988), Bae (2009), and Khan and Mansur (2013), and opposes the findings of Carlton (1983).

Study	Industries	Electricity price effect on location	Our findings
Carlton (1983)	Fabricated plastic products, etc	Strong effect	No effect on rubber and plastic goods
Nijkamp and Perrels (1988)	Rubber, plastic processing, etc	Almost no effect	No effect on rubber and plastic goods
Bae (2009)	Light users of electric energy, heavy users with high mobility, heavy users with low mobility	Tend to not relocate (instead substitute energy source)	No indication of relocation (but our data on this is poor)
Khan and Mansur (2013)	Primary metal, chemical, plastics and rubber products, fabricated metal products, etc	Effect for some manufacturing such as primary metals, modest effect for typical manufacturing	No effect on rubber and plastic goods, and chemical Negative effect on steel and metal in one zone Negative effect on metal goods in one zone

Table 3. Research findings on electricity price effect on industry location choice.

8 Conclusion

This thesis has tried to answer the question: has splitting the Swedish electricity market into four price zones resulted in new patterns for where electricity-intensive firms are located? We analysed four industries using the difference-in-differences method. Some results are significant, but most of them are not. For this reason, interpretation of the results should be made with caution. We consider the results to not provide enough evidence to confirm our hypothesis that the number of firms in electricity-intensive industries will decrease in the southern zones relative to the northern zones as a result of the reform. Although we see a negative effect for the significant results, we would like to see more significant coefficients to conclude a general reform effect on industries.

There could be effects of the reform that this study did not investigate. For example, increasing regional electricity prices may lead manufacturing production to slow down in an area (Kwon 2016a), and firms may switch their main production to something less electricity intensive (Bae 2009; Elliot, Sun & Zhu 2019). Something that may weaken the effect of zonal electricity prices is that the most electricity-intensive firms most likely have special contracts for electricity and negotiating power (Kahn & Mansur 2013; Nijkamp & Perrels 1988). As discussed in section 5.2.1, we also do not know what impact including firms of different sizes in the dataset may have on the results, considering that small and large firms may respond differently to the reform. Future research may have more accurate identification of effects by differentiating between small and large firms and finding ways to ensure that a higher proportion of firms in the data are electricity-intensive.

It has been 11 years since the reform, and deciding firm location and/or relocation can take a long time. It is therefore possible that the effects of the market split will be stronger in the future. Electricity price differences between price zones have been small during most of the years studied, which could explain why findings of reform effects have been weak. If the electricity price differences between zones remain as large as they have been since 2020, it is reasonable to believe that electricity prices will become an even more important location factor for Swedish industries in the future. A similar, but more extensive study that controls for important factors for firm location could be made again in the future to investigate the long term effects of the reform. With the right data, future studies could also investigate if the reform has led existing firms to relocate. Bae (2009) finds no firm relocation effect due to different electricity prices in the United States, but this may not be the case for Swedish industries.

References

Bae, S. (2009). The responses of manufacturing businesses to geographical differences in electricity prices. *The Annals of regional science*, 43(2), pp. 453–472. doi:10.1007/s00168-008-0217-z

Barteková, E. & Ziesemer, T. (2019). The impact of electricity prices on foreign direct investment: evidence from the European Union. *Applied Economics*, 51(11), pp. 1183-1198. doi:10.1080/00036846.2018.1524983

Bijnens, G., Konings, J., & Vanormelingen, S. (2022). The impact of electricity prices on European manufacturing jobs. *Applied Economics*, 54(1), pp. 38-56. doi:10.1080/00036846.2021.1951647

Carlton, D. (1983). The Location and Employment Choices of New Firms: An Econometric Model with Discrete and Continuous Endogenous Variables. *The Review of Economics and Statistics*, 65(3), pp. 440–449. doi:10.2307/1924189

Elliott, R., Sun, P., & Zhu, T. (2019). Electricity prices and industry switching: Evidence from Chinese manufacturing firms. *Energy Economics*, 78, pp. 567-588. doi:10.1016/j.eneco.2018.11.029

Energimarknadsinspektionen (2014). *Utvärdering av effekterna av elområdesindelningen* (Ei R2014:08). https://www.ei.se/download/18.d4c49f01764cbd606218aa8/1608305354871/Utv%C3%A4rdering-av-effekterna-av-elomr%C3%A5desindelningen-Ei-R2014-08.pdf

Energimyndigheten (2019). *Elintensiv industri*. [2022-12-26] https://energimyndigheten.se/fornybart/elcertifikatsystemet/kvotpliktig/elintensiv-industri

Energimyndigheten (2022). *Total energianvändning (inkl. transporter) inom mineral- och tillverkningsindustri enligt SNI2007, 2008-*. https://pxexternal.energimyndigheten.se/sq/23197046-e26d-4426-b019-8ef6d6b1e421

ENTSO-E (2022). *Winter Outlook 2022-2023 Report*. European Network of Transmission System Operators for Electricity. https://entsoe.eu/outlooks/seasonal

European Commission (2022). *State Aid Transparency Public Search*. https://webgate.ec.europa.eu/competition/transparency/public/search

Feenstra, R. C. & Taylor, A. M. (2017). *International Trade*, 4th ed. Worth Publishers.

Frank, R. & Cartwright, E. (2016). *Microeconomics and Behaviour*, 2nd ed. McGraw-Hill Education.

Gonese, D., Hompashe, D., & Sibanda, K. (2019). The impact of electricity prices on sectoral output in South Africa from 1994 to 2015. *African Journal of Economic and Management Studies*, 10(2), pp. 198-211. doi:10.1108/AJEMS-12-2017-0305

Kahn, M.E. & Mansur, E.T. (2013). Do local energy prices and regulation affect the geographic concentration of employment? *Journal of Public Economics*, 101, pp. 105–114. doi:10.1016/j.jpubeco.2013.03.002

Karlsson, M., Nilsson, T., & Pichler, S. (2014). The impact of the 1918 Spanish flu epidemic on economic performance in Sweden: An investigation into the consequences of an extraordinary mortality shock. *Journal of Health Economics*, 36, pp. 1-19. doi:10.1016/j.jhealeco.2014.03.005

Kwon, S., Cho, S-H., Roberts, R. K., Kim, H. J., Park, K., & Edward Yu, T. (2016a). Effects of electricity-price policy on electricity demand and manufacturing output. *Energy*, 102, pp. 324-334. doi:10.1016/j.energy.2016.02.027

Kwon, S., Cho, S-H., Roberts, R. K., Kim, H. J., Park, K., & Edward Yu, T. (2016b). Short-run and the long-run effects of electricity price on electricity intensity across regions. *Applied Energy*, 172, pp. 372-382. doi:10.1016/j.apenergy.2016.03.016

Lundin, E. (2022). Geographic price granularity and investments in wind power: Evidence from a Swedish electricity market splitting reform. *Energy economics*, 113, Article 106208. doi:10.1016/j.eneco.2022.106208

Molnar, F. J., Hutton, B., & Fergusson, D. (2008). Does analysis using "last observation carried forward" introduce bias in dementia research? *Canadian Medical Association Journal*, 179(8), pp. 751–753. doi: 10.1503/cmaj.080820

Nijkamp, P. & Perrels, A. (1988). Impacts of electricity rates on industrial location. *Energy economics*, 10(2), pp. 107–116. doi:10.1016/0140-9883(88)90025-4

Nord pool (n.d). *Bidding areas*. https://www.nordpoolgroup.com/en/the-power-market/Bidding-areas/ [2022-12-04]

Perloff, J. M. (2020). *Microeconomics: Theory and Applications with Calculus*, 5th ed. Pearson Education.

Ratner, S. & Ratner, P. (2016). Regional Energy Efficiency Programs in Russia: The Factors of Success. *Region* (European Regional Science Association), 3(1), pp. 71-87. doi:10.18335/region.v3i1.71

ResearchGate (2023). *Low R-squared values in multiple regression analysis?* https://researchgate.net/post/Low-R-squared-values-in-multiple-regression-analysis [2023-01-14]

Roy, B. (2019). All About Missing Data Handling: Missing Data Imputation Techniques. *Towards Data Science*, Sep 3, 2019. https://towardsdatascience.com/all-about-missing-data-handling-b94b8b5d2184

SCB (2022a). *Regionala branschnyckeltal efter näringsgren SNI 2007 och storleksklass och kvartil. År 2008 - 2021*. https://www.statistikdatabasen.scb.se/sq/132703

SCB (2022b). *Sommarens elpriser varierar rejält.* https://scb.se/hitta-statistik/redaktionellt/sommarens-elpriser-varierar-rejalt [2022-12-04]

SCB (2023). *Elpriser och elavtal*. https://scb.se/en0301 [2023-02-03]

Stock, J. H. & Watson, M. W. (2020). *Introduction to Econometrics*, 4th ed. Pearson Education.

Svenska kraftnät (2022). *Elprisområden*. https://www.svk.se/om-kraftsystemet/om-elmarknaden/elomraden/ [2022-12-04]

SVT (2022). *Storföretag får hundratals miljoner i elstöd – trots dess låga kostnader för el*. https://svt.se/nyheter/inrikes/granskning-storforetag-far-hundratals-miljoner-i-elstod-trots-att-de-haft-laga-kostnader-for-el [2023-02-03]

Williams, R. (2015). *Missing Data Part 1: Overview, Traditional Methods*. https://www3.nd.edu/~rwilliam/stats2 [2022-12-28]

Appendix A. Counties per electricity area

Listed below are the price areas and counties.

SE1:
Norrbotten

SE2:
Gävleborg, Västernorrland, Jämtland, Västerbotten

SE3:
Stockholm, Uppsala, Södermanland, Östergötland, Jönköping, Gotland, Västra Götaland, Värmland, Örebro, Dalarna, Västmanland

SE4:
Kronoberg, Kalmar, Blekinge, Skåne, Halland

Appendix B. Missing data and imputations

First, we interpolated values from existing observations immediately before and after the missing values. When linear interpolation was not possible, the last existing value before the missing values was copied forward. When this was not possible, we imputed with the mean of that county's observations. Finally, when all county observations were missing, we replaced them with zero.

These basic methods have drawbacks that can introduce bias. However, in our time series with autocorrelation, these drawbacks do not apply as much and it is not apparent that more advanced methods (e.g. regress-predict) would improve reliability.

A common approach is to add a missing value dummy to the data, taking the value 1 where missing data has been replaced. In datasets where missing values are expected to occur randomly, a significant dummy coefficient can indicate non-randomness (Williams, 2015). We consider our missing data to be largely non-random without that being a problem, so this check is not relevant here. As a robustness check, we ran our main regression model with the missing value dummy and this did not change any coefficients of interest.

Rubber and plastic goods, Gotland															Mean
SCB data	-	5	-	-	-	-	-	-	-	-	-	-	-	-	5
Imputation	5		5	5	5	5	5	5	5	5	5	5	5	5	5

Method: last value carried forward, mean

Steel and metal, Jämtland															Mean
SCB data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Imputation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Method: zero constant

Steel and metal, Västerbotten															Mean
SCB data	6	6	5	5	5	5	5	6	7	5	5	-	5	5	5
Imputation												5			5

Method: interpolation

Steel and metal, Gotland															Mean
SCB data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Imputation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Method: zero constant

Steel and metal, Blekinge															Mean
SCB data	8	8	8	6	5	6	6	5	5	-	-	-	-	-	6
Imputation										5	5	5	5	5	5

Method: last value carried forward

We suspect there may be a downward trend through the missing values. Therefore, we also ran the main regression using value 4 for imputations. This did not change results.

Chemical, Jämtland															Mean
SCB data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Imputation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Method: zero constant

Chemical, Gotland															Mean
SCB data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Imputation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Method: zero constant

Chemical, Västmanland															Mean
SCB data	5	5	7	9	9	7	-	5	-	-	5	6	6	6	6
Imputation							6		5	5					5

Method: interpolation

Chemical, Kronoberg															Mean
SCB data	8	8	9	9	9	10	9	9	7	10	10	10	9	-	9
Imputation														9	9

Method: last observation carried forward

Chemical, Kalmar															Mean
SCB data	6	-	-	-	-	-	5	6	-	-	-	5	6	7	6
Imputation		6	6	6	5	5			6	6	5				

Method: interpolation

Chemical, Blekinge															Mean
SCB data	6	8	6	6	-	6	5	6	6	-	5	6	7	7	6
Imputation					6					6					6

Method: interpolation

Appendix C. Placebo regression

	Steel/metal	Metal goods	Rubber/plastic goods	Chemical
Zone 3 x post	0.082 (0.936)	0.027 (0.988)	0.727 (0.560)	0.445 (0.489)
Zone 4 x post	0.000 (1.000)	0.000 (1.000)	1.8 (0.182)	0.6 (0.551)
FE (yes/no)	yes	yes	yes	yes
R^2	0.003	0.0002	0.016	0.005
Observations	84	84	84	84

Table 4. Results of the main specification with placebo treatment.

Observations for each county are autocorrelated and therefore we use robust clustered standard errors.

p-value in parenthesis, * p < 0.1, ** p < 0.05, *** p < 0.01