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The effects of a 2016 electricity tax reform on French manufacturing Evidence from micro-panel data

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Abstract

This paper investigates the impact of a 2016 electricity tax reform on French manufacturing using micro-panel data spanning eight years. The reform introduced a tax reduction on electricity use contingent on gross electricity tax liability exceeding 0.5% of firm value-added. Firms that satisfy the threshold criteria are considered electro-intensive. This paper exploits both a differences-in-differences (DiD) and a regression discontinuity (RD) specification to estimate the effect of the preferential tax treatment granted to eligible firms. On average, electro-intensive firms experienced a relative drop in in their average electricity costs ranging between 12.5% and 19.5% in the post-reform period depending on the empirical approach. Nevertheless, results do not indicate that the reform had a significant or robust impact on either energy use input choices or on economic performance. Results cast doubt on the usefulness and necessity of the public policy vis-à-vis government revenues foregone.

Keywords: Electricity tax, Policy Evaluation, Manufacturing, France
JEL Codes: Q48, L5, L6

1 Introduction

Electricity accounts for three-fifths of total energy costs in French industry (Ministry of the Environment, 2022), rendering opportunities to benefit from preferential tax treatment potentially attractive to cost-conscious firms. In 2016 France introduced in its Tax Code an electro-intensity ratio with a cutoff above which firms are considered electro-intensive. More specifically, industry firms with a gross electricity tax liability exceeding 0.5% of their value-added can pay a substantially lower marginal tax rate

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on electricity use. Tax expenditures related to the tax cut reached almost €2 billion by 2019 (PLF, 2021). The purpose in introducing the tax relief in 2016 was twofold: to conform to the EU Energy Taxation Directive and to preserve firm competitiveness against a high energy tax burden.

Accordingly, the first purpose of this paper is to investigate the impact of the reform on the average cost of electricity use. A back of the envelope calculation indicates that the statutory electricity tax rate, absent any preferential tax treatment, would have represented between 22% and 25% of the total price of electricity in 2019 among non-residential consumers, whereas the effective tax rate paid represented between 14% and 16% of the total price on average (Ministry of the Environment, 2023). As preferential tax treatment is not automatically granted in France, a relative drop in average electricity costs, ceteris paribus, indicates elector-intensive firms requested to benefit from the tax cut upon proof of eligibility. A second purpose of this paper is to evaluate the impact of the reform on energy use input choices and economic performance, as electro-intensive firms that rely on energy for production would have benefited from a relatively lower electricity and energy tax burden. More broadly, this paper contributes to the scarce but growing empirical literature that investigates the effect of energy tax policy and regulation, specifically in the form of subsidies, on manufacturing performance.

Exploiting two different empirical strategies and based on energy use microdata and corporate tax returns, this paper uncovers robust evidence that the reform generated relative cuts in average electricity costs for eligible firms. A differences-in-differences (DiD) specification estimates that electro-intensive firms experience a relative 12.5% drop in such costs on average, or equivalently about 11 euros per MWh of electricity in savings. Results are robust to a joint DiD approach with propensity score matching (PSM) to mitigate selection bias. Event study DiD graphs further corroborate the assumption of parallel trends necessary for identification in a DiD setting. An additional regression discontinuity (RD) analysis similarly finds that eligible firms around the electro-intensity cutoff experiences 19.5% drop in average electricity costs, equivalent to about 14 euros per MWh in savings following the reform. All regression results are statistically significant at the 1% level. RD results are robust to artificial placebo cutoff tests and different bandwidth choices. More generally this paper does not uncover evidence of firm manipulation around the threshold. Nevertheless, findings also do not estimate significant or robust effects of the reform on energy use indicators and economic performance despite the cut in the cost of electricity inputs. Results cast doubt on the usefulness and necessity of the public policy vis-à-vis government revenues foregone.

The next section provides a summary of the relevant empirical literature on the impact of energy tax subsidies on corporate environmental, energy, and economic performance. Section (2) outlines the institutional background related to electricity taxation in France and details the calculation of the electro-intensity ratio. Section (3) describes the data sources, the construction of the balanced panel and summarizes the data. Section (4) describes the empirical strategies and identification assumptions. Section (5) reports the empirical findings. The last section concludes.

1.1 Related empirical literature

This paper contributes to the scarce but growing empirical literature that investigates the effect of energy tax policy and regulation, specifically in the form of subsidies, on manufacturing performance. Tax subsidies are generally granted to businesses to mitigate any detrimental impact of increasing energy tax rates on competitiveness, to the extent that energy costs can represent a large share of total production costs in certain industries. Similar to the French context, these subsidies are typically granted based on set energy use thresholds. Overall, the ongoing empirical research does not uncover evidence that granting energy tax subsidies significantly influences economic indicators, although it does tend to find significant effects on energy input choices.

In the United Kingdom (UK), a Climate Change Levy (CCL) applies to energy consumed by professionals since 2001. Industry can benefit from a substantial rate reduction if they enter into a Climate Change Agreement (CAA) whereby plants voluntarily adopt a binding energy use or carbon emission reduction target. Exploiting an instrumental variable (IV) for eligibility to treatment and a DiD specification, Martin, de Preux, and Wagner (2014) find that plants that paid the full CCL rate experienced lower energy intensity relative to CCA plants, as well as a reduction in electricity use. Nevertheless, they do not uncover any significant impact on economic performance, including on plant exit.

In Finland, a 2012 energy tax reform not only substantially increased excise tax rates on energy, but also expanded a pre-existing energy tax reduction measure for large, energy-intensive firms. From January 2012 onward, Finnish firms with an energy tax liability exceeding 0.5% of value-added could benefit up to a 85% refund of their energy taxes, compared to 3.7% cutoff before the reform. Accordingly, Laukkanen, Ollikka, and Tamminen (2019) take a matching DiD approach to evaluate the causal impact of energy tax reductions on Finnish manufacturing from 2007 to 2016. They do not find any significant effect on neither economic outcomes nor energy use, with the exception of a negative effect on gross output and energy efficiency.

In Germany from 1999, manufacturing firms could benefit from reduced marginal tax rates on electricity use contingent on quantity consumed: from above 50 MWh in 1999 to above 25 MWh in 2003. Using a regression discontinuity design (RDD) and leveling firm micro-data from 1995 to 2005, Flues and Lutz (2015) also do not uncover any significant impact of reduced electricity tax rates on economic performance.

Additionally since 2000 in Germany, energy use is subject to a Renewable Energy Levy (REL), a surcharge on electricity prices to finance feed-in-tariffs (FiTs) payments. From 2003 to 2012, manufacturing plants that consumed over 10 GWh of electricity, along with a ratio of electricity cost to gross value-added exceeding 15%, could benefit from a drastically reduced REL rate on electricity use. Gerster and Lamp (2024) take a fuzzy RDD approach to estimate the impact of the reduced rate on German manufacturing energy use choice and economic performance, and based on a list of plants that benefited from the exemption. They also take a matched DiD approach to exploit a 2012 reform that altered eligibility criteria. They find that treated plants significantly increased their electricity use under both tax regimes and econometric approaches (by 3.1 GWh or 78% under the RDD and by 3% under the DiD). Nevertheless, they also do not uncover any significant impact of the tax reduction on competitiveness indicators.

This paper specifically adds to the related empirical literature by investigating the effect of a French 2016 electricity tax reform that introduced a new threshold above which firms can benefit from a substantial reduction on their marginal electricity tax rate. Echoing the energy tax system in other European countries, the cutoff at 0.5% is determined by the ratio of statutory tax liability over value-added: the same cutoff as in Laukkanen, Ollikka, and Tamminen (2019), but a substantially lower cutoff than detailed in Gerster and Lamp (2024).

2 Institutional context

2.1 Conforming to the EU Energy Taxation Directive

The taxation of electricity use in France conforms to the European Union (EU) framework for energy product taxation as defined by Council Directive 2003/96/EC that sets minimum tax rates on energy use.

Before the 2016 reform
All electricity consumers were subject to the CSPE (*Contribution au Service Public de l'Electricité*) from 2003 to 2015. CSPE rates were set by the CRE (*Commission de Régulation de l'Energie*), an independent administrative authority, to offset costs associated with public service charges borne by public electricity network suppliers (CRE, 2014). The CSPE rate steadily increased from €3 per megawatt-hour (MWh) to €19.5 per MWh by 2015. Under the CSPE regime, industry taxpayers could exploit three alternative and cumulative tax reduction measures. As a share of total tax revenue foregone from 2003 to 2015, the largest measure (69% of €6.8 billion) was a monetary cap on total CSPE tax owed equivalent to 0.5% of value-added for firms consuming over 7 gigawatt-hour (GWh) of electricity. Additionally, around 29% of foregone revenues were due to a plant-level cap on CSPE tax payments (European Commission, 2019). In 2012 and 2013, 1 085 firms and 400 plants requested a reimbursement of the CSPE based on these set caps, respectively (CRE, 2014). Note also that from 2011, taxpayers with a subscribed power exceeding 250 kilovolt-ampere (kVA) were additionally subject to the TICFE (*Taxe intérieure sur la consommation finale d'électricité*), at a fixed rate of €0.5 per MWh[1]. The purpose in introducing the TICFE was to transpose the provisions of Directive 2003/96/EC into French domestic law (PLF, 2015).

The 2016 electricity tax reform
On January 2016, both the CSPE and TICFE rates merged to form a single national-level excise duty on electricity consumption (henceforth TICFE_{2016}) at a fixed rate of €22.5 per MWh. The objective of the reform was to conform to EU law and to secure revenue flows (PLF, 2015). It introduced new tax rate reductions applicable to electro-intensive firms (defined below) to preserve competitiveness and to compensate for the loss in preferential tax treatment cap-related measures granted under the former CSPE regime. The TICFE_{2016} rate applies to all taxpayers, no matter their subscribed electricity power. In 2019, the effective TICFE_{2016} paid represented around 14% of the total electricity price on non-residential consumption below 150 gigawatt-hours (GWh) (Ministry of the Environment, 2023).

[1]Taxpayers with a subscribed power below 250 kVA were subject to two (communal and departmental-level) local electricity taxes, but not to the TICFE.

2.2 Electro-intensity status

According to the French Tax Code, electro-intensity is determined by the ratio of total gross TICFE_{2016} liability - abstracting from any preferential tax treatment - over value-added (French Customs, 2019a), as shown in Equation (1) and (2). The statutory TICFE_{2016} rate post-reform is fixed at €22.5 per MWh. Value-added is defined in Art. 1586 sexies of the Tax Code.

$$\text{Gross TICFE}_{2016} \text{ liability (€)} \equiv \text{Electricity use (MWh)} \times \text{€22.5 per MWh} \tag{1}$$

$$\text{Electro-intensity ratio} \equiv \frac{\text{Gross TICFE}_{2016} \text{ liability (€)}}{\text{Value added (€)}} \times 100 \begin{cases} \geq 0.5\%, \text{Electro-intensive} \\ < 0.5\%, \text{Not electro-intensive} \end{cases} \tag{2}$$

A firm is characterized as electro-intensive if the ratio detailed in Equation (2) exceeds 0.5 percent. An electro-intensive firm can benefit from a rate reduction on their electricity use. At a minimum, it can benefit from a EUR 15 per MWh reduction on the statutory TICFE_{2016} rate: a rate drop from €22.5 per MWh to €7.5 per MWh applied to all electricity use. More specifically, the applied reduced TICFE_{2016} rate depends on the quantity of electricity consumed per euro of valued-added[2].

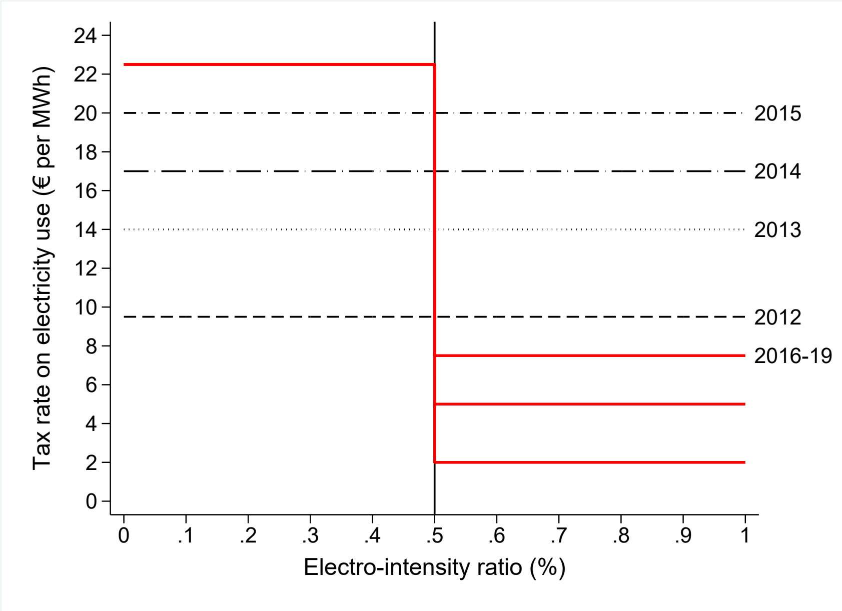
$$\text{Applicable reduced TICFE}_{2016} : \frac{\text{Electricity use (kWh)}}{\text{Value added (€)}} \begin{cases} > 3 \text{ kWh}, \text{€2 per MWh} \\ \geq 1.5 \text{ kWh and} \leq 3 \text{ kWh}, \text{€5 per MWh} \\ < 1.5 \text{ kWh}, \text{€7.5 per MWh} \end{cases} \tag{3}$$

To benefit from the tax rate reduction on delivery, firms must send a certificate to their supplier and to Customs with a justification of their electro-intensity status. Absent any certificate, the consumer pays the full rate on electricity use. Firms can also request a reimbursement on electricity tax paid up to two years after payment with a justification of eligibility to reduced taxation. The reduction applies to all electricity consumption.

Figure (1) illustrates the applicable tax rates on electricity consumption around the electro-intensity ratio cutoff (0.5%) introduced from 2016 onward. Table (A1) reports estimates of foregone electricity tax revenues. In 2016, total expenditure amounted to €968 million and reached almost €2 billion by 2019. The majority of expenditures are from businesses that are neither at risk of carbon leakage, nor hyper-electro-intensive. From 2016 to 2017 total expenditures increased by over a third, highlighting the fact that preferential tax treatment has to be requested by the firm upon proving its electro-intensity and is not automatically granted to eligible firms.

[2] Firms that consume over 6 kWh per euro of value-added (hyper-electro-intensive) or that are considered at risk of carbon leakage - as defined in European Commission, 2012 - can benefit from even lower TICFE rates reductions. Firms that estimate a negative value-added are also considered hyper-electro-intensive.

Figure 1: Tax rates on electricity use based on the electro-intensity ratio, 2012-2019



Note: Figure (1) illustrates the preferential tax treatment granted to electro-intensive firms, as defined in Equation (2), from 2016 onward at the 0.5% cutoff. It shows estimated marginal tax rates (MRT) on electricity use applicable to firms with a subscribed power exceeding 250 kilovolt-ampere (kVA). The MRT for years 2012-2015 represent the sum of the CSPE and the TICFE. For years 2016-2019 and in descending order, the MRT are those applicable to firms consuming less than 1.5 kWh, less than 3 kWh and more than 3 kWh per euro of value-added, respectively (see Equation 3). Note that certain firms can benefit from even lower rates (see Footnote 2). Before 2016, firms were not granted any preferential tax treatment based on this ratio. From 2016, firms exceeding the cutoff benefit from a large drop in their applicable tax rate, relative to firms that fall short from the cutoff and pay the full statutory rate, abstracting from the application of any other preferential electricity tax treatment.

3 Data

3.1 Data sources and panel construction

The final balanced panel is composed of manufacturing firms located in metropolitan France, and spans years 2012 through 2019. It merges five different data-sets.

The Eacei (*Enquête sur les consommations d'énergie dans l'industrie*) database[3] provides plant-level survey data on energy consumption and expenditure by fuel and in aggregate. Eacei surveys only production plants. It surveys all plants with over 250 employees, as well as a stratified random sample of plants with at least 20 employees. The response rate was 90% in 2014. Each year, surveyed plants provide information on purchased quantities of electricity in megawatt-hours (MWh), as well as the monetary cost value of electricity purchase (excluding any deductible value-added tax), for the prior calendar year. The total cost of electricity includes the cost of transport and

[3]Marin and Vona (2018) provide an overview of the Eacei database and its applications.

distribution. The average cost of electricity refers to the ratio of electricity purchased (in MWh) over its total cost value (in €). The Eacei database helps construct the numerator in Equation (2).

The BIC-RN and CVAE databases provide administrative data from french corporate tax and value-added tax returns. The analysis also relies on the FARE data-sets that provide financial and economic business statistics that also largely come from corporate tax returns. Nevertheless, FARE does not provide all variables required to calculate an electro-intensity ratio, as detailed in Annex 4bis of French Customs (2019a) - French Customs (2019b). Hence while the denominator in Equation (2) is based on the administrative data, the rest of the analysis relies on corporate statistics. Finally, data on EU-ETS participation comes from the European Union Transaction Log (EUTL), and more specifically from Abrell (2021). The EUTL provides data on participating plants in the carbon market, including compliance status and verified emissions.

As noted above the energy use data is provided at the plant level, whereas the unit of observation in this paper is at the firm level since electro-intensity status can only be determined at that level. A plant is identified by its 14-digit plant identifier number, Siret, in France. The firm identifier, Siren, is the first nine digits of the Siret. Therefore Eacei variables are summed by Siren and by year. In the case of multi-plant firms, the panel should only include firms whose establishments are fully covered in Eacei. Echoing Dussaux (2020) and Dussaux, Vona, and Dechezleprêtre (2023), the sum of plant employees as reported in Eacei is compared to the sum of employees as reported in the corporate statistics. A very low ratio may suggest that the aggregated energy use and cost data may not adequately represent total firm level energy use and cost. A very high ratio (notably above 100%) may suggest measurement errors[4]. To minimize bias, the panel omits the bottom and top 10th percentile of the ratio across all years. Note that as a robustness check, this paper also presents results based on the sample without this omission.

3.2 Descriptive statistics

Switcher firms

Note that 154 firms per year switch across their electro-intensity status at least once any year of the panel (i.e. their electro-intensity ratio increases from below to above 0.5% or decreases from above to below 0.5% any year). Such firms are identified as "switcher" firms. An increase in the ratio suggests a larger increase in electricity use versus value-added, whereas a decrease suggests a relatively larger increase in value added compared to electricity consumption. Figure (A1) indicates that switcher firms tend to oscillate around the 0.5% cutoff. On average, switcher firms have an electro-intensity around 0.69%, whereas firms that never change their status have an electro-intensity ratio around 2.52 percent. Identification of the effect of the electricity tax reform rests on the assumption that firms cannot precisely manipulate their electricity use or their value-added levels, or both, in order to benefit from preferential tax treatment from 2016. Section (4.2.1) does not uncover evidence of such manipulation, suggesting that the firm oscillations around the electro-intensity cutoff are likely random, as opposed to reflecting strategic behavior. Notwithstanding the above, the main results presented below are based on the sample that omits switcher firms, miti-

[4]In Eacei, the number of employees is the average number of employees by the end of the year. Whereas in the corporate statistics, employment is measured as the number of full time equivalents (FTE).

gating any remaining concern of manipulation. Results based on the larger sample that includes switcher firms are provided as robustness checks.

Summary statistics and industry composition
Table (A2) presents summary statistics by electro-intensity status in 2012, the first year of the panel. It more specifically presents summary statistics for the balanced panel inclusive of switcher firms (column **i**), as well as the smaller balanced panel excluding switcher firms (column **ii**). Focusing on column (**i**), electro-intensive firms pay lower average electricity costs (€73 per MWh compared to €82 per MWh) and are larger energy users, although they are smaller in terms of economic and fiscal variables. Column (**ii**) suggests the same conclusions. Across all firms, electricity represents roughly half of total energy use and over three-fifths of total costs. Across both panels in table (A3), industry composition differs across electro-intensive and non-electro-intensive firms. Non-electro-intensive firms include more technology-oriented industries (notably in the manufacturing of different types of equipment), whereas the electro-intensive include more traditional manufacturing known to be energy and carbon-intensive.

Effective tax rate rates paid and policy take-up
Since 2017, the French Ministry of the Environment details a breakdown of the average effective electricity price by electricity use bracket and including the TICFE_{2016} rate paid (Ministry of the Environment, 2023). Figure (A2) indicates that the smallest consumers pay an electricity tax rate on average close to the statutory rate (€22.5 per MWh) compared to larger consumers that pay much lower rates. From 2017 to 2019 in the panel, 57% of all firms and three-fifths of all electro-intensive firms are located in consumption bracket ID, i.e., consume between 2 and 20 GWh of electricity. Based on the figure, firms in bracket ID experienced on average a 7.9 euro per MWh drop in the tax rate relative to the statutory rate across all three post-reform years. Full take-up suggests a relative drop of at least 15 euros per MWh among electro-intensity firms in the post-reform period.

While Figure (A2) includes all non-residential consumers and not specifically electro-intensive firms, these results echo observations regarding policy take-up by eligible firms in Gerster and Lamp (2024). They analyse the effects of similar threshold-based policies on German manufacturing and observe that only around three-quarters of eligible plants claim their preferential tax treatment the first year it came into effect. They conclude businesses make a trade-off between the financial benefits of the preferential tax treatment and the compliance cost associated with its use.

4 Empirical strategies

4.1 Differences-in-Differences (DiD)

4.1.1 Construction of treatment variable

A first empirical strategy exploits a DiD approach to investigate the effects of eligibility to the electro-intensity tax cuts relative to ineligible firms. Equation (5) estimates for each firm i the pre-reform (2012-2015) average value of their electro-intensity ratio. Hence it estimates post-reform treatment status as under the TICFE_{2016} regime but based on pre-reform electricity use and value-added values.

$$\text{Gross TICFE}_{2016}\text{ liability (€)}_{i,<2016} \equiv \text{Electricity use (MWh)}_{i,<2016} \times \text{€22.5 per MWh} \tag{4}$$

$$\text{Electro-intensity ratio}_{i,<2016} \equiv \left[\frac{\text{Gross TICFE}_{2016}\text{ liability (€)}}{\text{Value added (€)}} \times 100\right]_{i,<2016} \tag{5}$$

Equation (6) is the treatment variable: it equals one if the average pre-reform electro-intensity ratio of firm i exceeds 0.5%, and zero otherwise. The use of the pre-reform average minimizes the risk of capturing unobserved confounders correlated with both the tax reform and the outcomes of interest.

$$\text{Electro-intensive}_{i,<2016} \begin{cases} 1, & \text{Electro-intensity ratio}_{i,<2016} \geq 0.5\% \\ 0, & \text{Electro-intensity ratio}_{i,<2016} < 0.5\% \end{cases} \tag{6}$$

4.1.2 Regression equations

Equation (7) is the event study specification. $y_{i,t}$ represents the outcome variable for firm i at time t, where t denotes years in the panel t = {2012,...,2019}. The equation includes a set of 8 year indicators $\mathbb{1}_{s=t}$ equalling one when the year observed, t, equals the specific indexed year s, and zero otherwise. The main coefficient of interest, β_s, evaluates the evolution of the dynamic effect of electro-intensity status. The reference year (indicator) is set to 2015 for β_s.

$$\begin{aligned} y_{i,t} = \alpha_i + \sum_{\substack{s=2012 \\ s\neq 2015}}^{2019} \beta_s(\text{Electro-Intensive}_{i,<2016} \times \mathbb{1}_{s=t}) + \sum_k \sum_s \delta_{k,s}(industry_k \times \mathbb{1}_{s=t}) \\ + \sum_s \gamma_{e,s}(ETS_e \times \mathbb{1}_{s=t}) + \sum_s \eta_s(\mathbf{X}_i^{2012} \times \mathbb{1}_{s=t}) + \varepsilon_{i,t} \end{aligned} \tag{7}$$

Equation (8) is the pooled DiD specification. Its main coefficient of interest, β, estimates the average effect of exposure to the carbon tax in the post-reform period relative to the pre-reform period. The dummy $Post_t$ equals one for the post-reform period ($t = 2016, ..., 2019$) and zero for pre-reform ($t = 2012, ..., 2015$). Both equations are constructed the same except for the terms on β_s and β.

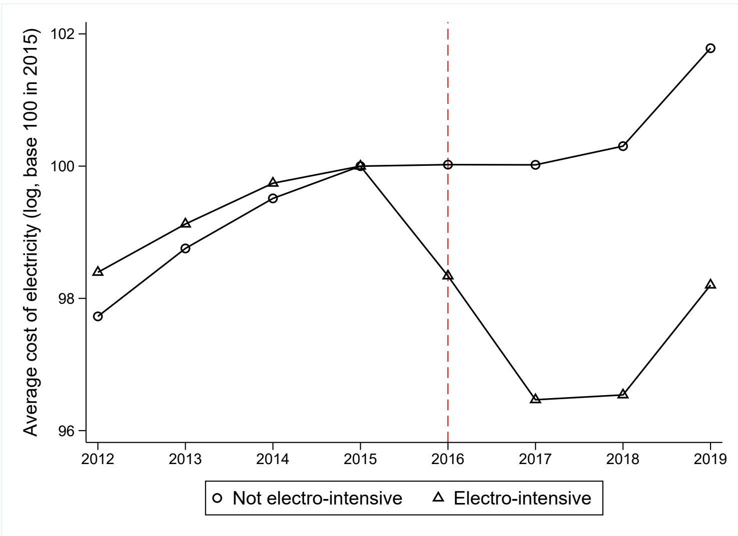
$$\begin{aligned} y_{i,t} = \alpha_i + \beta(\text{Electro-intensity}_{i,<2016} \times Post_t) + \sum_k \sum_s \delta_{k,s}(industry_k \times \mathbb{1}_{s=t}) \\ + \sum_s \gamma_{e,s}(ETS_e \times \mathbb{1}_{s=t}) + \sum_s \eta_s(\mathbf{X}_i^{2012} \times \mathbb{1}_{s=t}) + \varepsilon_{i,t} \end{aligned} \tag{8}$$

The main outcome of interest is the average cost of electricity use to attest to whether eligible firms request their tax cuts in the post-reform years. Other outcomes of interest include energy use and economic and financial indicators to gauge both input choice and economic performance under the new electricity tax regime. To help account for omitted variable bias, firm dummies (α_i) control for time-invariant firm-specific characteristics. Coefficient $\delta_{k,s}$ captures industry by year shocks and trends at the NACE Rev.2 2-digit industry code level, where k denotes each sector. Coefficient $\gamma_{e,s}$ accounts for any yearly impact of the European cap-and-trade system. Finally, coefficient η_s captures size by year effects. Variable $\chi_{i,2012}$ includes (logged) total energy use, net operating income and the ratio of gross operating surplus over value-added set at their 2012 levels to minimize correlation with the policy in the post-reform years. Coefficient $\varepsilon_{i,t}$ is the error term.

4.1.3 Identification

The principal identification assumption in a DiD setup is that the trajectory of electro-intensive firms would have followed the trajectory of the non-electro-intensive firms in the absence of the electricity tax reform (parallel trends). Figure (2) plots the year-by-year evolution of the average cost of electricity by electro-intensity eligibility status for the panel of firms that excludes switcher firms.

Figure 2: Parallel trends by electro-intensity status - average cost of electricity (log)



Note: Figures (2) shows the evolution of the average cost of electricity use between electro-intensive firms and non-electro-intensive firms, as defined in Equation (6). The sample omits switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Average trends are indexed to year 2015.

The figure shows that electricity costs followed the same parallel upwards trajectory across all firms in pre-reform period, followed by a considerable drop in costs among electro-intensive firms from 2016. Figure (A3) similarly plots the data for various other energy use and economic performance indicators. The parallel trends assumption is less convincing for some figures.

4.2 Regression Discontinuity (RD) Design

A second empirical strategy employs a RD approach. The electricity tax reform in France introduced tax rate reductions on electricity consumption for electro-intensive firms. Firms are identified as electro-intensive (treated) if their gross electricity tax liability exceeds 0.5% of their value added starting from 2016 (see Equation 2). Hence eligibility to (preferential tax) treatment (T_i) of firm i is a deterministic function of an assignment variable (the electro-intensity ratio, or X_i) based on a clear cutoff (c = 0.5%): $T_i = \mathbb{1}(X_i) \geq$ c). Moreover, firms are assumed to have two potential outcomes (Y_i), where $Y_i(1)$ is the outcome when treated and $Y_i(0)$ when not treated.

The RD treatment effect can be defined as the local average treatment effect at the cutoff (Imbens and Lemieux, 2008).

$$\tau_{RD} \equiv \mathbb{E}[Y_i(1) - Y_i(0)|X_i = c] \quad (9)$$

Equation (9) estimates the average outcome change for firms with an electro-intensity ratio very near 0.5% if their electro-intensity status changed from control to treated via local extrapolation (Cattaneo, Idrobo, and Titiunik, 2019).

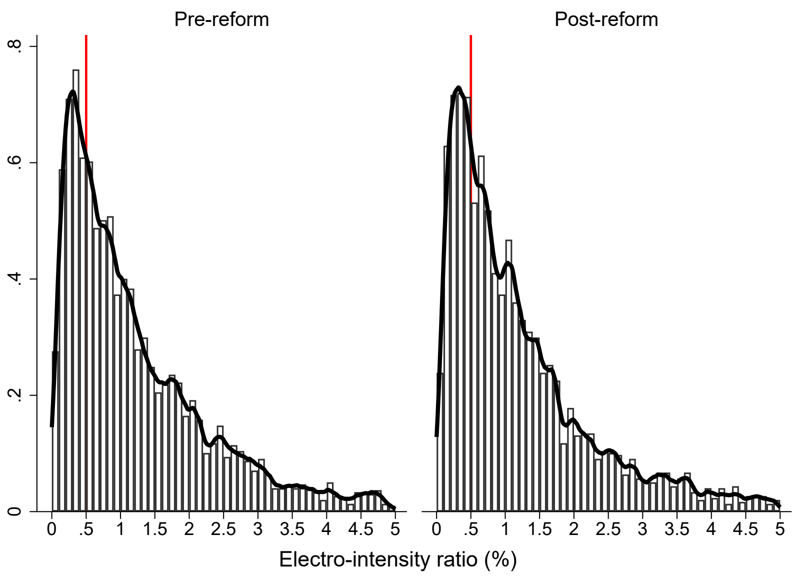
4.2.1 Identification

Continuity of the electro-intensity ratio at the cutoff

A principal identifying assumption in RD setup is the continuity of the assignment variable (the electro-intensity ratio) at the cutoff value (0.5% in the context of this paper). This assumption implies that firms are not able to precisely manipulate their electricity use levels, value-added levels, or both, in order to benefit from preferential tax treatment following the reform. Strategic corporate behavior suggests firms increase their electro-intensity ratios (i.e., increase their electricity consumption more than their value-added) so as to exceed the 0.5% cutoff. Manipulation would also imply an abnormal clustering of electro-intensity ratio values at the right-hand side of the cutoff (bunching). Accordingly, firms with an electro-intensity ratio just below 0.5% have an incentive to increase their ratio to slightly above it so as to benefit from the lower tax rates on electricity consumption.

Figure (3) illustrates density distributions of electro-intensity ratios pooled across both the pre-reform and the post-reform period. A typical prerequisite for bunching analysis is a clear visual illustration of bunching behavior, which the figure does not provide. The highest density peak across both periods is at the left-hand side of the the 0.5% cutoff (red line) where firms are not eligible to the preferential tax treatment. Figure (A4) presents the same density graph for each year of the panel.

Figure 3: Density distribution of electro-intensity ratios by reform period



Note: Figure (3) illustrates a kernel density distribution of electro-intensity ratios in the pre-reform and in the post-reform periods. The kernel function is triangle. The bin width is 0.1 percent. For readability, the x-axis is limited to electro-intensity ratios ranging between null and 5%, effectively representing 92% of all firms. The panel includes switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2).

Table (1) more formally tests the assumption of continuity of the electro-intensity ratio, or the assignment variable. The test estimates the density of firms near the electro-intensity cutoff (0.5%), separately for firms above and below it (Cattaneo, Idrobo, and Titiunik, 2019). Results fail to reject the null hypothesis that the density of the electro-intensity ratio is continuous at the cutoff for both periods and across all years ("no manipulation").

Similar papers to this one also do not find evidence of strategic manipulation. Flues and Lutz (2015) do not uncover evidence that firms purposely increase their electricity use levels above specified thresholds to pay reduced marginal tax rates in German manufacturing prior to 2005. They posit that the complex nature of production processes in the manufacturing industry and the influence of external market conditions, which introduce random fluctuations in electricity usage, make it unlikely for firms to deliberately manipulate their electricity consumption. Gerster and Lamp (2024) also do not find evidence of manipulation of electricity levels in German manufacturing several years later. They exploit the 2008 economic crisis, which created substantial economic uncertainty and plausibly made it difficult for firms to strategically adjust their electricity consumption. They also more generally conclude that firms weigh the financial benefits of an exemption against the compliance costs involved in obtaining it, the latter mitigating incentives for manipulation.

Table 1: Continuity test: electro-intensity ratio at cutoff (0.5%)

Time	Test statistic	p-value
Pre-reform	1.5035	.1327
Post-reform	-1.0034	.3157
2012	-.2682	.7885
2013	.8809	.3784
2014	1.7346	.0828
2015	1.6244	.1043
2016	-.6288	.5295
2017	-.3485	.7275
2018	-1.0484	.2944
2019	.1944	.8459

Note: Table (1) tests the null hypothesis ("no manipulation") that the density of the electro-intensity ratio is continuous at the electro-intensity eligibility cutoff (0.5%). It is based on a local polynomial estimator. See (Cattaneo, Jansson, and Ma, 2018). For the purposes of the RD analysis and to maintain a clean comparison around the electro-intensity cutoff, the sample is restricted to firms with a non-negative electro-intensity ratio, since firms with a negative ratio are considered electro-intensive (treated) in the context of the electricity tax reform..

Electro-intensive firms are similar to non-electro-intensive firms at the cutoff
Another identifying assumption in the RD setup is that electro-intensive (treated) and non-electro-intensive (control) firms are similar in terms of observable characteristics pre-reform. The assumption is that if firms cannot precisely control their electro-intensity ratio, there should be no systematic differences between firms with similar electro-intensity values (Cattaneo, Idrobo, and Titiunik, 2019).

Table 2: RD results on firm characteristics in 2012

Observable characteristics	MSE-Optimal Bandwidth	RD Estimator	p-value
Average cost of electricity (log)	.382	-.03128	.606
Electricity use (log)	.388	.00675	.986
Total cost of electricity (log)	.407	-.00961	.978
Electricity over total energy cost (%)	.395	5.8255	.440
Electricity over total energy use (%)	.404	-1.6083	.839
Fossil fuel use (log)	.400	-.55141	.525
Total cost of energy use	.366	-.15858	.703
Cost of operations (log)	.367	-.15696	.702
Value added (log)	.396	-.07594	.848
Net operating income over sales [operating margin]	.380	-.00616	.794
Value added over sales	.301	.04015	.382

Note: Results in Table (2) are based on a data-driven bandwidth selection method that minimizes the mean squared error (MSE) of the local polynomial RD point estimator, in conjunction with a triangle kernel function (Cattaneo, Idrobo, and Titiunik, 2019) and a local quadratic fit. For the purposes of the RD analysis and to maintain a clean comparison around the electro-intensity cutoff, the sample is restricted to firms with a non-negative electro-intensity ratio, since firms with a negative ratio are considered electro-intensive (treated) in the context of the electricity tax reform.

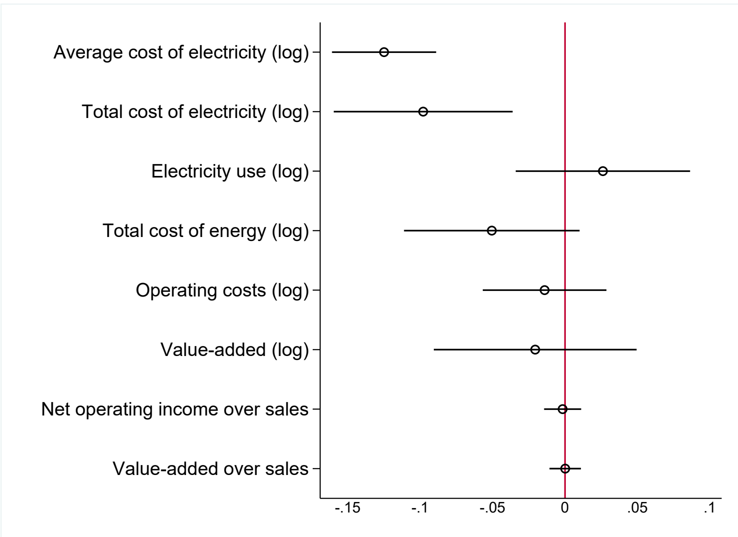
Table (2) presents RD results on the average cost of electricity use and on all other outcome variables detailed in the next section. The RD analyses test whether the covariates are continuous at the electro-intensity cutoff when set at their 2012 level. Following Cattaneo, Idrobo, and Titiunik, 2019, the RD regressions employ a data-driven selection procedure that minimizes the mean squared error (MSE) of the local polynomial RD estimator (τ_{RD}), in conjunction with a triangle kernel function. Results do not indicate that near the cutoff electro-intensive and non-electro-intensive firms differ based on the selected observable characteristics.

5 Results

5.1 Main DiD results

Figure (4) illustrates average DiD effects of the electricity tax reform on select energy use input choices and economic performance indicators. Table (B1) presents the same results in table format (column **i**). With the exception of the average cost of electricity, total electricity costs and the ratio of electricity over total energy costs, the reform did not have a statistically significant impact on firm outcomes on average. On average, electro-intensive firms experienced a 12.5% (or €10.81 per MWh) drop in average electricity costs relative to non-electro-firms in the post-reform period, along with a relative 9.79% drop in total electricity costs and a 2.416 percentage point (pp) cut in the proportion of electricity attributed to total energy costs.

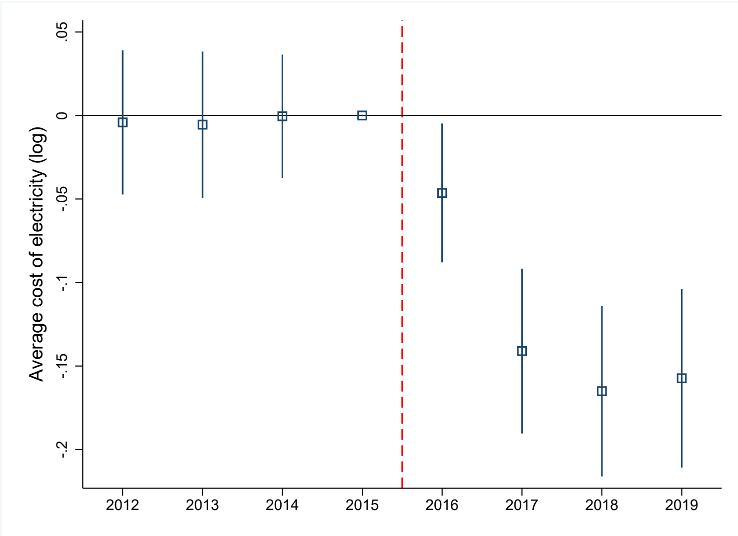
Figure 4: Average DiD effect of electro-intensity on energy use input choices and economic performance indicators



Note: Figure (4) illustrates average DiD effects of electro-intensity status on energy use and economic and financial performance indicators based on Equation (8). It graphs results detailed in Table (B1) (columns **i**). For readability, it omits outcomes in percentage form. Standard errors are clustered at the firm-level. Confidence intervals are set at the 5% level.

Figures (5) and (6) present the dynamic DiD results for the average cost of electricity and all other outcome variables, respectively. Treatment did not have statistically significant effect on the average cost of electricity during all pre-reform years. The flat pre-trends further support the assumption of common trends necessary for identification in the DiD set-up. Once the preferential tax treatment options were introduced in 2016, eligible firms experienced a relative significant drop in average electricity costs across all post-reform years, with a wider relative reduction stabilizing at around 15% during the last three years of the panel.

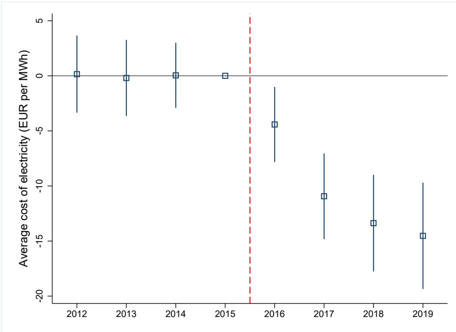
Figure 5: Event study effect of electro-intensity on the average cost of electricity (log)



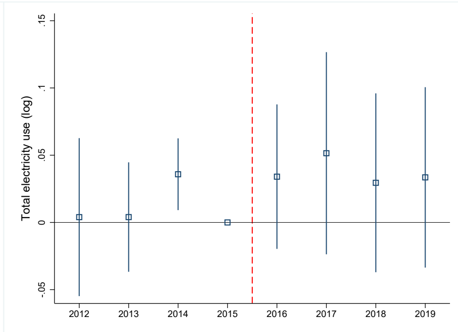
Note: Figure (5) illustrate the event study DiD dynamic results of the effect of the 2016 electricity tax reform on the average cost of electricity (log), based on Equation (7). The sample omits switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Standard errors are clustered at the firm-level. Confidence intervals are set at the 5% level.

Note that by 2019, the average relative cut in average electricity costs reached around €15 per MWh, or the minimum tax cut benefit an eligible electro-intensive firm could obtain under the new tax regime (see section 2.2), as shown in Figure (6a). Overall, both figures (5) and (6a) suggests an adjustment period to the new preferential tax treatment, as reflected by the initially smaller treatment effect the first year of the reform. The implementation lag may reflect the time needed for eligible firms to better understand and capitalize on the incentives provided by the policy, and perhaps also more generally reflecting administrative delays in implementation. Figure (6) illustrates a downward trend post-reform in total electricity costs, the share of electricity over total energy costs and in total energy costs, albeit the latter is not statistically significant on average. Figure (6e) also present pre-trends, mitigating the common trends assumption. Figure (6) does not suggest the reform had an effect on other firm outcomes.

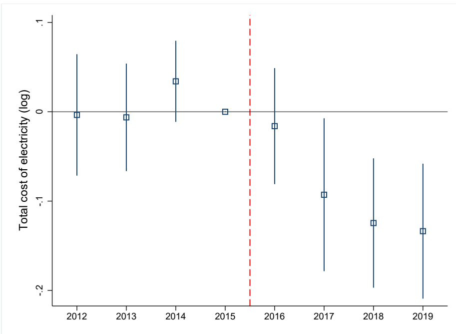
Figure 6: Event study DiD effects of electro-intensity on energy use input choices and economic performance indicators



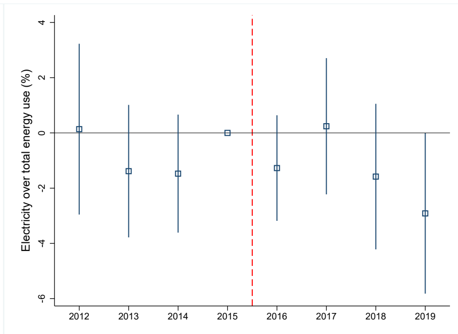
(a) Average cost of electricity (EUR per MWh)



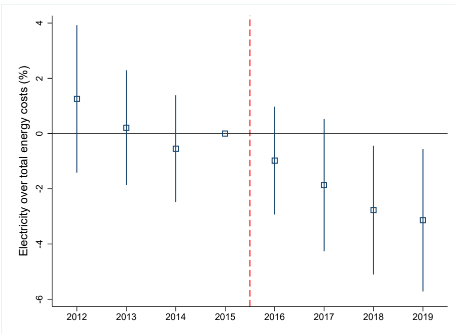
(b) Total electricity use (log)



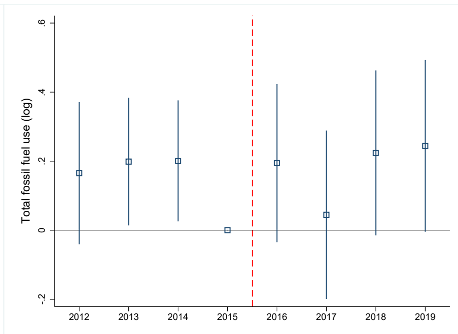
(c) Total electricity costs (log)



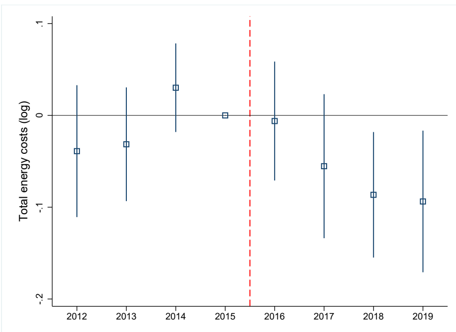
(d) Electricity over total energy use (%)



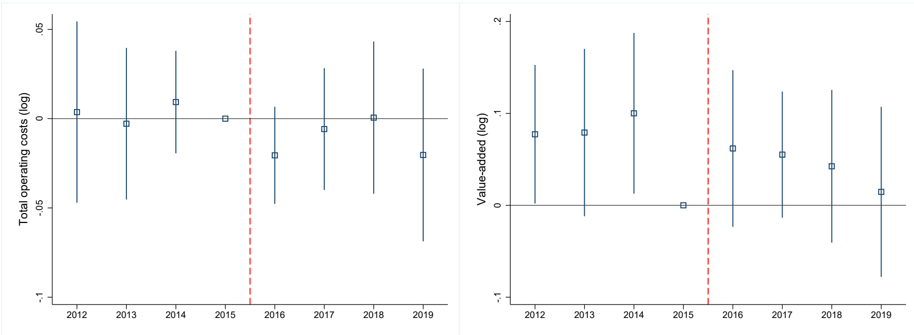
(e) Electricity over total energy costs (%)



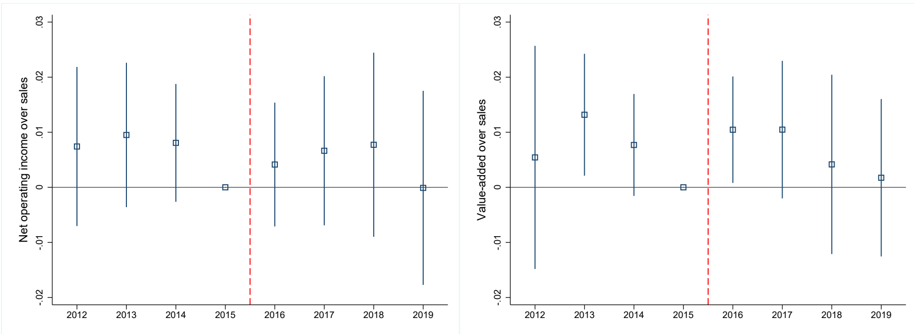
(f) Total fossil fuel use (log)



(g) Total energy costs (log)



(h) Total operating costs (log)   (i) Value added (log)



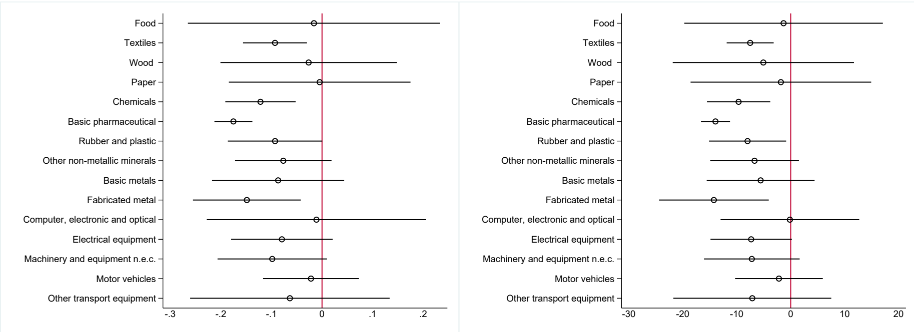
(j) Net operating income over sales   (k) Value added over sales

Note: Figure (6) illustrates the event study DiD dynamic results of the effect of the 2016 electricity tax reform on energy use input choices and economic performance indicators, based on Equation (7). The sample omits switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Standard errors are clustered at the firm-level. Confidence intervals are set at the 5% level.

Heterogeneous treatment effects across different manufacturing sectors.

Figure (7) additionally indicates differential industry responses to the policy. With varying degrees of noise, electro-intensive firms in the manufacturing of chemicals, basic pharmaceuticals, rubber and plastic, basic metals, fabricated metals and textiles experience the largest significant drops in electricity costs on average compared to all other sectors. Specific industries appear to be more responsive or better positioned to benefit from the policy's incentives. It is also noteworthy that these reactive industries are also likely to be relatively more energy and carbon-intensive, and therefore would likely benefit the most from a tax cut on electricity use more generally.

Figure 7: Average DiD effects of electro-intensity the average cost of electricity by manufacturing sector



(a) log (b) EUR per MWh

<u>Note</u>: Figure (7) presents results based on a modification of Equation (8), whereby β is additionally interacted with a dummy equalling for one if the firm belongs to each 2-digit NACE Rev.2 industry code, and zero otherwise. The sample omits switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Standard errors are clustered at the firm-level. Confidence intervals are set at the 5% level.

5.1.1 Robustness checks

Including switchers
Column (**ii**) in Table (B1) estimates results based on the larger sample of firms including switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Regression results are largely akin to those found in column (**i**) although the magnitude of the coefficients tend be smaller. Electro-intensive firms experienced a relative 8.54% decrease in the average cost of electricity on average when including switcher firms in the sample, compared to 12.5% when excluding them. Hence the inclusion of switcher firms tends to dilute treatment effects, reflecting their less consistent behavior regarding their electro-intensity status.

Omit negative electro-intensity ratios
Firms with a negative value-added estimate negative electro-intensity ratios, and are considered (hyper) electro-intensive under the post-reform electricity tax regime. They can benefit from even larger electricity tax rate reductions than other eligible firms. In the DiD setup, they are identified as treated. To ascertain that results are not driven by such firms, columns (**iii**) and (**iv**) re-estimate results from Equation (8) based on the same two former samples while omitting firms that hold a negative electro-intensity ratio any year of the panel. Results under both columns remain consistent, although the magnitude of the results slightly drop. Figure (B1) shows the event study effects for this sample of firms excluding switcher firms.

Propensity score matching (PSM)
Selection bias can arise when treatment and control groups are not comparable in a quasi-experimental design, resulting in differences in average outcomes that cannot be attributed solely to treatment itself. In this paper, the presence of selection bias would suggest that the relative drop in average electricity costs experienced by electro-

intensive firms is not only attributable to the electricity tax reform but also due to other factors that uniquely characterize eligible and non-eligible firms. The principal identification assumption in the DiD setting is the assumption of common trends, i.e. the average change in the average cost of electricity among electro-intensive and non-electro-intensive firms would have been the same in the absence of the electricity tax reform. This assumption allows for the presence of selection bias in levels, given that the bias remains constant over time (Roth et al., 2023).

Nevertheless to mitigate this bias, column (**v**) in Table (B1) re-estimates average DiD results based on a matched sample of electro-intensive and non-elecro-intensive firms following propensity score matching (PSM) techniques. The purpose of PSM is to construct a more comparable treatment and control group to mitigate the risk of selection bias in determining treatment effects. The sample is obtained in a one-to-one nearest-neighbor (NN) matching without replacement and with common support[5]. Firms are matched on total energy use, total energy costs, total electricity use, total employment and total net assets in log form and set in 2012. They are also matched on 2-digit manufacturing sector and on EU-ETS participation to control for sector-specific and EU-ETS specific shocks.

The resulting matched sample includes 186 firms per year, including 147 non-electro-intensive (untreated) and 39 electro-intensive (treated) firms. Table (3) details the estimated p-values from two-sample t-tests on the equality of means across treated and untreated firms characteristics in 2012, the first year of the panel. Column (**i**) is based on the pre-matched sample of firms. It shows that treated and untreated firms are statistically different on average across a number of characteristics, with the exception of the proportion of electricity attributed to total energy costs, employment, operating costs and the export share of revenues. Post-matching, firms are not statistically different on average across all characteristics, with the exception of the ratio of electricity over total energy costs.

[5]NN matching means that non-electro-intensive (untreated) firms are chosen as matching partners to electro-intensive (treated) firms when closest in terms of their estimated propensity score, i.e. their probability to be electro-intensive given observed characteristics (Caliendo and Kopeinig, 2008). Matching without replacement means an untreated firms can only be used once as a match to a treated firm. The common support restriction discards firms whose estimated propensity score does not overlap across treated and untreated firms.

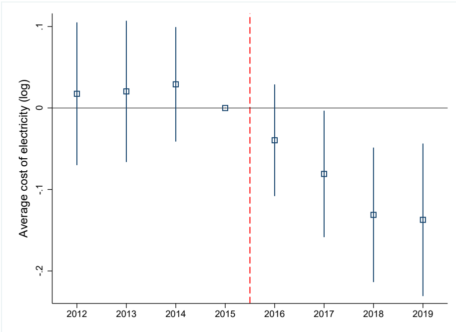
Table 3: Summary statistics comparing pre-matched and matched samples

	Two-sample t-tests p-values	
	Baseline	Matched
	i	**ii**
Average cost of electricity (EUR per MWh)	.0000	.2030
Total electricity use	.0009	.7947
Total electricity costs	.0001	.7238
Total energy use	.0012	.8004
Electricity over total energy costs (%)	.9144	.0017
Total energy costs	.0020	.8083
Employment	.1620	.3900
Operating costs	.1427	.2871
Value added	.0051	.2076
Total net assets	.0110	.3403
Gross operating surplus	.0002	.1090
Exports over total revenues (%)	.2953	.0878

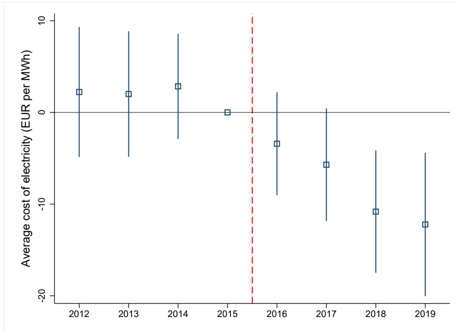
Note: Table (3) details the estimated p-values from two-sample t-tests on the equality of means across electro-intensive firms and non-electro-intensive firms based on various energy use and economic performance indicators in 2012. Column (**i**) is based on the (pre-matched) sample of firms that exclude switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Column (**ii**) is based on a matched sample of electro-intensive and non-electro-intensive firms. The matched sample is obtained in a one-to-one nearest-neighbor matching without replacement and with common support.

On average, electricity intensive firms experienced a 11.4% relative drop in average electricity costs, ergo an effect at a magnitude similar to the results based on the pre-matched sample (column **i** in table B1). All other results are not statistically significant from zero, with the exception of total electricity use. Figure (8) additionally illustrates the dynamic results. The event study DiD results on the average cost of electricity are akin to those found for the pre-matched sample (figures 5 and 6a). Figure (8c) shows a linear upward trend in the pre-reform period, weakening the premise that the electricity tax reform uniquely motivated electro-intensive firms to increase their electricity use as inferred in the average DiD results.

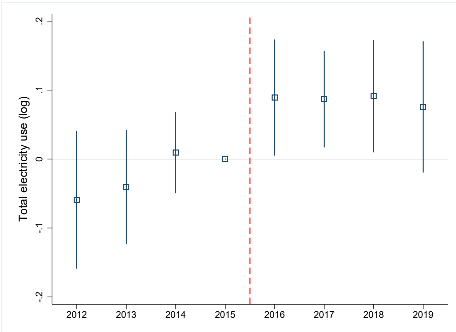
Figure 8: Event study DiD effects of electro-intensity on energy use input choices and economic performance indicators based on matched sample



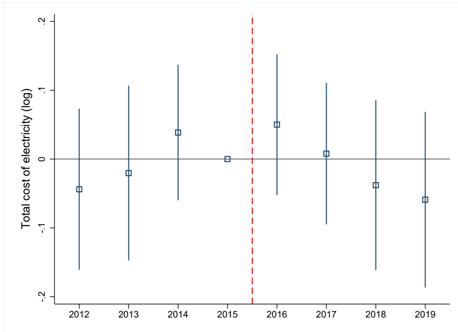
(a) Average cost of electricity (log)



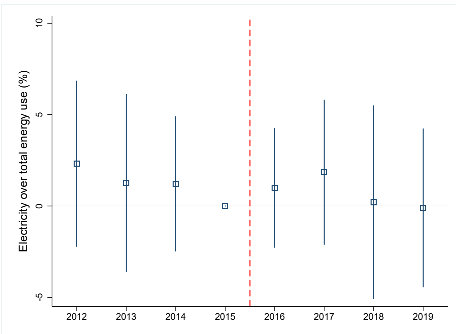
(b) Average cost of electricity (EUR per MWh)



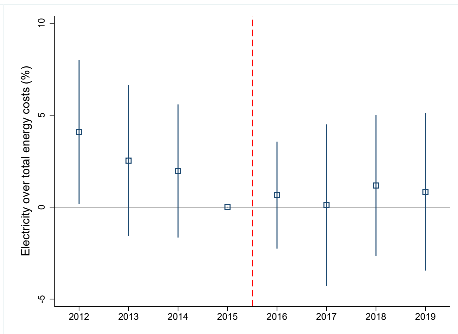
(c) Total electricity use (log)



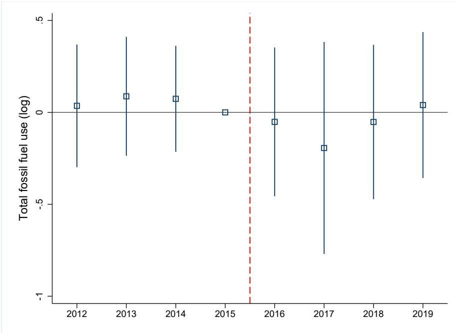
(d) Total electricity costs (log)



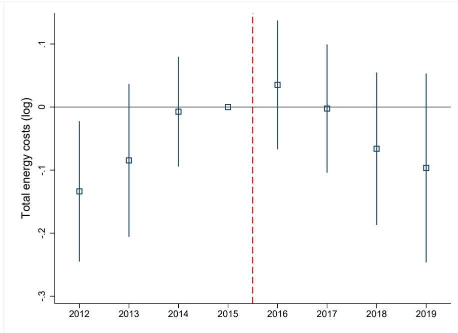
(e) Electricity over total energy use (%)



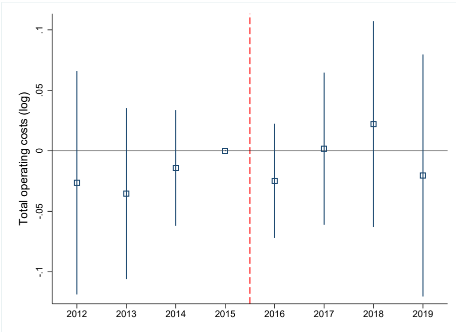
(f) Electricity over total energy costs (%)



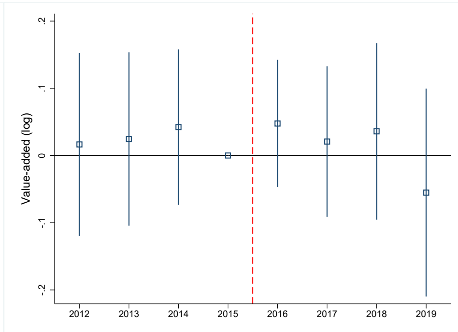
(g) Total fossil fuel use (log)



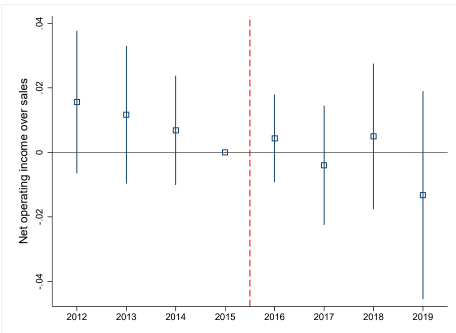
(h) Total energy costs (log)



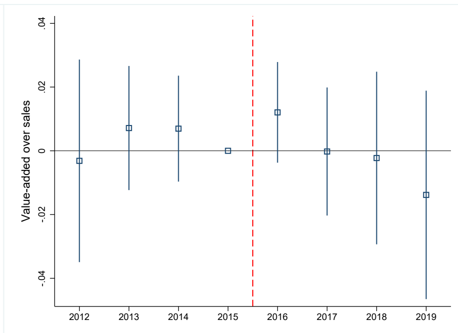
(i) Total operating costs (log)



(j) Value added (log)



(k) Net operating income over sales



(l) Value added over sales

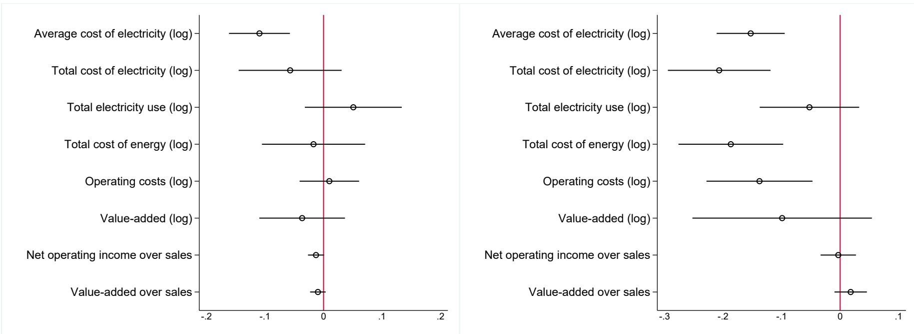
Note: Figure (8) illustrates the event study DiD dynamic results of the effect of the 2016 electricity tax reform on energy use input choices and economic performance indicators, based on Equation (7). The sample of firms is based on the matched sample following propensity score matching (PSM) techniques detailed in this section. Standard errors are clustered at the firm-level. Confidence intervals are set at the 5% level.

Larger panel

Treatment effects are estimated based on a larger balanced panel, i.e., without the employment-based exclusions detailed in Section (3.1). For consistency, the panel still omits switcher firms, amounting to 1 207 firms per year. Average DiD results found in column (**vi**) of Table (B1) are akin to those found in column (**i**), with the exception of the significant negative effect on operation costs and value-added.

Pre-reform cap on electricity tax for consumers over 7 GWh
As detailed in section (2.1), under the old electricity regime firms consuming over 7 GWh of electricity could benefit from a cap on total electricity tax owed. To assess potential differences between firms that benefited from the pre-reform cap and those that did not, firms are identified as benefiting from the previous tax regime if their electricity use exceeds 7 GWh during any year in the pre-reform years. Figure (9) illustrates average DiD results for two samples of firms: firms that would have never benefited from the electricity tax cap pre-reform (Figure 9a), and firms that could have because their electricity use exceeded 7 GWh at least once before 2016 (Figure 9b).

Figure 9: Average DiD effects of electro-intensity based on pre-reform electricity consumption



(a) Below 7 GWh

(b) Above 7 GWh

Note: Figure (9) illustrates average DiD effects of the 2016 electricity tax reform among firms that consumed below 7 GWh of electricity in the pre-reform period (Figure 9a) and firms that consumed in excess of that amount (Figure 9b). Firms in Figure (9b) could benefit from a cap on total electricity tax liability prior to 2016. In Figure (9a) the total number of firms amount to 296 per year, with 173 treated. In Figure (9b) the total number of firms amount to 358 per year, with 334 treated. Standard errors are clustered at the firm-level. Confidence intervals are set at the 5% level.

Electro-intensive firms experienced relative and statistically significant drops in average electricity costs across all firms, but only electro-intensive firms in Figure (9b) also experienced relative drops in total electricity costs, their total energy bill and in operating costs. Moreover, the magnitude of the effect on average electricity costs is larger among firms that consumed over 7 GWh of electricity pre-reform. Larger consumers of electricity in absolute terms, that are also identified as electro-intensive, may mechanically experience greater savings on their electricity and operating costs because of their larger reliance on electricity inputs. It is also noteworthy that firms in Figure (9b) also likely already had the administrative experience and regulatory knowledge to navigate and maximize the benefits of the tax cap more effectively. This could suggest that administrative know-how and expertise may play a role in the ability to reduce costs post-reform, to the extent that preferential tax treatment is not automatically provided in France, it must be requested by the firm upon proof of eligibility. Notwithstanding the above, the relative small number of non-electro-intensive firms in Figure (9b) (24 per year), relative to electro-intensive firms (334 per year) tends to limit the generalizability of findings for this group of firms. Nevertheless, one effect that remains robust is the drop in average costs of electricity across both figures.

5.2 Main RD results

Table (4) presents results from a regression discontinuity (RD) analysis on energy use and economic performance indicators, pooled across both the pre-reform and post-reform period. The pooled estimation of RD results across all years is not appropriate in this policy context because the electricity tax reform was implemented in 2016, whereby the panel includes four years prior to 2016. Therefore, the RD estimation is conducted separately for the pre-reform (2012–2015) and post-reform (2016–2019) periods to account for potential structural breaks and differences in behavior across the two electricity tax regimes. Note also that to maintain a clean comparison around the electro-intensity cutoff, the sample is also restricted to firms with a non-negative electro-intensity ratio, since firms with a negative ratio are considered electro-intensive (treated) in the context of the electricity tax reform (albeit are situated to the left of the electro-intensity cutoff). DiD results based on the same firm samples are provided in columns (**iii**) in Table (B1) and in Figure (B1).

As for the results detailed in Table (2), the RD analysis in Table (4) tests whether the variables are continuous at the electro-intensity cutoff. Following Cattaneo, Idrobo, and Titiunik, 2019, it employs a data-driven selection procedure that minimizes the mean squared error (MSE) of the local polynomial RD estimator (τ_{RD}), in conjunction with a triangle kernel function. Across the pre-reform period, results do not uncover statistically significant evidence that electro-intensive and non-electro-intensive firms differ near the cutoff across all indicators. On the other hand in the post-reform period, the RD estimator indicates that electro-intensive firms experienced a significant drop in average electricity costs by around 19.5%, or equivalently a decrease of €14.4 per MWh. They also experience a very large and statistically significant increase in total electricity use (112.25%).

Table 4: RD results on energy use and economic performance indicators across reform periods

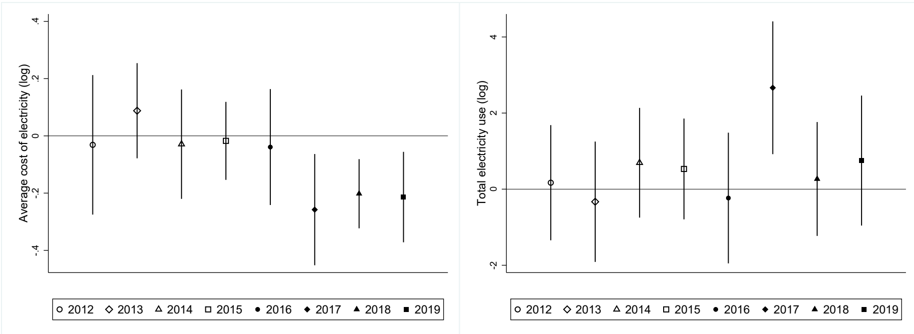
	Pre-reform			Post-reform		
	MSE-Optimal Bandwidth	RD Estimator	p-value	MSE-Optimal Bandwidth	RD Estimator	p-value
Energy use indicators						
Average cost of electricity (log)	.276	.08946	.116	.235	-.19528	.000
Average cost of electricity (EUR per MWh)	.274	8.0896	.094	.267	-14.417	.001
Total electricity use (log)	.257	-.14307	.785	.204	1.1225	.043
Total electricity costs (log)	.258	-.07358	.882	.208	.89531	.095
Electricity over total costs (%)	.266	13.45	.109	.296	1.5919	.827
Electricity over total energy use (%)	.279	-.95751	.930	.284	-4.9979	.571
Total fossil fuel use (log)	.321	-.52086	.520	.236	.89612	.215
Total energy costs (log)	.235	-.28036	.630	.208	.98768	.073
Other competitiveness indicators						
Total operating costs (log)	.285	-.51482	.319	.206	.70779	.213
Value added (log)	.275	-.37288	.463	.186	1.0599	.068
Net operating income over sales [operating margin]	.245	-.02691	.322	.230	.02792	.360
Value added over sales	.278	.0679	.169	.224	.07138	.085

Note: Table (4) presents results from a regression discontinuity (RD) analysis. Results are based on a data-driven bandwidth selection method that minimizes the mean squared error (MSE) of the local polynomial RD point estimator, in conjunction with a triangle kernel function (Cattaneo, Idrobo, and Titiunik, 2019) and a local quadratic fit. The sample omits switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). For the purposes of the RD analysis and to maintain a clean comparison around the electro-intensity cutoff, the sample is also restricted to firms with a non-negative electro-intensity ratio, since firms with a negative ratio are considered electro-intensive (treated) in the context of the electricity tax reform.

Figure (10) further investigates the RD results on average electricity costs and on electricity use, illustrating the same regressions for each year of the panel. Akin to the DiD results found in Figure (5), RD estimates are not statistically significant across all pre-reform years in Figure (10a), supporting the premise that results are capturing the effect of the electricity tax reform. While the RD estimator is not significant in the first year of the reform in 2016, results are significant, negative and relatively constant in magnitude from 2017 onward. Note that while the DiD result for 2016 was statistically significant, the magnitude of the effect was much lower than those found for subsequent years. The RD estimate for 2016 may again reflect some form of implementation lag discussed in section (5.1). Figure (B2) shows the same RD regressions on the sample including switcher firms, i.e., firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). The inclusion of switcher firms in the RD setup entirely eliminates the significance of the treatment effects on the average cost of electricity, reinforcing conclusions found in section (5.1.1).

On the other hand, yearly RD results in Figure (10b) are not statistically significant across all years with the exception of 2017 by an abnormally large magnitude. Furthermore, the inclusion of switcher firms in Figure (B2b) also entirely eliminates any significant effects on electricity use, suggesting a lack of evidence of any manipulation via electricity consumption among switcher firms to benefit from the preferential tax treatment post-reform. Overall, the significant effect on electricity use in the post-reform period in Table (4) is likely not driven by the 2016 electricity tax reform.

Figure 10: RD results on the average cost of electricity and electricity use by year



(a) Average cost of electricity (log)

(b) Electricity use (log)

Note: Figure (10) presents year-by-year results from a regression discontinuity (RD) analysis. Results are based on a data-driven bandwidth selection method that minimizes the mean squared error (MSE) of the local polynomial RD point estimator, in conjunction with a triangle kernel function (Cattaneo, Idrobo, and Titiunik, 2019) and a local quadratic fit. The sample omits switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). For the purposes of the RD analysis and to maintain a clean comparison around the electro-intensity cutoff, the sample is also restricted to firms with a non-negative electro-intensity ratio, since firms with a negative ratio are considered electro-intensive (treated) in the context of the electricity tax reform. Confidence intervals are set at the 5% level.

5.2.1 Robustness checks

Artificial placebo cutoffs

Table (5) presents results from a regression discontinuity (RD) analysis based on artificial cutoffs beyond 0.5%. A constant across this paper is the significant negative effect on average cost of electricity due to the electricity tax reform, the outcome of interest in the table. The time period is post-reform. To avoid "contamination" due to real treatment effects, the sample of firms for artificial cutoffs between 0.1% and 0.4% only includes non-electro-intensive firms. The sample of firms for artificial cutoffs between 0.6% and 1% only includes electro-intensive firms (Cattaneo, Idrobo, and Titiunik, 2019). The results for the real cutoff at 0.5% are the same found in Table (4) for comparison. Results are based on a data-driven bandwidth selection method that minimizes the mean squared error (MSE) of the local polynomial RD point estimator, in conjunction with a triangle kernel function (Cattaneo, Idrobo, and Titiunik, 2019) and a local quadratic fit.

The table shows that for artificial cutoffs 0.1%-0.4% and 0.6%-1%, the RD estimates do not detect any discontinuities in the average cost of electricity around the cutoff between firms left and right of the selected threshold. These findings help confirm the validity of the RD design in this policy setting.

Table 5: Placebo tests for artificial cutoffs

Cutoff (%)	MSE-Optimal Bandwidth	RD Estimator	p-value
0.1	.038	-.04416	.657
0.2	.071	-.01136	.854
0.3	.086	.03717	.590
0.4	.037	.04261	.693
0.5	**.235**	**-.19528**	**.000**
0.6	.363	-.01109	.878
0.7	.368	-.02534	.542
0.8	.296	-.02043	.678
0.9	.354	-.00929	.796
1	.346	-.004	.916

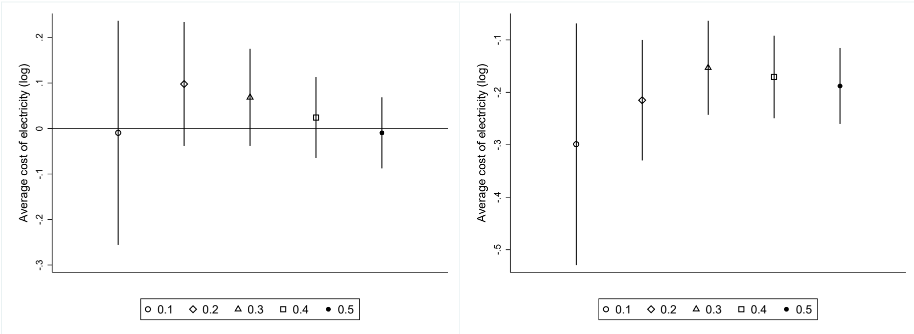
Note: Table (5) presents results from a regression discontinuity (RD) analysis based on artificial cutoffs beyond 0.5%. The outcome is the logged average cost of electricity. The time period is post-reform. To avoid "contamination" due to real treatment effects, the sample of firms for artificial cutoffs between 0.1% and 0.4% only includes non-electro-intensive firms. The sample of firms for artificial cutoffs between 0.6% and 1% only includes electro-intensive firms (Cattaneo, Idrobo, and Titiunik, 2019). The results for the real cutoff at 0.5% are the same found in Table (4) for comparison. Results are based on a data-driven bandwidth selection method that minimizes the mean squared error (MSE) of the local polynomial RD point estimator, in conjunction with a triangle kernel function (Cattaneo, Idrobo, and Titiunik, 2019) and a local quadratic fit. The sample omits switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). For the purposes of the RD analysis and to maintain a clean comparison around the electro-intensity cutoff, the sample is also restricted to firms with a non-negative electro-intensity ratio, since firms with a negative ratio are considered electro-intensive (treated) in the context of the electricity tax reform.

Bandwidth choice

Results and conclusions in a RD design can be sensitive to the choice of bandwidth in the regressions. For a given bandwidth h and cutoff c, RD results are based on local extrapolation within $[c-h, c+h]$ of the assignment variable. Following (Cattaneo, Idrobo, and Titiunik, 2019) so as to avoid specification searching and ad hoc decisions, results in this paper are based on a data-driven bandwidth selection method that minimizes the mean squared error (MSE) of the local polynomial RD point estimator. This approach chooses a bandwidth h that optimizes a bias-variance trade-off, since the MSE of an estimator is the sum of its squared bias and its variance.

To further check the sensitivity of the results to bandwidth choice, Table (11) presents RD effects on the average cost of electricity imposing bandwidth choice $h = \{0.1\% - 0.5\%\}$ separately for each regression across both reform periods. Across all bandwidth choices, results are not statistically different from zero in the pre-reform period, and are negative and significant in the post-reform period. Note that results become more precise as h increases, reflecting the fact that the sample excludes switcher firms which tend to oscillate near the cutoff.

Figure 11: RD results on the average cost of electricity (log) across reform periods and bandwidth choices (%)



(a) Pre-reform

(b) Post-reform

Note: Figure (11) presents results from a regression discontinuity (RD) analysis imposing bandwidth choice $h = \{0.1\% - 0.5\%\}$ separately for each regression across both reform periods.. The sample omits switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). For the purposes of the RD analysis and to maintain a clean comparison around the electro-intensity cutoff, the sample is also restricted to firms with a non-negative electro-intensity ratio, since firms with a negative ratio are considered electro-intensive (treated) in the context of the electricity tax reform. Confidence intervals are set at the 5% level.

6 Discussion and concluding remarks

The 2016 electricity tax reform introduced new preferential tax treatment in the form of tax rate reductions on electricity consumption for firms with a gross electricity tax liability exceeding 0.5% of their value added. Firms that satisfy the cutoff requirement are identified as electro-intensive. A first-order effect of this reform should be a relative reduction in the average electricity cost burden among eligible firms. Employing various empirical strategies and robustness checks, this paper uncovers evidence corroborating this hypothesis.

Employing a differences-in-differences (DiD) strategy, electro-intensive firms experience a relative 12.5% drop in average electricity costs, equivalent to about 11 euros per MWh of electricity in savings. Data plots and event study DiD graphs further support the assumption of common trends necessary for identification in a DiD setting. When accounting for potential selection bias using propensity score matching techniques, the DiD findings result in a relative 11% cut in average electricity costs. Moreover findings from a regression discontinuity (RD) design observes a larger 19.5% drop on average, equivalent to around 14 euros per MWh in cost reductions. Moreover, this paper does not uncover evidence of firm manipulation around the cutoff to benefit from the preferential tax treatment, helping support the validity of the RD design in this policy setting.

A second-order effect of the reform would include changes in corporate behavior on various energy use and economic performance indicators, as eligible firms reliant on electricity inputs for manufacturing save on electricity costs. Nevertheless, additional findings do not uncover significant or robust effects on electricity or fossil fuel use decisions, nor on on total cost of manufacturing operations, value-added and other competitiveness indicators across both DiD and RD specifications.

Such second order effects may take time to materialize beyond 2019, the last year of the panel. That said, while Gerster and Lamp (2024) do uncover evidence that eligible German manufacturing firms consumed more electricity following the introduction of a tax cut, this paper does not in the case of french firms. A possible explanation for this discrepancy lies in the energy mix: French firms may have less flexibility to substantially increase electricity inputs given their already relatively high share of total energy use. Another possible explanation stems in policy design, and particularly in the policy's incentive structure, i.e. whether the magnitude of the tax cut was substantial enough to change corporate behavior. Note that this paper also does not address more international dimensions such as offshoring as a consequence of the 2016 electricity tax reform. Such movements in capital could also mitigate the effects of the reform. Nevertheless and overall, present findings in this paper cast doubt on the usefulness and necessity of the public policy vis-à-vis tax revenues foregone which reached almost €2 billion by 2019.

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A Descriptive statistics

Table A1: Foregone tax revenues due to preferential tax treatment granted to electro-intensive businesses, 2016-2019

Characteristic	2016	2017	2018	2019
Not at risk of carbon leakage	561	1,014	1,035	1,245
At risk of carbon leakage	297	198	210	253
Hyper-electro-intensive	110	104	75	105
Total	968	1,316	1,320	1,603

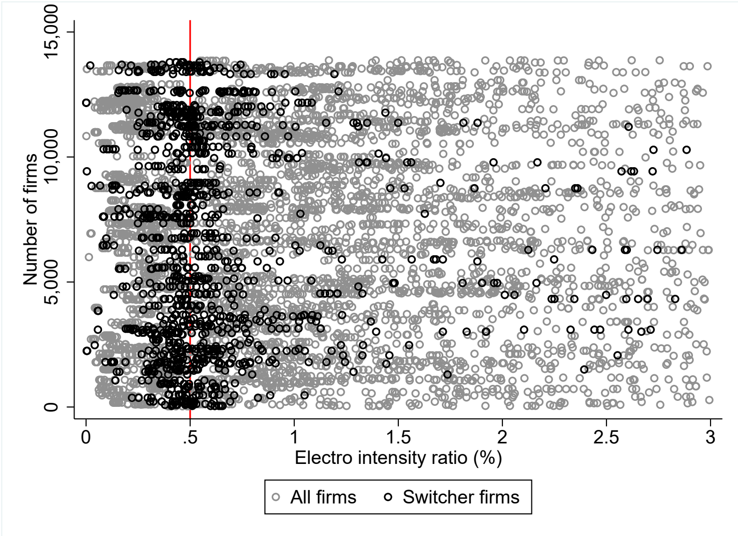
Note: Tax expenditures are in EUR million. Firms that consume over 6 kWh of electricity per euro of value-added or that estimate a negative value-added are considered hyper-electro-intensive. Carbon leakage is defined in European Commission (2012). Sources: PLF (2021), PLF (2020), PLF (2019) and PLF (2018).

Table A2: Summary statistics by electro-intensity status in 2012

	i				ii			
	Incl. switcher firms n = 808 per year				Excl. switcher firms n = 654 per year			
	Not Electro-Intensive		Electro-Intensive		Not Electro-Intensive		Electro-Intensive	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Electro-intensity ratio (%, pre-reform average)	.29	.13	3	8	.24	.10	3	8
Average cost of electricity use (€ per MWh)	82	14	73	12	83	15	72	12
Electricity use (‘100 toe)	6	15	39	127	6	17	43	137
Fossil fuel use (‘100 toe)	6	17	86	385	5	15	98	415
Electricity over total energy use (%)	54	22	50	27	52	20	50	27
Fossil fuel over total energy use (%)	43	23	44	28	46	21	43	28
Total cost of electricity (‘10 000 €)	49	117	248	650	47	126	277	696
Electricity over total energy costs (%)	64	20	62	24	62	19	62	24
Total energy costs (‘10 000 €)	81	194	615	2 251	74	193	693	2 420
Total energy use (‘100 toe)	12	34	148	542	11	31	168	582
Employment (#)	511	1 244	394	613	503	1 277	397	597
Total net assets (‘1 000 000 €)	177	651	96	225	192	740	98	206
Operating costs (‘1 000 000 €)	181	554	130	231	183	605	134	233
Net operating income (‘1 000 000 €)	12	38	5	19	14	43	5	18
Total sales (‘1 000 000 €)	178	493	131	231	180	537	135	236
Net operating income over sales	.08	.08	.03	.07	.09	.09	.03	.07
Value added (‘1 000 000 €)	55	154	33	64	58	173	33	56
Value-added over sales	.36	.13	.30	.13	.37	.13	.30	.13
Net operating income over gross operating surplus	.29	.20	.18	.40	.30	.21	.18	.42
Export share of total sales (%)	40	33	36	32	40	33	37	33
EU-ETS (%)	2.30	-	15.57	-	2.04	-	16.57	-

Note: Values are rounded to the nearest integer. Electro-intensity status is based on Equation (6). Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Toe is an acronym for tons of oil equivalent. Net operating income refers to gross operating revenues minus operating costs. Net assets refer to the difference between total assets and total liabilities. Gross operating surplus (or *Excédent Brut d'Exploitation*, EBE) refers to value-added including operating grants and minus labor costs.

Figure A1: Distribution of change in electro-intensity ratio



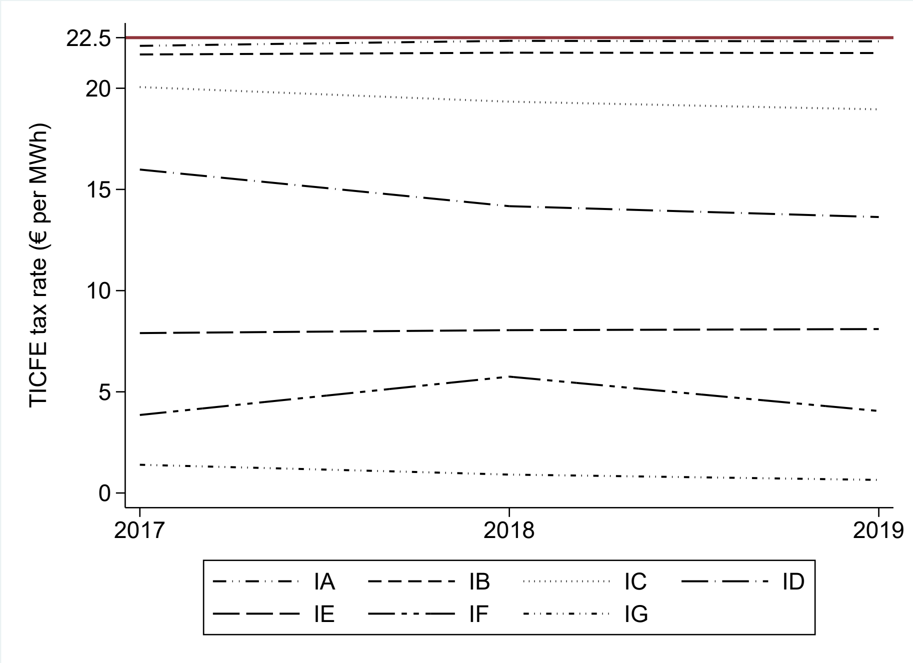
Note: Figure (A1) presents a scatter-plot of electro-intensity ratios across all years. The darker markers illustrate the distribution of electro-intensity ratios of switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). For readability, the x-axis is limited to electro-intensity ratios ranging between null and 3%, effectively representing 85% of all firms and 97% of all switcher firms. The figure shows that switcher firms tend to oscillate around the 0.5% electro-intensity cutoff.

Table A3: Manufacturing sector frequency distribution by electro-intensity status in 2012

i				ii			
Incl. switcher firms n = 808 per year				Excl. switcher firms n = 654 per year			
Not electro-intensive		Electro-intensive		Not electro-intensive		Electro-intensive	
Chemicals	19	Food	15	Chemicals	19	Food	16
Fabricated metals	13	Chemicals	15	Machinery and equipment n.e.c.	13	Chemicals	16
Electrical equipment	11	Other non-metallic minerals	10	Electrical equipment	12	Paper	10
Machinery and equipment n.e.c.	11	Paper	9	Fabricated metals	12	Other non-metallic minerals	10
Computer, electronic and optical	6	Fabricated metals	9	Other transport equipment	7	Basic metals	9
All other manufacturing	40	All other manufacturing	42	All other manufacturing	37	All other manufacturing	39

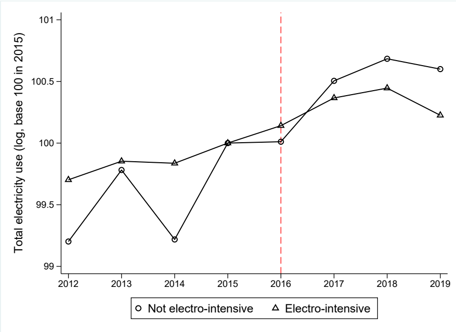
Note: Values are rounded to the nearest integer. Electro-intensity status is based on Equation (6). Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2).

Figure A2: Evolution of the average effective tax on electricity use rate by consumption brackets, 2017-2019

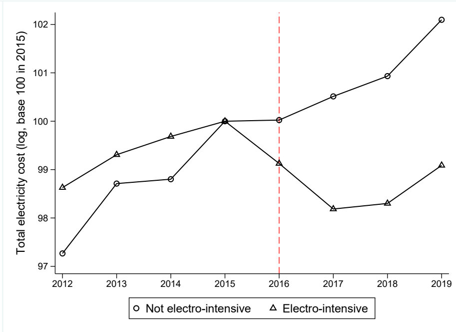


Note: Firms in consumption bracket (IA) consume below .02 GWh of electricity; in (IB) between .02 GWh and 0.5 GWh of electricity; in (IC) between 0.5 GWh and 2 GWh; in (ID) between 2 GWh and 20 GWh; in (IE) between 20 GWh and 70 GWh; in (IF) between 70 GWh and 150 GWh and firms in consumption level (IG) consume above 150 GWh of electricity. Figure (A2) shows that the effective tax rate paid on electricity is close to the statutory rate among the smallest consumers (€22.5 per MWh), whereas the larger ones benefit from more reduced rates. Source: Ministry of the Environment (2023).

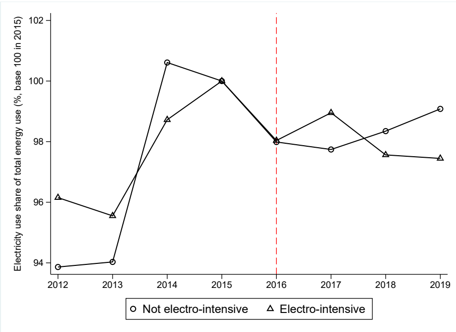
Figure A3: Parallel trends by electro-intensity status - input choice and economic performance indicators



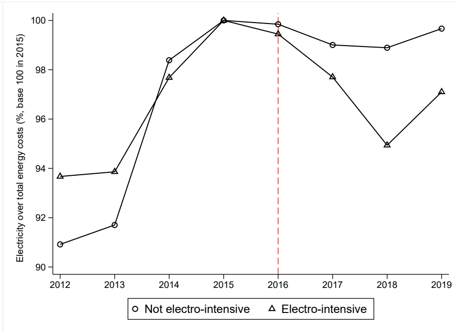
(a) Total electricity use



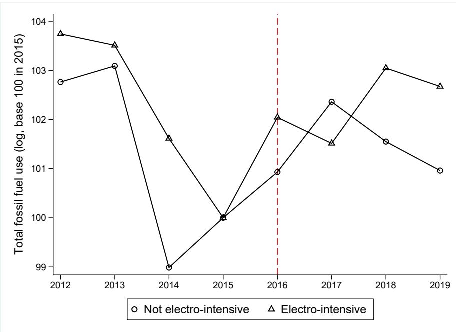
(b) Total electricity cost



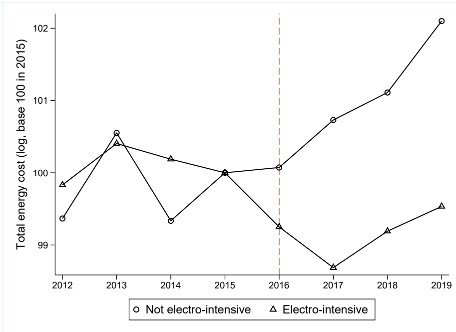
(c) Electricity over total energy use



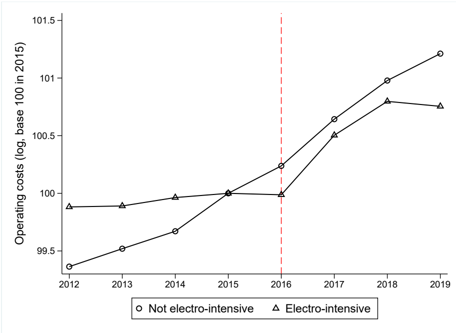
(d) Electricity over total energy cost



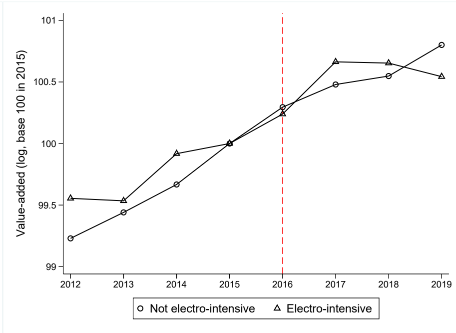
(e) Fossil fuel use



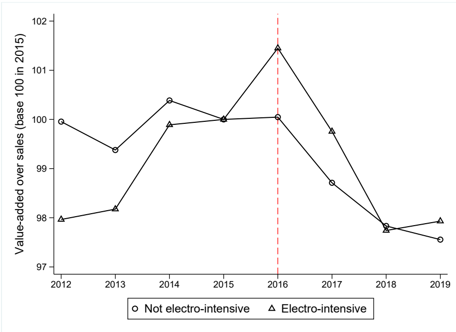
(f) Total energy costs



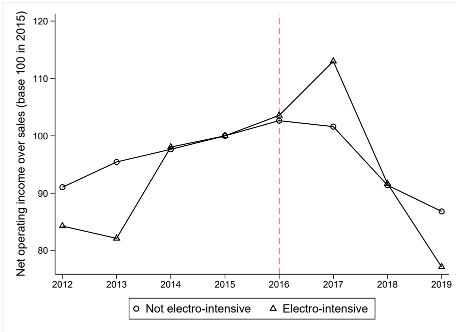
(g) Total operating costs



(h) Total value-added



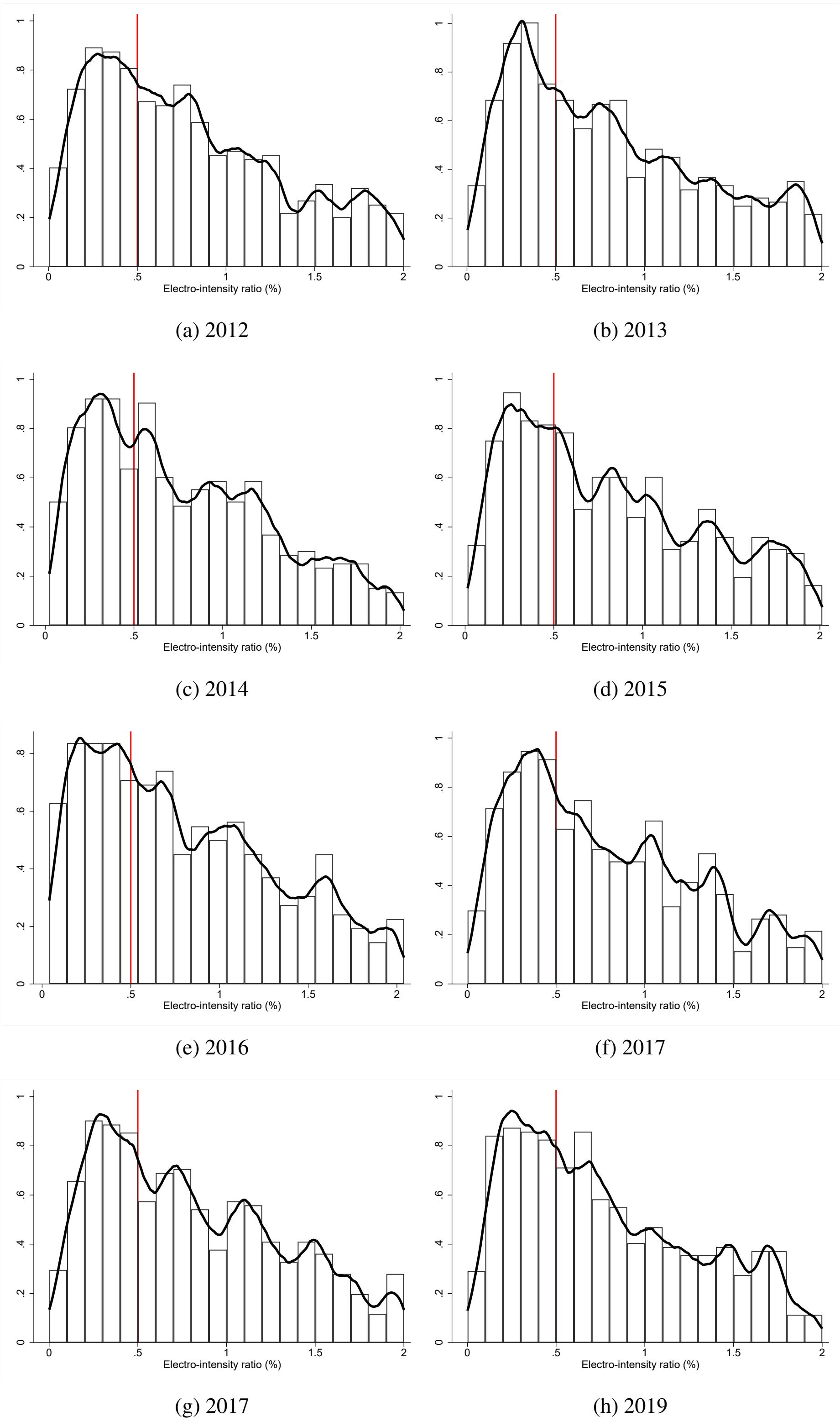
(i) Value added over sales



(j) Operating margin

Note: Figure (A3) shows the evolution of various energy use and economic performance indicators between electro-intensive firms and non-electro-intensive firms, as defined in Equation (6). Operating margin refers to net operating income over sales. The sample omits switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Average trends are indexed to year 2015.

Figure A4: Density distribution of electro-intensity ratios by year



(a) 2012

(b) 2013

(c) 2014

(d) 2015

(e) 2016

(f) 2017

(g) 2017

(h) 2019

Note: Figure (A4) illustrates a kernel density distribution of electro-intensity ratios for each year of the panel. The kernel function is triangle. The bin width is 0.1 percent. For readability and to preserve firm confidentiality, the x-axis is limited to electro-intensity ratios ranging between null and 2 percent. The panel includes 808 firms per year, including switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2).

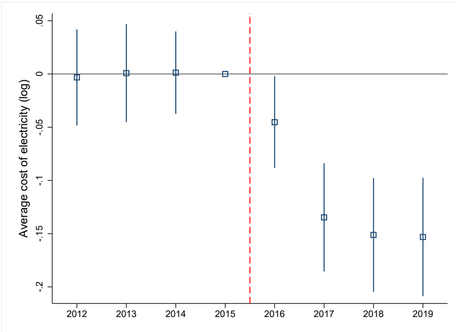
B Results

Table B1: Average DiD effect of electro-intensity on energy use input choices and economic performance indicators

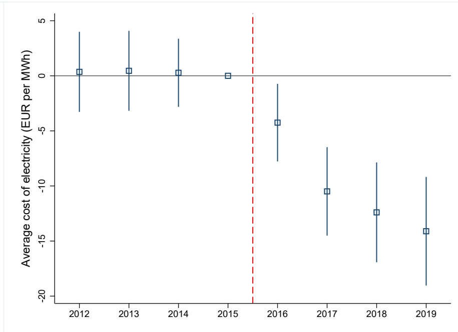
Manufacturing firms (n) located in France from 2012 to 2019	Exposure to electro-intensity preferential tax treatment					
			Omit negative electro-intensity ratios			
	Baseline (excl. switchers)	Incl. switchers	Baseline (excl. switchers)	Incl. switchers	PSM	Larger panel
	n = 654 per year	n = 808 per year	n = 627 per year	n = 773 per year	n = 186 per year	n = 1 207 per year
	i	**ii**	**iii**	**iv**	**v**	**vi**
Energy use indicators						
Average cost of electricity (log)	-.125***	-.0854***	-.121***	-.0811***	-0.114***	-.115***
	(.0183)	(.0141)	(.0191)	(.0149)	(.0303)	(.0128)
Average cost of electricity (EUR per MWh)	-10.81***	-7.356***	-10.58***	-7.102***	-9.772***	-9.627***
	(1.539)	(1.168)	(1.578)	(1.211)	(2.427)	(1.052)
Total electricity use (log)	.0262	-.00192	.0387	.00993	.0108***	.0236
	(.0307)	(.0259)	(.0302)	(.0254)	(.0377)	(.0241)
Total cost of electricity use (log)	-.0979***	-.0868***	-.0841***	-.0736***	-.00323	-.100***
	(.0315)	(.0271)	(.0320)	(.0273)	(.0478)	(.0257)
Electricity over total energy cost (%)	-2.416***	-1.601**	-2.333***	-1.455*	-1.439	-2.593***
	(.859)	(.738)	(.892)	(.761)	(1.531)	(.674)
Electricity over total energy use (%)	-.702	-.522	-.773	-.529	-.446	-.883
	(.937)	(.777)	(.974)	(.808)	(1.715)	(.710)
Total fossil fuel use (log)	.0361	.0385	.0605	.0559	-.115	.0769
	(.0884)	(.0696)	(.0914)	(.0730)	(.191)	(.0689)
Total cost of energy use (log)	-.0505	-.0546**	-.0409	-.0454*	.0238	-.0433*
	(.0309)	(.0243)	(.0316)	(.0247)	(.0419)	(.0251)
Other competitiveness indicators						
Total cost of operations (log)	-.0141	.00595	-.00740	.0105	.0137	-.0348**
	(.0217)	(.0251)	(.0224)	(.0264)	(.0419)	(.0169)
Value added (log)	-.0206	.0368	-.0209	.0275	-.00808	-.0784***
	(.0357)	(.0308)	(.0296)	(.0275)	(.0524)	(.0234)
Net operating income over sales [operating margin]	-.00164	.00822	-.00991*	-.000637	-.0104	-.00595
	(.00652)	(.00575)	(.00541)	(.00494)	(.00854)	(.00434)
Value added over sales	.000136	.00737	-.00285	.00400	-.00375	-.00481
	(.00553)	(.00594)	(.00541)	(.00620)	(.00986)	(.00403)

Note: The baseline sample (column **i**) excludes switcher firms so as to mitigate any remaining concerns that firms strategically manipulated their electro-intensity ratios to benefit from the tax rate reductions on electricity use from 2016. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Column **ii** includes switcher firms. Columns **iii** and **iv** are akin to columns **i** and **ii**, respectively, with the exception that the samples omit firms with negative electro-intensity ratios any year (i.e. negative value-added). Firms with negative electro-intensity ratios are considered hyper-electro-intensive (see section 2.2). Column **v** details results based on a matched sample following propensity score matching (PSM) techniques. The matched sample is obtained in a one-to-one nearest-neighbor (NN) matching without replacement and with common support. Results in column **vi** are estimated based on the balanced panel omitting switcher firms, but without the employment-based exclusions detailed in Section (3.1). Standard errors are provided in parenthesis and are clustered at the firm level. Statistical significance is marked with *($0.1 >$ p-value> 0.05), **($0.05 >$ p-value > 0.01), ***(p-value < 0.01).

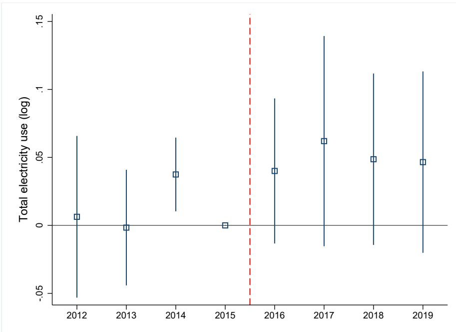
Figure B1: Event study DiD effects of electro-intensity on energy use input choices and economic performance indicators omitting negative electro-intensity ratios



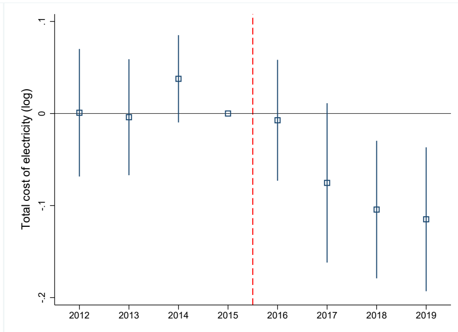
(a) Average cost of electricity (log)



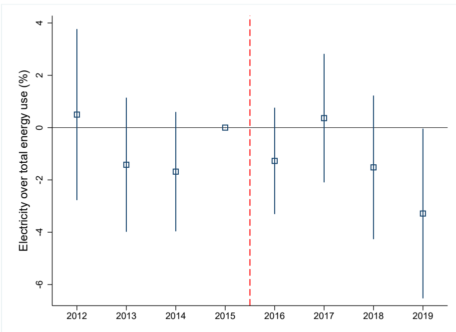
(b) Average cost of electricity (EUR per MWh)



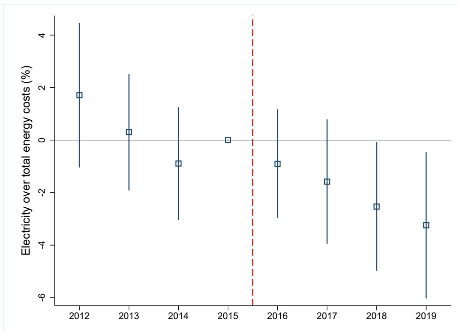
(c) Total electricity use (log)



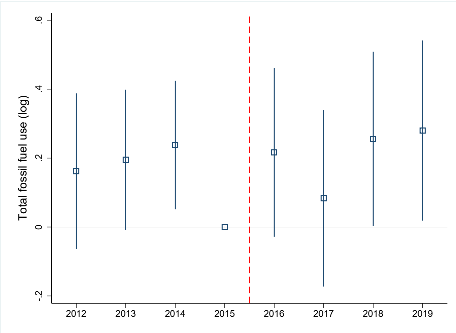
(d) Total electricity costs (log)



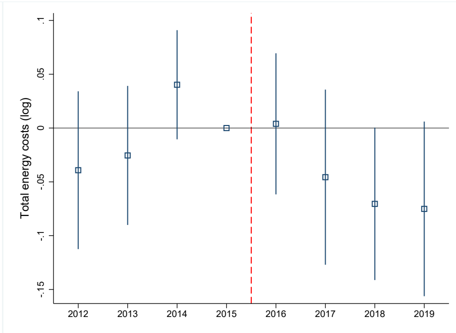
(e) Electricity over total energy use (%)



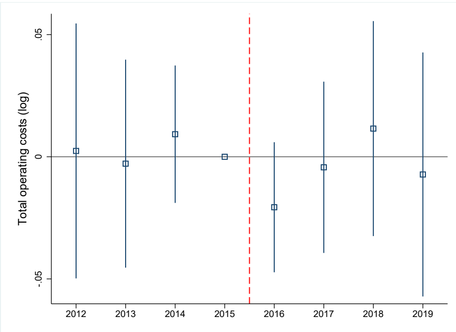
(f) Electricity over total energy costs (%)



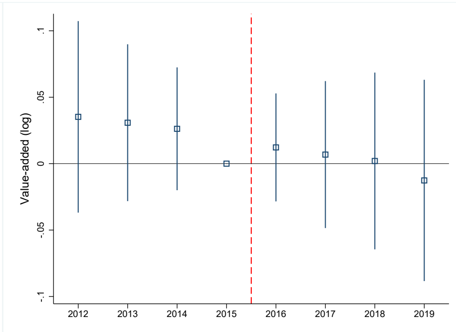
(g) Total fossil fuel use (log)



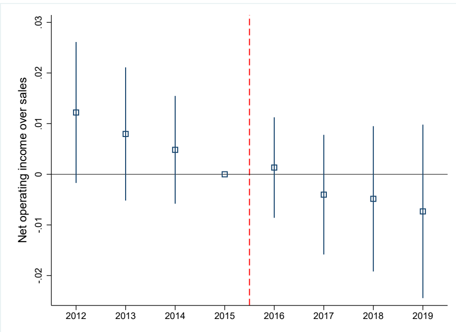
(h) Total energy costs (log)



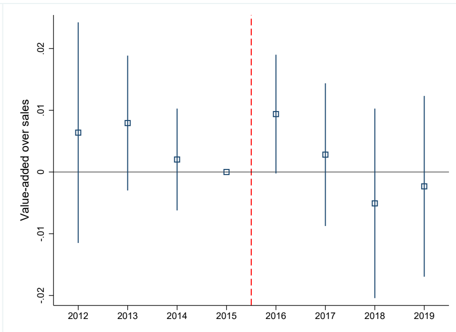
(i) Total operating costs (log)



(j) Value added (log)



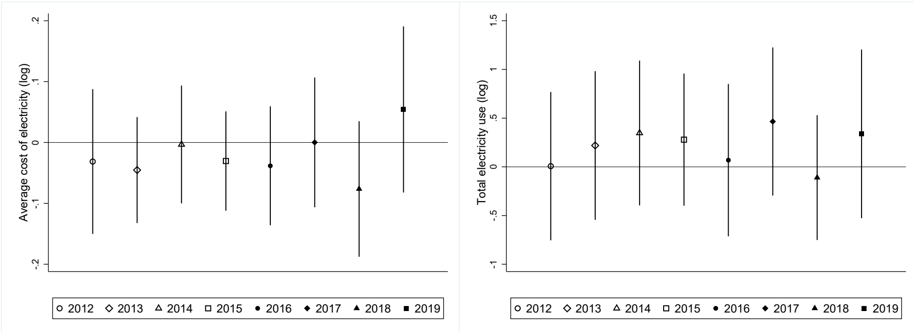
(k) Net operating income over sales



(l) Value added over sales

Note: Figure (B1) illustrates the event study DiD dynamic results of the effect of the 2016 electricity tax reform on energy use input choices and economic performance indicators, based on Equation (7). The sample of firms only includes firms with a non-negative electro-intensity ratio. It also excludes switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). Standard errors are clustered at the firm-level. Confidence intervals are set at the 5% level.

Figure B2: RD results on the average cost of electricity and electricity use by year including switcher firms



(a) Average cost of electricity (log)

(b) Electricity use (log)

Note: Figure (B2) presents year-by-year results from a regression discontinuity (RD) analysis. Results are based on a data-driven bandwidth selection method that minimizes the mean squared error (MSE) of the local polynomial RD point estimator, in conjunction with a triangle kernel function (Cattaneo, Idrobo, and Titiunik, 2019) and a local quadratic fit. The sample includes switcher firms. Switcher firms are firms that switch across their electro-intensity status at least once any year of the panel (see section 3.2). For the purposes of the RD analysis and to maintain a clean comparison around the electro-intensity cutoff, the sample is also restricted to firms with a non-negative electro-intensity ratio, since firms with a negative ratio are considered electro-intensive (treated) in the context of the electricity tax reform. Confidence intervals are set at the 5% level.